CITY OF LOVELAND
STORM DRAINAGE CRITERIA
(ADDENDUM TO THE
URBAN STORM DRAINAGE CRITERIA MANUALS
VOLUMES 1, 2, AND 3)

Prepared by: RESPEC, Inc.

Date: July 31, 2020

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PREFACE

In 1986 the City of Loveland Master Drainage Plan and Storm Drainage Criteria Manual were completed and adopted. The City of Loveland Storm Drainage Criteria Manual was modeled after the 1969 version of the Urban Drainage & Flood Control District (UD&FCD) in Denver, Colorado. The 1969 version of the Urban Storm Drainage Criteria Manual (USDCM) consisted of Volumes 1 & 2. Many of the local communities outside of the Denver area have since adopted the USDCM as their drainage criteria, even though they were not within the UD&FCD. However, the USDCM was written with the regional concept in mind and provides criteria and design standards for many different conditions within the UD&FCD. Late in the 1990's the UD&FCD began a process to write Volume 3 titled, Best Management Practices, which addresses stormwater quality and erosion control. Upon completion and adoption of Volume 3, the UD&FCD realized that they needed to update Volumes 1 & 2 to bring their criteria manuals current with technology. In July of 2001 the UD&FCD completed and adopted updated Volumes 1 & 2 of their drainage criteria. In 2002, the City of Loveland adopted USDCM Volumes 1, 2 and 3 with an Addendum relating to City of Loveland's specific needs. An Amendment to the Addendum followed in April 2008 to update the Storage Chapter.

Further revisions by UD&FCD of the USDCM have been made over time. This Addendum is based upon the USDCM Volumes 1, 2 and 3 as of December 31, 2019 (attached at the end of this Addendum), and supersedes the previous Addendums that have been issued by the City of Loveland. The City of Loveland would like to provide engineering professionals working within the Loveland community with tools and information related to the design of storm drainage infrastructure. The USDCM Volumes 1, 2 and 3 include several Excel Spreadsheets for consistent calculation purposes. To provide engineering professionals with tools and information in storm drainage and the EPA Phase 2 Stormwater Quality Permit requirements, the City of Loveland has revised the Addendum to maintain consistency with USDCM. The City of Loveland is adopting USDCM Volumes 1, 2 and 3 with an Addendum relating to City of Loveland needs. The Addendum makes changes to USDCM Volumes 1, 2 and 3 to enable the criteria to become specific to the Loveland community. USDCM Volumes 1, 2, and 3 are attached at the end of this Addendum for ease of reference.

AMENDMENTS AND REVISIONS

The USDCM and Addendum have been prepared utilizing state-of-the-art technology and procedures. Due to the dynamic nature of urban storm drainage, amendments and revisions will be required from time to time as experience is gained in the use of the USDCM and Addendum. Amendments and revisions will be posted within the Stormwater Utility link of the City of Loveland web site at www.cityofloveland.org.

Users of the USDCM and Addendum are encouraged to submit their comments, criticism, and errors that are found. Comments can be submitted through the Stormwater Utility link of the City of Loveland web page, by email, or by mailing written comments to:

Kevin Gingery
City of Loveland
Public Works Department – Stormwater Engineering Division
2525 W. 1st Street
Loveland, CO 80537
Kevin.Gingery@CityofLoveland.org

or

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2525 W. 1st Street
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1.0 General Provisions

1.1 Short Title

The USDCM and Addendum together with all future amendments shall be known as the Loveland Storm Drainage Criteria (LSDC).

1.2 Jurisdiction

The LSDC shall apply to all incorporated land within the City of Loveland. Lands within the Urban Growth Area considered for annexation and requiring drainage analysis, shall follow the regulations set forth herein.

1.3 Purpose

Presented in the LSDC are the minimum design and technical criteria for the analysis and design of storm drainage facilities. All new developments, or any other proposed construction submitted for acceptance, shall include adequate storm drainage system analysis and appropriate drainage system design. Such analysis and design shall conform to the criteria set forth herein.

1.4 Enactment Authority

The City of Loveland Municipal Code (CODE) has been adopted pursuant to the authority conferred within Title 31, Article 16 and other applicable sections of CRS 1973 as amended. Title 18, Unified Development Code, " of the CODE adopts the LSDC by reference.

1.5 Amendment and Revisions

The policies and criteria are basic guidelines which may be amended as new technology is developed and/or experience gained in the use of the LSDC indicate a need for revision. Amendments and revisions will be made through ordinance adoption.

1.6 Enforcement Responsibility

It shall be the duty of the Stormwater Utility Senior Civil Engineer to enforce provisions of the LSDC.

1.7 Interpretation

The Stormwater Utility Senior Civil Engineer is responsible for the interpretation of provisions of the LSDC using the following guidelines:

1. In the interpretation and application, the provisions of the LSDC shall be held as the minimum requirements for promotion of the health, safety, and general welfare of the community.

2. The LSDC is not intended to interfere with, abrogate, or annul any other regulation, statue, or other provision of law.

3. Where any provision of the LSDC impose restrictions different from those imposed by any other provisions of the LSDC or any other regulation, or provision of law, that provision which is more restrictive or imposes higher standards shall govern.

4. The LSDC is not intended to abrogate any easement, covenant, or any other private agreement or restriction, provided that where the provisions of the LSDC are more restrictive or impose higher standards or requirements than such easement, covenant, or other private agreement or restriction, the provisions of these Regulations shall govern.

1.8 Exceptions

The City Council may at its discretion grant exceptions to the regulations of the LSDC in accordance with the provisions of Title 18, Unified Development Code, of the CODE.

2.0 Drainage Planning Submittal Requirements

2.1 Review Process

All new developments within the jurisdiction of the LSDC shall submit drainage reportsand drainage plans in accordance with the requirements of this section. For all projects that disturb one acre or more, a separate Stormwater Management Plan (SWMP) is required to be submitted in electronic pdf format to COL for review and acceptance. The SWMP shall be completed in accordance with the Colorado Department of Public Health and Environment requirements.

2.2 Conceptual Drainage Report

The purpose of the Conceptual Drainage Report is to identify and define conceptual solutions to problems, which may occur on-site and off-site as a result of the development. In addition, those problems that exist on-site prior to development must be addressed during the conceptual phase. During the application review period, all reports shall be submitted by electronic means (pdf) in 8 ½" x 11" paper size format with 24" x 36" drainage plans included in the report . . Once City approval has been granted for the development

application, the submittal of reports and 24" x 36" drainage plans shall be by both electronic means (pdf) and 8 1/2 " x 11" unbound, hard paper copy, with the 24" x 36" drainage plans included within both forms of the report. The report needs to stand-alone and therefore all important reference material should be copied and included within the report appendix. The report shall include a cover letter presenting the conceptual design for review and shall be prepared by or supervised by an engineer licensed in Colorado. The report shall contain a certification sheet as follows:

"I hereby certify that this report for the conceptual drainage design of (Name of Development) was prepared by me (or under my direct supervision) in accordance with the provisions of the City of Loveland Storm Drainage Criteria for the owners thereof."

_____
Registered Professional Engineer
State of Colorado No. _____
(Affix Seal)

2.2.1 Report Contents

The Conceptual Drainage Report shall be prepared in accordance with the following outline and contain the applicable information listed:

I. General Location and Description
  A. Location
    1. Township, range, section, ¼ section.
    2. Local streets within and adjacent to the development.
    3. Major open channels and facilities.
    4. Names of surrounding developments.
  B. Description of Property
    1. Area in acres.
    2. Ground cover.
    3. Major open channels.
    4. General project description.
    5. Irrigation facilities.

II. Drainage Basins and Sub-Basins
  A. Major Basin Description
    1. Reference to City of Loveland Master Drainage Plan.
    2. Major basin drainage characteristics
    3. Identification of all nearby irrigation facilities within 100- feet of the property boundary.
  B. Sub-Basin Description
    1. Historic drainage patterns on the subject property.
    2. Off-site drainage flow patterns and impact on the subject property.

III. Drainage Facility Design
  A. General Concept
    1. Concept and typical drainage patterns.
    2. Compliance with offsite runoff considerations.
    3. Anticipated and proposed drainage patterns.

4. Anticipated landscaping and permanent water quality improvements

B. Specific Details
   1. Drainage problems encountered and solutions at specific locations.
   2. Maintenance access and aspects of the design.

2.2.2 Drainage Plan Contents

A General Location Map shall be provided at a scale of 1" = 2000' or larger in sufficient detail to identify upstream off-site drainage areas flowing into the development and general drainage patterns.

A Drainage Plan of the proposed development shall be provided at a scale from 1" = 100' to 1" = 200' on a 24" x 36" drawing. If the entire development can't fit on a single 24" x 36" drawing at the scales listed, an additional drainage plan shall be included drawn at a scale where the entire development fits on one 24" x 36" drawing. The plan shall show the following information:

1. Existing contours at 2-feet maximum intervals.
2. Property lines, lot lines, and easements.
3. Streets with names.
4. Existing drainage facilities, structures, irrigation facilities, and sizes.
5. Overall drainage area boundary and sub-area boundaries.
6. Proposed flow directions using arrows.
7. Conceptual location of storm sewers, swales, open channels, culverts, permanent water quality BMPs, detention ponds, and other appurtenances.
8. Location of all defined 100-year floodplains affecting the property.
9. Any other items so noted within the Drainage Report.

2.3 Preliminary Drainage Report

The purpose of the Preliminary Drainage Report is to identify and define preliminary solutions to problems, which may occur on-site and off-site as a result of the development. In addition, those problems that exist on-site prior to development must be addressed during the preliminary phase. During the application review period, all reports shall be submitted by electronic means (pdf) in 8 ½" x 11" paper size format with 24" x 36" drainage plans included in the report. . Once City approval has been granted for the development application, the submittal of reports and 24" x 36" drainage plans shall be by both electronic means (pdf) and 8 1/2 " x 11" unbound, hard paper copy, with the 24" x 36" drainage plans included within both forms of the report.

The report needs to stand-alone and therefore all important reference material should be copied and included within the report appendix. The report shall include a cover letter presenting the preliminary design for review and shall be prepared by or supervised by an engineer licensed in Colorado. The report shall contain a certification sheet as follows:

"I hereby certify that this report for the preliminary drainage design of (Name of Development) was prepared by me (or under my direct supervision) in accordance with the provisions of the City of Loveland Storm Drainage Criteria for the owners thereof."

_____
Registered Professional Engineer
State of Colorado No. _____
(Affix Seal)

2.3.1 Report Contents

The Preliminary Drainage Report shall be in accordance with the following outline and contain the applicable information listed:

I. General Location and Description
   A. Location
      1. Township, range, section, ¼ section.
      2. Local streets within and adjacent to the development.
      3. Major open channels and facilities.
      4. Names of surrounding developments.
   B. Description of Property
      1. Area in acres.
      2. Ground cover.
      3. Major open channels.
      4. General project description.
      5. Irrigation facilities.

II. Drainage Basins and Sub-Basins
   A. Major Basin Description
      1. Reference to City of Loveland Master Drainage Plan.
      2. Major basin drainage characteristics.
      3. Identification of all nearby irrigation facilities within 100- feet of the property boundary.
   B. Sub-Basin Description
      1. Historic drainage patterns on the subject property.
      2. Off-site drainage flow patterns and impacts on the subject development.

III. Drainage Design Criteria
   A. Regulations: Discussion of the optional criteria selected or the deviation from the LSDC if any.
   B. Development Criteria Reference and Constraints
      1. Discussion of previous drainage studies (i.e., project master plans) for the subject property that influence or are influenced by the drainage design and how the plan will affect drainage design for the site.
      2. Discussion of the drainage impact of site constraints such as street, utilities, existing structures, and development or site plan.
   C. Hydrological Criteria
      1. Identify design rainfall.
      2. Identify runoff calculation method.

a. Rational Method shall be utilized to determine runoff for drainage basins 90 acres or less in size.
b. CUHP used for drainage basins over 90 acres in size. CUHP may be used, in addition to the Rational Method calculations, to determine runoff rates from design points consisting of smaller, combined sub-basins that fall under 90 acres for the purpose of routing flows through detention ponds.

3. Identify detention discharge and storage calculation method.
4. Identify design storm recurrence intervals.
5. Discussion and justification of other criteria or calculation methods used that are not presented in or referenced by the LSDC.

D. Hydraulic Criteria
1. Identify various capacity references.
2. Identify detention outlet type.
3. Identify check/drop structure criteria used.
4. Discussion of other drainage facility design criteria used that are presented in the LSDC.

IV. Drainage Facility Design
A. General Concept
1. Discussion of concept and typical drainage patterns.
2. Discussion of compliance with off-site runoff considerations.
3. Discussion of the content of tables, charts, figures, or drawings presented in the report.
4. Discussion of anticipated and proposed drainage patterns.
5. Discussion on selection of WQ BMPs

B. Specific Details
1. Discussion of drainage problems encountered and solutions at specific design points.
2. Discussion of water quality BMPs and design
3. Discussion of detention storage and outlet design.
4. Discussion of maintenance access and aspects of the design.
5. Discussion of anticipate temporary erosion controls (types and locations) to be used during construction (only include in Final Drainage Report)

V. Conclusions
A. Compliance with the LSDC
B. Drainage Concept
1. Effectiveness of drainage design to control damage from storm runoff.
2. Effectiveness of WQ BMPs for water quality enhancement.
3. Influence of proposed development on the City of Loveland Master Drainage Plan recommendations.
4. Approval of affected irrigation company or other property owner to be obtained.

VI. References
Reference all criteria and technical information used.

VII. Appendices
- A. Hydrology Computations
  1. Land use assumptions regarding adjacent properties.
  2. Initial and major storm runoff computations at specific design points.
  3. Historic and fully developed runoff computations at specific design points.
- B. Hydraulic Computations
  1. Culvert sizing.
  2. Storm sewer sizing.
  3. Street capacity evaluation.
  4. Storm inlet sizing.
  5. Swale sizing.
  6. Open channel sizing.
  7. Check and/or drop structure sizing.
  8. Detention pond area/volume capacity and outlet sizing.
  9. WQ BMP sizing
- C. Checklists
  1. Stormwater Quality BMP Point System Checklist
  2. Sediment/Erosion Control Development Submittal Checklist (with Final Drainage Report)
  3. Site Work Permit Checklist (with Final Drainage Report)

2.3.2 Drainage Plan Contents

A General Location Map shall be provided at a scale of 1" = 2000' or larger in sufficient detail to identify upstream off-site drainage areas flowing into the development and general drainage patterns.

A Drainage Plan of the proposed development shall be provided at a scale from 1" = 100' to 1" = 200' on a 24" x 36" drawing. If the entire development can't fit on a single 24" x 36" drawing at the scales listed, an additional drainage plan shall be included drawn at a scale where the entire development fits on one 24" x 36" drawing. The plan shall show the following information:

1. Existing and proposed contours at 2-feet maximum intervals.
2. Property lines, lot lines, and easements.
3. Streets with names.
4. Existing drainage facilities, structures, irrigation facilities, and sizes.
5. Overall drainage area boundary and sub-area boundaries.
6. Proposed flow directions using arrows.
7. Proposed storm sewers, swales, open channels, culverts, cross-pans, and other appurtenances, including cross-sections of swales and open channels.
8. Proposed outfall point for runoff from the development area and facilities to convey flows to the final outfall point without damage to downstream properties.
9. Routing and accumulation of flows at various critical points for the minor storm runoff.

10. Routing and accumulation of flows at various critical points for the major storm runoff.
11. Detention storage facilities and outlet works, including proposed 100-year water surface elevations.
12. Location and elevations of all defined 100-year floodplains affecting the property.
13. Location of all existing and proposed utilities.
14. Routing of off-site drainage flows through the development.
15. Minimum lowest opening elevations of residential and commercial buildings above the 100-year water surface in streets, open channels, ditches, swales, or other drainage facilities, as illustrated by the preliminary grading plans.
16. Proposed on-site private and public drainage easements.
17. Proposed off-site private and public drainage easements.

2.4 Final Drainage Report

The purpose of the Final Drainage Report is to update the conceptual or preliminary design concepts, and to present the design details for the drainage facilities discussed in the Conceptual or Preliminary Drainage Report. Also, any change to the conceptual or preliminary concept shall be presented.

During the application review process, all reports shall be submitted in electronic form (pdf) in 8 ½" x 11" paper size format with 24" x 36" drainage plans included in the report. Once City approval has been granted for the development application, the submittal of reports and 24" x 36" drainage plans shall be by both electronic means (pdf) and unbound, hard paper copy, with the 24" x 36" drainage plans included within both forms of the report. All hard copy reports shall be reproduced on 8-1/2" x 11" paper. The 24"x 36" drainage plans shall be included in both the electronic copy and the hard copy report. The report needs to stand-alone and therefore all important reference material should be copied and included within the report appendix. The report shall include a cover letter presenting the final design for review and shall be prepared by or supervised by an engineer licensed in Colorado. The report shall contain a certification sheet as follows:

"I hereby certify that this report for the final drainage design of (Name of Development) was prepared by me (or under my direct supervision) in accordance with the provisions of the City of Loveland Storm Drainage Criteria for the owners thereof."

_____
Registered Professional Engineer
State of Colorado No. _____
(Affix Seal)

The final drainage report shall be prepared in accordance with the outline shown in Section 1.4.1. The report drawings shall follow the requirements presented in Section 1.4.1. Final design hydraulic calculations shall be provided for each of the proposed elements of the final drainage design.

2.4.1 Report Contents

The Final Drainage Report shall be in accordance with the following outline and contain the applicable information listed:

I. General Location and Description
  A. Location
    1. Township, range, section, ¼ section.
    2. Local streets within and adjacent to the development.
    3. Major open channels and facilities.
    4. Names of surrounding developments.
  B. Description of Property
    1. Area in acres.
    2. Ground cover.
    3. Major open channels.
    4. General project description.
    5. Irrigation facilities.

II. Drainage Basins and Sub-Basins
  A. Major Basin Description
    1. Reference to City of Loveland Master Drainage Plan.
    2. Major basin drainage characteristics.
    3. Identification of all nearby irrigation facilities within 100- feet of the property boundary.
  B. Sub-Basin Description
    1. Historic drainage patterns on the subject property.
    2. Off-site drainage flow patterns and impacts on the subject development.

III. Drainage Design Criteria
  A. Regulations: Discussion of the optional criteria selected or the deviation from the LSDC if any.
  B. Development Criteria Reference and Constraints
    1. Discussion of previous drainage studies (i.e., project master plans) for the subject property that influence or are influenced by the drainage design and how the plan will affect drainage design for the site.
    2. Discussion of the drainage impact of site constraints such as street, utilities, existing structures, and development or site plan.
  C. Hydrological Criteria
    1. Identify design rainfall.
    2. Identify runoff calculation method
      a. Rational Method shall be utilized to determine runoff for drainage basins 90 acres or less in size.
      b. CUHP used for drainage basins over 90 acres in size. CUHP may be used, in addition to the Rational Method calculations, to determine runoff rates from design points consisting of smaller, combined sub-basins that fall under 90 acres for the purpose of routing flows through detention ponds.

3. Identify detention discharge and storage calculation method.
4. Identify design storm recurrence intervals.
5. Discussion and justification of other criteria or calculation methods used that are not presented in or referenced by the LSDC.

D. Hydraulic Criteria
1. Identify various capacity references.
2. Identify detention outlet type.
3. Identify check/drop structure criteria used.
4. Discussion of other drainage facility design criteria used that are presented in the LSDC.

IV. Drainage Facility Design
A. General Concept
1. Discussion of concept and typical drainage patterns.
2. Discussion of compliance with off-site runoff considerations.
3. Discussion of the content of tables, charts, figures, or drawings presented in the report.
4. Discussion of anticipated and proposed drainage patterns.
5. Discussion on selection of WQ BMPs

B. Specific Details
1. Discussion of drainage problems encountered and solutions at specific design points.
2. Discussion of water quality BMPs and design
3. Discussion of detention storage and outlet design.
4. Discussion of maintenance access and aspects of the design.
5. Discussion of anticipate temporary erosion controls (types and locations) to be used during construction (only include in Final Drainage Report)

V. Sediment, Erosion Control and Stormwater Quality
A. Temporary Sediment and Erosion Control
1. Discussion on the selection of temporary sediment and erosion control devices and methods that will be used to mitigate sediment and erosion on and off of the site.

B. Permanent Water Quality BMPs.
1. Discussion on the selection of permanent water quality BMPs.
2. Discussion on why each permanent water quality BMP has been specifically selected for the development.

V. Conclusions
A. Compliance with the LSDC
B. Drainage Concept
1. Effectiveness of drainage design to control damage from storm runoff.
2. Effectiveness of WQ BMPs for water quality enhancement.
3. Influence of proposed development on the City of Loveland Master Drainage Plan recommendations.

4. Approval of affected irrigation company or other property owner to be obtained.

VI. References
Reference all criteria and technical information used.

VII. Appendices
A. Hydrology Computations
1. Rational Method Calculations
2. Land use assumptions regarding adjacent properties.
3. Initial and major storm runoff computations at specific design points.
4. Historic and fully developed runoff computations at specific design points.
B. Hydraulic Computations
1. Culvert sizing.
2. Storm sewer sizing.
3. Street capacity evaluation.
4. Storm inlet sizing.
5. Swale sizing.
6. Open channel sizing.
7. Check and/or drop structure sizing.
8. Modified FAA Method Detention pond area/volume capacity and outlet sizing.
9. WQ BMP sizing
C. Worksheets
1. Permanent Stormwater Quality Control Measure(s) Base Design Standard Worksheet
D. Exhibits
1. An 11" x 17" schematic drawing into the Final Drainage & Erosion Control Report and SWMP documents titled "Permanent Stormwater Quality BMPs" that clearly identifies where each of the proposed Permanent Stormwater Quality BMPs are located within the development site, i.e., Grass Swales (GS), Grass Buffers (GB), Extended Detention Basins (EDB), etc. Please lightly shade or hatch the extent of each BMP.

2.3.2 Drainage Plan Contents

A. A General Location Map shall be provided at a scale of 1" = 2000' or larger in sufficient detail to identify upstream off-site drainage areas flowing into the development and general drainage patterns.

B. A Drainage Plan of the proposed development shall be provided at a scale from 1" = 100' to 1" = 200' on a 24" x 36" drawing. If the entire development can't fit on a single 24" x 36" drawing at the scales listed, an additional drainage plan shall be included drawn at a scale where the entire development fits on one 24" x 36" drawing. The plan shall show the following information:

1. Existing and proposed contours at 2-feet maximum intervals.
2. Property lines, lot lines, and easements.

3. Streets with names.
4. Existing drainage facilities, structures, irrigation facilities, and sizes.
5. Overall drainage area boundary and sub-area boundaries.
6. Proposed flow directions using arrows.
7. Proposed storm sewers, swales, open channels, culverts, cross-pans, and other appurtenances, including cross-sections of swales and open channels.
8. Proposed outfall point for runoff from the development area and facilities to convey flows to the final outfall point without damage to downstream properties.
9. Routing and accumulation of flows at various critical points for the minor storm runoff.
10. Routing and accumulation of flows at various critical points for the major storm runoff.
11. Detention storage facilities and outlet works, including proposed 100-year water surface elevations.
12. Location and elevations of all defined 100-year floodplains affecting the property.
13. Location of all existing and proposed utilities.
14. Routing of off-site drainage flows through the development.
15. Minimum lowest opening elevations of residential and commercial buildings above the 100-year water surface in streets, open channels, ditches, swales, or other drainage facilities, as illustrated by the preliminary grading plans.
16. Proposed on-site private and public drainage easements.
17. Proposed off-site private and public drainage easements.

2.5 Construction Drawings and Specifications

Where drainage improvements are to be constructed in accordance with the accepted Final Drainage Report, the construction plans (on 24" x 36" paper) and specifications shall be submitted in conformance with the Final Plat for review and acceptance prior to construction. The plans and specifications for the drainage improvements shall include all drainage components designed within the Final Drainage Report.

The information required for the drawings and specifications shall be in accordance with sound engineering principles, the LSDC and the City requirements for subdivision design. Construction documents shall include geometric, dimensional, structural, foundation, bedding, hydraulic, landscaping, and other details as needed to construct the storm drainage facilities. The accepted Final Drainage Plan shall be included as part of the construction documents for all facilities affected by the drainage plan.

The design engineer shall provide an electronic drawing of the proposed stormwater and water quality improvements in a GIS format suitable for use by the City in the city's GIS system. The drawing must include, as a minimum, centerlines of storm sewers and channels and outlines of all detention and water quality improvements.

2.6 Checklists

The checklists located in Appendix A of the Preface contains a list of common design items that need to be included in the final drainage report and construction drawings as well as other documents required for submittal. These checklists are not all-inclusive lists and other items may be required in the final drainage report and construction drawings, based on the nature of the design.1.7 As-Built Drawings

2.7.1 Recording of Drawings

A. The project record drawings shall be submitted to and accepted by the Public Works Department Inspectors.
B. Each drawing shall be labeled "DRAWINGS OF RECORD" in neat large printed letters.
C. Construction information shall be recorded concurrently with construction progress by the Contractor.
D. Project Record Drawings shall be marked legibly and with an indelible pen.
E. Project Record Drawings shall record actual construction and contain, but not limited to, the following:
    1. Field dimensions, elevations, and details.
    2. Field changes which are made by minor deviations to the design drawings.
    3. Details, which are not on the original Construction Drawings.
    4. Elevations of manhole and inlet inverts in relation to project datum.
    5. Critical hydraulic structure dimensions.
    6. Orifice plate sizes.
    7. Detention pond volumes.
    8. All other critical hydraulic elevations.

2.7.2 Submission

A. The project record drawings shall be submitted to and accepted by the Public Works Department Inspectors with a transmittal letter containing the following:

    1. Date.
    2. Project Title.
    3. Design Engineer's name, address, and telephone number.
    4. Title and number of each Record Document.
    5. The signature of the Design Engineer, and their Professional Engineering stamp.

B. The initial acceptance of the storm drainage improvements will not be made until all City installation requirements are satisfied and the Project Record Drawings are received and accepted by the City.

C. The final drawings of the storm drainage improvements will not be made until the Project Record Drawings are received and accepted by the City.

D. The City requires that the Project Record Drawings first be submitted in blueline form for preliminary acceptance before final mylars are submitted.

E. The City requires the submittal of a video taping of all storm sewer lines prior to final acceptance.

APPENDIX A

DESIGN CHECKLISTS FOR FINAL DRAINAGE REPORTS AND PUBLIC IMPROVEMENTS CONSTRUCTION PLANS

CHECKLIST – FINAL DRAINAGE REPORT	
FINAL DRAINAGE REPORT – WRITTEN PORTION	
□	Certification statement with professional engineer's stamp and signature
□	Discussion of hydrologic soil group(s) on the project site
□	Discussion of City of Loveland master drainage basin in which the site is located
□	Discussion of master-planned facilities and patterns are followed
□	Discussion of FEMA or local floodplains and floodways that are located on the site, as applicable
□	Discussion of irrigation ditches on the site and permission granted from irrigation company to complete construction operations within irrigation canal, as applicable
□	Discussion of where the stormwater flows after it leaves the site (based on the Civil Law Rule)
□	Discussion of how are upstream flows being handled through the site
□	Paragraph regarding temporary sediment and erosion control used on the site during construction
□	Paragraph regarding permanent stormwater quality designed for the development after construction
□	Within permanent stormwater quality paragraph, discuss what control measures are used and why they have been selected for this development.
□	All stormwater directed through permanent stormwater quality feature before leaving site
□	Include adjacent street into drainage pattern and detain and release street runoff from on-site detention pond
□	Discuss specific stormwater release rates for each lot within business park subdivisions
□	Discussion of hydrological and hydraulic capacity calculations used (UDFCD spreadsheets used as much as available)
□	Supporting/referenced existing drainage report(s) included in appendix
□	Variance Requests: Explain why a proposed design component that is not allowed by the City of Loveland Storm Drainage Standards and why it is a hardship for the owner to not use the City standard
DRAWINGS	
□	General Location Map
□	Drainage Plan
□	Permanent Stormwater Quality BMPs exhibit
FINAL DRAINAGE REPORT APPENDIX – DESIGN CALCULATIONS	
□	Rational Method shall be utilized to determine runoff for drainage basins 90 acres or less in size.
□	CUHP used for drainage basins over 90 acres in size. CUHP may be used, in addition to the Rational Method calculations, to determine runoff rates from design points consisting of smaller, combined sub-basins that fall under 90 acres for the purpose of routing flows through detention ponds.
□	UDFCD spreadsheets used when applicable
□	Street depths calculated for 100-year flow
□	Riprap sizing and bed dimension calculations
□	Swale hydraulic capacity calculations include freeboard and Froude Number
□	Swales with a Froude Number > 0.80 contain permanent erosion protection up to the swale freeboard
□	Inlet types chosen for site are approved for use in City of Loveland

□	Inlet clogging factors follow Loveland criteria
□	Hydraulic grade line calculations for all designed storm sewers and culverts
□	Energy grade line in storm sewers are no more than 6 inches under rim of inlets/manholes
□	Manning's n=0.013 used for all storm sewer pipe materials
□	Adjacent streets are routed back into proposed development and included in detention calculations if it is a new street or existing street that has not been included in other detention design
□	Rundowns designed to contain the 100-year runoff plus freeboard and are in the shape of a swale.
□	Street capacity calculations utilizing UD-INLET
□	Curb cut weir calculations
□	Mile High Flood District Stormwater Detention and Infiltration Design Data Sheets within the report appendix to demonstrate that the Stormwater detention ponds are designed to comply with the release rates described in Senate Bill 15-212
□	Required volume using Modified FAA Method to calculate the detention pond volumes
□	Stage-storage calculations to demonstrate available volume
□	WQVC orifice size calculations
□	EURV and 100-year pond orifice outlet sizing calculations with no clogging factors used to size orifice
□	Emergency spillway weir calculations
□	All necessary hydraulic capacity calculations for all design features
□	Permanent Stormwater Quality Control Measure(s) Base Design Standard Worksheet

CHECKLIST – CONSTRUCTION PLANS	
CONSTRUCTION PLANS	
□	Standard Erosion And Sediment Control Construction Plan Notes included
□	Qualifed Stormwater Manager listed on Title Sheet (if none has been chosen, designate the developer, planner, engineer, etc. as the coordinator)
□	City of Loveland Level Net Benchmark used - no exceptions
□	Irrigation Ditch Agreement signature block on title sheet of construction plans
RESIDENTIAL SUBDIVISION LOTS	
□	Spot elevations for flowlines, lot corners, and finish grades, & top of foundations
□	Rear lot drainage (with easements and concrete pan) in multiple lots
□	Finished grade a minimum 6 inches lower than top of foundation
□	Type A,B, G, and W graded lots are labeled correctly
□	Type A, B, G or W lot layout detail
□	Flow direction arrows on each residential lot
□	Side and rear lot line slopes labeled on each residential lot (2% minimum allowable slopes)
□	High point spot elevations labeled on lots
□	Minimum opening elevation labeled on walkout basements or lots located by waterways or detention ponds
□	Basements not lower than 100-year WSEL in pond or pond is lined
□	If three or more rear lots combine their drainage waters in a common rear lot line swale, a concrete trickle channel shall be provided within the common rear lot line swale and extend to the nearest public street.
FLOODPLAINS AND FLOODWAYS	
□	100-year FEMA floodplain and floodway delineated on plans
□	Local floodplain delineation on plans
□	City Floodplain Development Permit Application (as applicable)
SITE GRADING	
□	Existing contours shown at a minimum of two foot intervals
□	Proposed contours shown at a minimum of two foot intervals
□	Contours extending a minimum 50' off-site, and tying into existing contours
□	Roof drains and direction of flow shown on commercial buildings
□	Maximum side slope of 4:1 or 3:1 on embankments within rights-of-way.
□	Permanent erosion protection provided on slopes steeper than 3:1 on private or public property
□	Permanent erosion protection provided at ends of pipes and pans
□	Written permission signed by neighbors provided to City if grading is planned said neighbor's property as part of site design
□	Sidewalk chases located at areas of concentrated flow at sidewalks/driveways
SWALES	
□	Cross-sections cut through each of the proposed grass swales and show the cross-sections on the grading plans with the following information on each swale cross-section: side slopes, longitudinal slope, bottom width, 100-year flow depth, and freeboard.
RUNDOWNS	
□	Permanent erosion protection in the form of a concrete or grouted riprap rundown provided to protect the pond embankment from erosion. Rundown designed to contain the 100-year runoff plus freeboard and is in the shape of a swale.
□	Details provided for each rundown including: specifying rock size (if riprap is used. Riprap should have no fines.), specifying grout depth for riprap or pan depth for concrete, cutting cross-sections

	through each one, labeling channel dimensions and showing/labeling each cross-section on the grading plans.
INLETS	
□	Inlet length and type labeled on plan and/or profile view
□	Only inlets that are approved for use in the city allowed in parking lots and streets
STORM SEWERS	
□	Hydraulic grade line and design storm that is represented by the hydraulic grade line is labeled on each storm sewer profile
□	Pipe and inlet elevations, slopes, pipe size and material labeled on profile view
□	Only pipe materials that are allowed within the City of Loveland used for the private and public storm sewer and culvert systems
□	Distance between dual pipes specified on plans
□	Horizontal and vertical location of existing and proposed utility crossings shown on plans per senate bill 18-167
□	Label calling for core drilling & grouting new pipes into existing inlets & manholes
□	No grates on culverts if you can see the light at the other end of the culvert
□	Storm sewers located within pavement of streets
□	No exception to 10-foot separation from water and sanitary sewer
□	Elevation drops in manholes
□	Storm sewer is locatable with manholes per senate bill 18-167 (roof drains are exempt)
□	Business park storm sewers: has individual lot drainage been included in street storm sewer sizing?
DETENTION POND	
□	Forebays at outfall of each pipe entering an extended detention basin
□	Maintenance access provided for detention pond outlet structure
□	Extents of 100-year water surface elevation shaded and 100-year water surface elevation labeled on plan.
□	Emergency spillway flow depth is less than or equal to 6 inch or maximum 50% of spillway height.
□	Minimum 1-foot freeboard from 100-yr WSEL to top of pond berm
□	Cut-off wall dimensions labeled
□	Cut-off wall structural construction plan and detail provided in construction plans
UNDERDRAINS	
□	Underdrains designed where ever seasonal peak groundwater tables will be within three feet of foundation bearing elevations
□	Laterals have tracer wire
□	Main line has cleanouts or manholes at all bends and junctions
□	All cleanouts/manholes and lateral connections labeled on plans
□	Designed as a separate utility line located within the street right-of-way or located within a rear lot line utility easement, in accordance with the Larimer County Urban Area Street Standards for the Loveland area
□	Show and label cleanouts and connections/services to each residential home foundation drain
□	The underdrain system is a gravity system tied into each residential home foundation drain
□	Gravity system daylights to detention pond or water way (but not irrigation ditch)
□	Plan and profile for each underdrain and label each profile view pipe as “private”
□	Private underdrain systems also require a formal written agreement with the City and approval by the Loveland City Attorney’s Office

□	Backflow/flap gates installed at each outfall of underdrain into pond/waterway
□	No perforated pipe in ROW or public areas - main line pipe wall is solid
□	Detail for tracer wire included in plans
□	Details - LCUASS 713.1L and 713.2L included in plan set
MISCELLANEOUS ITEMS	
□	Channels and rundowns with large stormwater flows need label with boulder size with no fines (label example: "12" D_{50} No Fines")
□	Permanent water quality features included in design
□	Irrigation ditch culverts have erosion protection on either end
□	Retaining wall structural construction plans and details included in Public Improvement Construction Plan set (always needed despite height)
□	Rails around retaining walls with detail included in Public Improvement Construction Plan set
□	Pump station/lift station: complete construction design plans included in Public Improvement Construction Plan set
□	Waste stations and other contaminants set away from drainage facilities
□	Roof drain material slope size, tees, inverts labeled on plans
□	Labels to direct contractors to special details (PLDs, raingardens, sidewalk chases, curb cuts, etc.)
□	Details for all components included on the detail sheet of Public Improvement Construction Plans set

CHECKLIST - ADDITIONAL DOCUMENTS TO BE PROVIDED WITH THE PROJECT SUBMITTAL	
□	Standard Operating Procedure for Stormwater Permanent Control Measures
□	Stormwater Management Plan (if the project site disturbs one acre or more)
□	Irrigation Ditch Agreements for all private and public utility or public right-of-way ditch crossings
□	Water Quality Control Plan (if applicable to project)

Volume 1

Preface

Section 2.0 Purpose
Change …USCDM…
To …LSDC…

Section 3.0 Overview

First bullet titled "Chapter 1: Drainage Policy."
Change …UDFCD.
To …the COL.

Delete: Second Bullet titled "Chapter 2: Drainage Law."

Third bullet titled "Chapter 3: Planning."
Delete last sentence.

Fourth bullet titled "Chapter 4: Flood Risk Management."
Change …UDFCD…
To …COL…

Fifth bullet titled "Chapter 5: Rainfall."
Change …USDCM.
To …LSDC.

Delete …guidance for the development of …
Delete Last sentence.

Tenth bullet titled "Chapter 10: Stream Access and Recreational Channels."

Change …UDFCD…
To …LSDC…

Twelfth bullet titled "Chapter 12: Storage."

Delete Last sentence beginning with "UD-FSD and UD-Detention…".

First paragraph after bullet list
Change …USDCM…
To …LSDC…

Second paragraph after bullet list

Change …USDCM…
To …LSDC…

Change …UDFCD.
To …COL.

Section 4.0 List of Abbreviations

Add COL City of Loveland

Add GLIC Greeley and Loveland Irrigation Canal

Add LMDP Loveland Master Drainage Plan

Add LSDC Loveland Storm Drainage Criteria

Chapter 1 Drainage Policy

1.0 Policies and Principles

Third Paragraph:

Change …UDFCD's principles and policies for urban drainage and floodplain…

To …COL's principles and policies for urban drainage and floodplain…

1.1 Principles

Paragraph 1:

Delete Since 1969, UDFCD has embraced the principles of drainage planning that guide the criteria in this manual.

Add The COL embraces the principles of drainage planning that guide the criteria in this manual.

Change …must be quantified and discussed in the master plan.

To …are as presented in the City of Loveland's adopted Master Drainage Plan and the COL has entered into an agreement with Larimer County to cooperate on regional planning for the projected Urban Growth Boundary. The Policy of the City of Loveland shall be to pursue a jurisdictionally unified drainage effort to assure an integrated plan and to cooperate with other regional and local planning agencies on drainage matters.

Paragraph 5:

Change Urbanization tends to increase downstream peak…

To Urbanization, without mitigation, tends to increase downstream peak…

Change …slowly released via detention facilities to manage peak flows…

To …slowly released via detention facilities to manage and mitigate peak flows…

Paragraph 7:

Change …plan should carefully map and identify the existing natural system.

To …plan should carefully consider the existing natural system.

Paragraph 8:

Change …and reduce where possible…

To …and reduce where legally and physically possible

Paragraph 9:

Add The COL requires that the design of a site provide for historic off-site flows that enter a property be routed around or through the site in a channelized

manner in order to protect the property from damage or sedimentation. Offsite flows are not permitted to sheet flow across a property.

Paragraph 10:
Change Local maintenance…
To Maintenance…

Add Master planned facilities will be maintained by the COL. Private on-site detention facilities shall be privately maintained.

Paragraph 11:
Change …policy of UDFCD…
To …policy of the COL…

Paragraph 12:
Add The COL also requires setbacks from property line along Ditches, Natural Water Courses, and Waterbodies. Refer to the Development Code for specifics regarding setbacks.

1.2 Basic Hydrologic Data Collection Policies

Delete Entire section

1.3 Planning Policies

Paragraph 1:
Delete A master plan for storm drainage should be developed and maintained in an up to date fashion at all times for each urbanizing drainage watershed.
Add The policy of the City of Loveland shall be to enforce and implement the adopted Master Drainage Plan for the Urban Growth Area. This Master Drainage Plan may be amended from time to time in the future.

Paragraph 4:
Change Storage of runoff in detention and retention reservoirs…
To Storage of runoff in detention reservoirs…

1.4 Technical Criteria

First Bullet:
Change …presented in this Urban Storm Drainage Criteria Manual (USDCM)
To …presented in the LSDC

Fifth Bullet:
Add In 1977 the Greeley and Loveland Irrigation Company (GLIC) filed on all stormwater entering the Company's lakes and canals in Case No. W-8665-77.

Therefore, all modifications to stormwater rates and volumes must accommodate GLIC's water rights for stormwater.

Sixth Bullet:

Change …detention basins and retention ponds is necessary…
To …detention basins is necessary…

Change …detention and retention facilities…
To …detention facilities…

Eighth Bullet:

Change The various governmental entities within the UDFCD boundary have…
To COL has…

Change Floodplain management must encompass…
To The COL's floodplain management program encompasses…

Last Bullet:

Change Exposure of life, property….
To (connect to previous paragraph)…exposure of life, property…

1.5 Flood Insurance Policy

Change UDFCD encourages the continued participation of local governments in…
To The COL participates in…

1.6 Levee Policy

Change UDFCD strongly discourages local governments from authorizing or permitting…
To The COL prohibits…

Delete 2. UDFCD will consider levees to protect existing development only as a last resort when no other mitigation option is feasible.

1.7 Criteria Implementation Policies

Delete Entire section including figure on next page

Add Refer to the COL website for a current map of the COL.

Delete Figure 1-1.

2.0 UDFCD Hydrologic Data Collection

Delete Entire section including bullets

3.1 Total Urban System

Delete Master plans for storm drainage have been developed and are maintained in an up to date fashion for most of the watersheds in the UDFCD region. An effort to complete the coverage of master plans for yet unplanned areas of UDFCD should be continued until full coverage is achieved.

3.1.1 Planning Process Elements

Paragraph 1:
Change Implementation of major drainage plans will reduce loss…
To Implementation of the COL's adopted master drainage plan will reduce loss…

Paragraph 2:
Delete Outfall system planning: Outfall system planning efforts identify detention, water quality and conveyance practices within a watershed that ultimately discharges to a receiving stream. Outfall system plans typically address storm drain improvements, stream crossing improvements, stream enlargement, stabilization, and floodplain preservation.

Paragraph 3:
Change …the runoff from 2-year to 5-year storms…
To …the runoff from 2-year storms…

Change …have a 50% to 20%...
To …have a 50%...

3.1.2 Master Planning

Delete Entire Section

Add The City of Loveland Master Drainage Plan sets forth improvements required for existing and future growth areas. The Policy of the City of Loveland regarding the design and construction of improvements within the Master Drainage Plan shall be as set forth below, subject to annual City Council budget and appropriation approval.

1. The City of Loveland shall arrange for the design and construction of improvements as set forth in the adopted Master Drainage Plan for existing and future growth areas.
2. The drainage systems for future development and redevelopment shall be designed and constructed by the Developer.
3. The Developers shall be responsible for design and construction of temporary or interim storm drainage systems required due to lack of adequate storm drainage facilities downstream of the new development.

Add The Policy of the City of Loveland shall be to enforce and implement the adopted Master Drainage Plan for the Urban Growth Area. This Master Drainage Plan may be amended from time to time in the future.

3.1.6 Managing Runoff from Frequently Occurring Storms (in blue section)

Blue Box
Water Quality Capture Volume (WQCV):
Change …from 0.6 inches of…
To …from 0.64 inches of…

Change UDFCD has…
To The COL has…

3.2 Multiple-Objective Considerations

Paragraph 8:
Delete First through fifth sentences.

Sixth Sentence:
Change Waterways, detention facilities and other drainage facilities…
To Public waterways, public detention facilities and public drainage facilities…
Add Private waterways, private on-site detention facilities and private drainage facilities shall be privately maintained.

3.4 Detention and Retention Storage

Delete …and Retention… from section title

Delete Entire Section

Add The Policy of the City of Loveland shall be to require regional and/or on-site detention for all future growth areas as set forth in the adopted Master Drainage Plan. Temporary or interim detention may be required if the downstream facilities have not yet been constructed per the Master Plan. The Greeley and Loveland Irrigation Company filed on all storm water entering the Company lakes and canals. The filing was done in 1977 and is Case No. W-8665-77. The final decree was entered into on June 5, 1978 and the Company received a 1977 priority for the storm water.

Add Stormwater detention is also governed by Colorado Revised Statute.

3.4.1 Upstream Storage

Paragraph 1:
Delete …and retention…

Paragraph 2:

Add Parking lots may be utilized to store stormwater runoff up to the 100-year storm event per City criteria set forth in the LSDC.

3.4.2 Downstream Storage

Delete …and retention…

3.4.3 Reliance on Privately Controlled Facilities and Water Storage Reservoirs

Change Privately controlled facilities cannot be used for flood….
To Privately controlled facilities, that have legal agreement when ensure flood storage in perpetuity, cannot be…

Change …purposes in master planning because…
To …purposes because…

Delete Exceptions may occur where legal agreements are in place ensuring flood storage in perpetuity.

Add New Section as follows:

3.4.5 Reliance on Non-Flood Control Reservoirs

Jurisdictional dams are classified by the State Engineer as either low, moderate, or high hazard structures depending on conditions downstream. Dams are classified as high hazard structures when, in the event of failure, there is a potential loss of life. Dams presently rated as low or moderate hazard structures may be changed to high hazard rating if development occurs within the potential path of flooding due to a dam breach. In this case, the reservoir owners would need to address the State Engineer's reclassification decision by either paying the cost of upgrading the dam structure to meet the higher hazard classification or removing the dam and draining the reservoir.

The Policy of the City of Loveland shall be to:

1. Restrict upstream development to areas outside of the jurisdictional dam water surface elevation created by a 100- year storm.
2. Restrict downstream development to areas outside of the jurisdictional dam 100-year floodplain. The jurisdictional dam 100-year floodplain is defined as one of the following areas, whichever restricts downstream development most:
    a. Either the 100-year floodplain downstream of the emergency spillway assuming the dam is full to the elevation of the emergency spillway at the beginning of the 100-year storm and the 100-year storm is routed through the dam and out the emergency spillway, or
    b. The path that the basin's 100-year floodplain would form through the downstream development if the dam were removed and the reservoir did not exist.

4.1 Intended Use of Design Criteria

Change	UDFCD revises…
To	The COL revises…
Change	…USDCM…
To	…LSDC…
Add	The City of Loveland Stormwater Utility Senior Civil Engineer may grant Variances from the design criteria of this Manual by his/her acceptance of the Final Drainage Report in which the variance request is well documented.

4.2.1 Design Storm Return Periods for Initial and Major Drainage Systems

Change	Recommended design storms…
To	The COL design storms…
Change	…drainage systems are specified in Table 1-1.
To	…drainage systems are the 2-year and 100-year storm events, respectfully.
Delete	Local governments should not be tempted to specify larger than necessary design runoff criteria for the initial drainage system because of the direct impact on the cost of urban infrastructure.
Delete	Table 1-1…(entire table)
Delete	Paragraph starting with “There are many developed areas within the UDFCD…”
Delete	Paragraph starting with “Strict application of the USDCM in the overall…”

4.2.3 Runoff Computations

Delete	The note in blue labeled as “Master Plan Hydrology”

4.3 Use of Streets

Change	…criteria summarized in Table 1-2 for…
To	…criteria summarized in chapter 6 Streets, Inlets, Storm Sewers for…
Change	…storm runoff, Table 1-3 for…
To	…storm runoff, for…
Change	…and Table 1-4 for…
To	…and for…

Delete Table 1-2…(entire table)

Delete Table 1-3…(entire table)

Delete Table 1-4…(entire table)

Second Bullet:
Change …discouraged…
To …prohibited…

4.4 Use of Irrigation Ditches

Change …major storm runoff should be prohibited…
To …major storm runoff are prohibited

Change …provided in a UDFCD master plan or approved by UDFCD and the ditch…
To …provided in the COL's master drainage plan and approved by the ditch…

Add New first bullet under "Other irrigation ditch-related considerations include:" that states "In 1977 the Greeley and Loveland Irrigation Company (GLIC) filed on all stormwater entering the Company's lakes and canals in Case No. W-8665-77. Therefore, all modifications to stormwater rates and volumes must accommodate GLIC's water rights for stormwater."

4.6 Maintenance of Storage and Water Quality Facilities

Delete … or retention facilities…

5.1 Purpose

Change Governmental entities within the UDFCD area should continue to implement floodplain…
To The City of Loveland has implemented a floodplain…

Change …programs…
To …program…

Change …permanent state or local measures…
To …permanent measures…

5.2 Goals

Change …manner by local governments and other entities.
To …manner by the COL and other entities.

5.3 National Flood Insurance Program

Change The cities and counties in the UDFCD area are encouraged to continue to participate in the National…
To The COL participants in the National…

Change …management program by the local government that,…
To …management program that,…

Change …permanent state or local regulatory measures…
To …permanent regulatory measures…

5.6 New Development

Add The Policy of the City of Loveland shall be to outsource engineering review of all CLOMR and LOMR submittals received with a development application. The Developers shall reimburse the City of Loveland Stormwater Utility for all outsourced engineering review costs. Upon FEMA approval of a CLOMR or LOMR, payment of all outsourced engineering review costs are due and payable to the City of Loveland Stormwater Utility. Developers are welcome to contract directly with our outsourced Consultant for the preparation of CLOMR's and LOMR's, if they so desire.

6.0 Implementation of Urban Storm Drainage Criteria

Change Implementation of Urban Storm Drainage Criteria
To Implementation of Storm Drainage Criteria and Master Drainage Plan

6.1 Adoption and Use of the USDCM and Master Plans

Change Adoption and Use of the USDCM and Master Plans
To Adoption and Use of the LSDC and LMDP

Change The USDCM should be adopted and used by local governments operating within the UDFCD boundary as a resource…
To The LSDC and the LMDP is a resource…

6.3 Amendments to Criteria

Change …encountered by any governmental entity should be reviewed by UDFCD to…
To …encountered by anyone should be reviewed by the COL to…

Change UDFCD should continually review the needs of the region…

To The COL should continually review the needs of the community….

Change …the USDCM
To …the LSDC

6.4 Financing Drainage Improvements

Add The City of Loveland Master Drainage Plan sets forth improvements required for existing and future growth areas. The Policy of the City of Loveland regarding the design and construction of improvements within the Master Drainage Plan shall be as set forth below, subject to annual City Council budget and appropriation approval.

1. The City of Loveland shall arrange for the design and construction of improvements as set forth in the adopted Master Drainage Plan for existing and future growth areas.
2. The drainage systems for future development and redevelopment shall be designed and constructed by the Developer and reimbursed by the City of Loveland by way of a Reimbursement Agreement.
3. The Developers shall be responsible for design and construction of temporary or interim storm drainage systems required due to lack of adequate storm drainage facilities downstream of the new development.
4. Regional detention ponds shall be designed and constructed by the Developer at the time of development. The City of Loveland shall reimburse the Developer, by way of a Reimbursement Agreement, for the design and construction cost difference between the detention volume/land area that is required to store the developed 100-year storm flows from the on-site development and the detention volume/land area required to store the developed 100-year storm flows for the entire contributory area that drains to the regional detention pond.

Chapter 2 Drainage Law

Delete entire chapter:

Add The COL follows the Civil Law Rule.

Chapter 3 Planning

1.0 Importance of Drainage Planning

Paragraph 3:

Change Urban Drainage and Flood Control District (UDFCD has…
To The COL has…

Change …streams in the metropolitan Denver area since the early 1970s.
To …streams since the early 1980's.

Change …participation by sponsoring municipalities, UDFCD and other…
To …participation by the COL, and other…

1.1 Planning Philosophy

Change …objectives presented in the USDCM.
To …objectives presented in the LSDC.

Paragraph 2:

Change General principles that UDFCD…
To General principles that the COL…

2.0 Minor (Initial) Drainage System Planning

Change For the area served by UDFCD…
To For the COL…

Change …once every 2- to 10 years.
To …once every 2-years.

Delete Generally, the initial drainage system drains a tributary no larger than 130 acres, as the runoff from this area would be in excess of the typical capacities of these features within a street section.

3.1 General

Delete Entire section in blue labeled "UDFCD's Master Planning Program"

Change Preparation of the Major Drainage Plan or Outfall System Plan…
To Preparation of the Master Plan…

Delete Entire section in blue labeled "Shelf Life"

3.2 Types of Drainage Plans

Delete Entire section

3.2.1 Major Drainageway Planning Studies

Delete Entire section

3.2.2 Outfall Systems Planning Studies

Delete Entire section

3.3 Phases of Planning

Delete Entire section

3.3.1 Baseline Hydrology

Delete Entire section

3.3.2 Alternatives Analysis

Delete Entire section including blue section labeled “Section 404 Permits”

3.3.3 Conceptual Designs

Delete Entire section

3.4 Alternative Plan Components

Change 3.4 Alternative Plan Components
To 3.4 Plan Components

3.4.5 Detention (Storage)
Paragraph 1, 1st Sentence
Delete and retention

Paragraph 1, 2nd Sentence
Delete and retention

Paragraph 1, 3rd Sentence
Change UDFCD
To COL

Delete Item #2a

Paragraph 4, 1st Sentence
Change UDFCD region
To COL

5.0 Multi-use Opportunities

Change …(NBFs), as discussed in the UDFCD's "Good Neighbor Policy." The…
To …(NBFs). The…

Delete Entire section in blue labeled "Good Neighbor Policy"

Chapter 4 Flood Risk Management

Replace entire chapter

With City of Loveland Municipal Code Chapter 15 Section 15.14 and

City of Loveland Municipal Code Chapter 18 Section 18.09.03

Chapter 5 Rainfall

Delete Entire chapter.

Add The Rainfall Chapter from the March 1986 Loveland Storm Drainage Criteria Manual in its entirety, without change, as included herein.

CITY OF LOVELAND
STORM DRAINAGE CRITERIA MANUAL

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SECTION 500 RAINFALL

501 INTRODUCTION

The data and procedures presented in this section were obtained from the Larimer County Storm Water Management Manual (Reference-18) for the Loveland region of Larimer County (Area II). The data and procedures for other areas of the county can be found in the referenced report.

The methods employed in this section have been adapted from procedures developed by the National Oceanic and Atmospheric Administration and published in Precipitation Frequency Atlas of the Western United States, NOAA Atlas II (Reference-16). These data and procedures presented in the NOAA Atlass II were verified utilizing 34 years of hourly precipitation data for Fort Collins. Utilizing these procedures and data, precipitation frequency curves were developed for the plains area of Larimer County.

502 BASIC DATA

A search of data and methods available for developing precipitation frequency relationships was made in order to determine the best methods and data for Larimer County. A search of published records indicated that there was a limited amount of rainfall data available for Larimer County. Review of established procedures for determining rainfall frequency relationships indicated that the most up-to-date procedures were those published in the NOAA Atlas.

A search of published rainfall data for the State of Colorado revealed that there are seven reporting stations in Larimer County. Table-501 shows the location and number of years of data available from each of these stations. The Fort Collins station is the only rainfall station with long-term hourly precipitation data. These hourly values are needed in order to analyze short-duration storms. Due to this limited amount of available data, other methods of determining precipitation-frequency relationships were employed.

The National Oceanic and Atmospheric Administration published a Precipitation Frequency Atlas of the Western United States in 1973 (mentioned above) of which Volume III contains data for Colorado. This atlas presents charts of precipitation of 6- and 24-hour duration for return periods of 2 to 100 years. The development of the atlas revises Weather Bureau Technical Paper No. 40 developed in 1961. The main emphasis of this revision was to more accurately depict the variation in the precipitation frequency regimes for mountainous regions. The atlas takes into account regional relationships between stations and therefore presents a better regional pattern of precipitation than an analysis of just the stations in Larimer County would produce.

503 FREQUENCY ANALYSIS

The development of the NOAA Atlas utilized two types of rainfall data. The main emphasis was put on utilization of the data from stations which had hourly records. To verify regional relationships, records from daily precipitation

gages were also analyzed. For short-duration storms (less than 24 hours), hourly data were used to develop precipitation-frequency relationships and were verified utilizing data from daily stations. For 24-hour duration storms, all data were analyzed.

To maintain as common a data base as possible, the atlas used 15 years of data for all stations to develop the 2-year precipitation data. Due to the low probability of obtaining a 100-year event within 15 years, data for the 100-year storm events were developed utilizing full lengths of records for stations.

The eastern slope area of Colorado was analyzed utilizing data from 75 rainfall recording stations. To further verify the NOAA Atlas data for Larimer County, a brief analysis was made of the 34 years of data for the Fort Collins station. Table-501 shows the relationships between the 6-hour storms as developed fromt he NOAA Atlas and as developed utilizing only the Fort Collins data. This analysis would indicate that the NOAA Atlas data does accurately predict the rainfall-frequency relationships for the Fort Collins area. A similar analysis of 86 years of Denver data was also made by the Urban Drainage and Flood Control District. The analysis produced approximately the same result as the NOAA Atlas data.

504 RAINFALL ZONES

The County was divided into three major hydrologic areas (as shown in Figure-501), and precipitation-frequency data for each area are different in order to closely match the local precipitation regimes.

The three major areas shown in Figure-501 are described as follows:

Area I: The area near Fort Collins from the east county line on to the first "hogback" on the west and from the watershed divide between the Cache la Poudre and Big Thompson rivers on the south through Township 9 North on the north.

Area II: The area near Loveland from the east county line to the first "hogback" on the west and from the south county line to the watershed divide between the Big Thompson and Cache la Poudre rivers on the north.

Area III: The remainder of the county not in Area I or Area II.

Only the data for Area II are presented herein. The data and procedures for the other areas can be found in Reference-18.

505 CUHP DESIGN STORMS

Rainfall in the Loveland area is influenced by the orographic effects of the Rocky Mountain, the topography of the high plains and the semi-arid climatology of the region. Rainstorms can often have an "upslope" character where easterly flow of moisture settles against the mountains. These types of rainstorms have durations that can exceed 6-hours and produce large amount of total precipitation. However, these storms are rarely intense and seldom result in urban flooding problems.

Very intense rainfall in the Loveland area results from convection storms or frontal stimulated convective storms. These types of storms are often less than 1-hour or 2-hours in duration and can produce brief periods of high rainfall

intensities. These short duration intense rainstorms appear to cause most of the urban flooding problems (reference-1).

Analysis of a 73 year record of rainfall at the Denver rain gage by the Urban Drainage and Flood Control District reveals that an overwhelming majority of the intense rainstorms produce their greatest intensities in the first hour of the storm. In fact, of the 73 most intense storms analyzed, 68 had the most intense period begin and end within the first hour of the storm and 52 had the most intense period begin and end within the first half hour of the storm. The data clearly shows that the leading intensity storms predominate among the "non-upslope" type storms in the Denver Region (Reference-1).

The recommended design storm distribution takes into account the observed "leading intensity" nature of the convection storms. In addition, the temporal distributions were designed to be used with the 1982 version of the CUHP (Section 600), the published NOAA 1-hour precipitation values (Reference-16), and the Horton's infiltration loss equation. They were developed to approximate the recurrence frequency of peak flows and volumes (i.e., 1- through 100-years) that were estimated for the watersheds whose rainfall/runoff data was collected. The procedure for the development of these design storm distributions and the preliminary results were reported at the 1979 International Symposium on Urban Storm Runoff. The recommendations contained in this MANUAL are the result of refinements to the work by the Urban Drainage and Flood Control District.

The recommended design storm distribution was obtained by first computing the incremental rainfall from the total rainfall data in the Larimer County Storm Water Management Manual (see Table-502) for the Loveland area. These incremental values were then rearranged to approximate the recommended distribution by the Urban Drainage and Flood Control District (Reference-1) resulting in the following ranking of values:

DESIGN STORM DISTRIBUTION

	INCREMENTAL PRECIPITATION RANKING					
TIME	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
5	9	9	9	(lowest)	(lowest)	(lowest)
10	7	7	7	10	10	10
15	4	4	4	8	8	8
20	2	2	2	4	4	4
25	1	1	1	2	2	2
30	3	3	3	1	1	1
35	5	5	5	3	3	3
40	6	6	6	5	5	5
45	8	8	8	6	6	6
50	10	10	10	7	7	7
55	11	11	11	9	9	9
60...	12...	12...	12...	11...	11...	11...

Using the distribution and the total rainfall values in Table-502, the design storms for the Loveland area were developed and are presented in Table-503 for drainage basins less than five square miles.

506 TIME-INTENSITY-FREQUENCY CURVES

The time-intensity-frequency data for the Loveland area was taken directly from the Larimer County Storm Water Management Manual and are presented in Figure-502. The data in this form are used primarily in the Rational Method Runoff Modelling Technique (see Section 600).

LARIMER COUNTY RAINFALL DATA

A) SUMMARY OF RAIN-GAGE STATIONS IN LARIMER COUNTY
(SEE TEXT, SECTION 502)

STATION	LOCATION LATITUDE	LONGITUDE	ELEV.	TYPE	YEARS OF RECORD
Fort Collins	40°35'	105°05'	5004	Recording	97
Fort Collins 9NW	40°40'	105°13'	5220	Recording	4
Waterdale	40°25'	105°12'	5260	Non-recording	83
Estes Park	40°23'	105°31'	7525	Non-recording	67
Red Feather Lake 2SE	40°48'	105°34'	8237	Non-recording	15
Rustic 12 WSW	40°42'	105°48'	8080	Recording	4
Drake	40°26'	105°20'	6170	Recording	4

B) COMPARISON OF HISTORICAL DATA WITH NOAA ATLAS 2 FOR FORT COLLINS
(SEE TEXT, SECTION 503)

RETURN FREQUENCY	34-YR. ANALYSIS 1940-1973 6-HR. PRECIPITATION (IN.)	NOAA ATLAS 2 6-HR. PRECIPITATION (IN.)
2-Yr	1.49	1.43
5-Yr	1.83	1.96
10-Yr.	2.18	2.28
50-Yr	3.04	3.08
100-Yr	3.41	3.45

DESIGN TOTAL RAINFALL
AREA II - LOVELAND

2hr-5min Storms

NOTE: All Rainfall Values are in Inches

	TIME	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
x12	5	0.29	0.41	0.49	0.59	0.68	0.77
x6	10	0.45	0.64	0.76	0.92	1.06	1.20
x4	15	0.57	0.81	0.96	1.16	1.34	1.52
x3	20	0.66	0.94	1.12	1.36	1.54	1.78
	25	0.73	1.04	1.24	1.50	1.71	1.98
x2	30	0.79	1.12	1.33	1.61	1.86	2.10
	35	0.83	1.19	1.41	1.70	2.00	2.30
	40	0.87	1.25	1.48	1.78	2.10	2.39
	45	0.91	1.30	1.54	1.85	2.18	2.47
	50	0.94	1.34	1.60	1.91	2.25	2.54
	55	0.97	1.38	1.65	1.97	2.31	2.60
x1	60	1.00	1.41	1.69	2.03	2.36	2.66
	65	1.03	1.44	1.73	2.08	2.40	2.71
	70	1.06	1.47	1.76	2.12	2.44	2.75
	75	1.08	1.50	1.79	2.16	2.48	2.79
	80	1.10	1.52	1.81	2.18	2.52	2.82
	85	1.11	1.54	1.83	2.22	2.55	2.85
	90	1.12	1.55	1.85	2.25	2.58	2.88
	95	1.13	1.56	1.87	2.27	2.60	2.91
	100	1.14	1.57	1.89	2.29	2.61	2.93
	105	1.15	1.58	1.91	2.30	2.62	2.95
	110	1.16	1.59	1.92	2.31	2.63	2.97
	115	1.17	1.60	1.93	2.32	2.64	2.99
x0.5	120	1.18	1.61	1.94	2.33	2.65	3.01

WRC ENG.

REFERENCE: Larimer County Storm Water Management Manual, FEBRUARY 1979

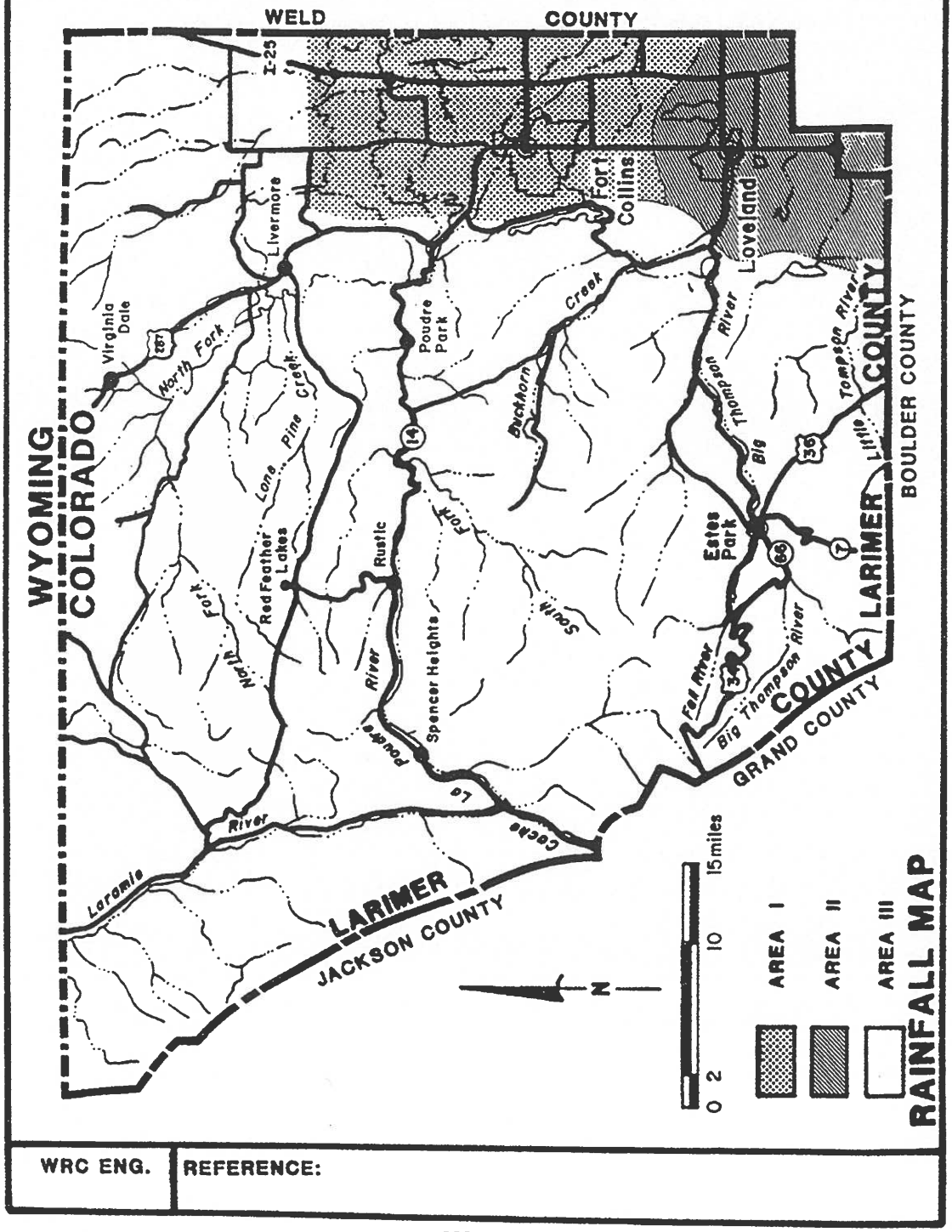
TWO-HOUR DESIGN STORM FOR BASINS LESS THAN 5 SQUARE MILES

TIME (MIN)	INCREMENTAL RAINFALL DEPTH 2-YR (IN)	5-YR (IN)	10-YR (IN)	25-YR (IN)	50-YR (IN)	100-YR (IN)
5	0.04	0.05	0.06	0.01	0.01	0.02
10	0.04	0.07	0.08	0.06	0.07	0.07
15	0.09	0.13	0.16	0.08	0.10	0.09
20	0.16	0.23	0.27	0.20	0.20	0.26
25	0.29	0.41	0.49	0.33	0.38	0.43
30	0.12	0.17	0.20	0.59	0.68	0.77
35	0.07	0.10	0.12	0.24	0.28	0.32
40	0.06	0.08	0.09	0.14	0.17	0.20
45	0.04	0.06	0.07	0.11	0.15	0.18
50	0.03	0.04	0.06	0.09	0.14	0.14
55	0.03	0.04	0.05	0.07	0.08	0.08
60	0.03	0.03	0.04	0.06	0.06	0.06
65	0.03	0.03	0.04	0.06	0.05	0.06
70	0.03	0.03	0.03	0.05	0.04	0.05
75	0.02	0.03	0.03	0.04	0.04	0.04
80	0.02	0.02	0.02	0.04	0.04	0.04
85	0.01	0.02	0.02	0.03	0.04	0.03
90	0.01	0.01	0.02	0.03	0.03	0.03
95	0.01	0.01	0.02	0.03	0.03	0.03
100	0.01	0.01	0.02	0.02	0.02	0.03
105	0.01	0.01	0.02	0.02	0.01	0.02
110	0.01	0.01	0.01	0.01	0.01	0.02
115	0.01	0.01	0.01	0.01	0.01	0.02
120	0.01	0.01	0.01	0.01	0.01	0.02
TOTAL	1.18	1.61	1.94	2.33	2.65	3.01

WRC ENG. | REFERENCE:

LOVELAND
STORM DRAINAGE CRITERIA MANUAL

FIGURE 501



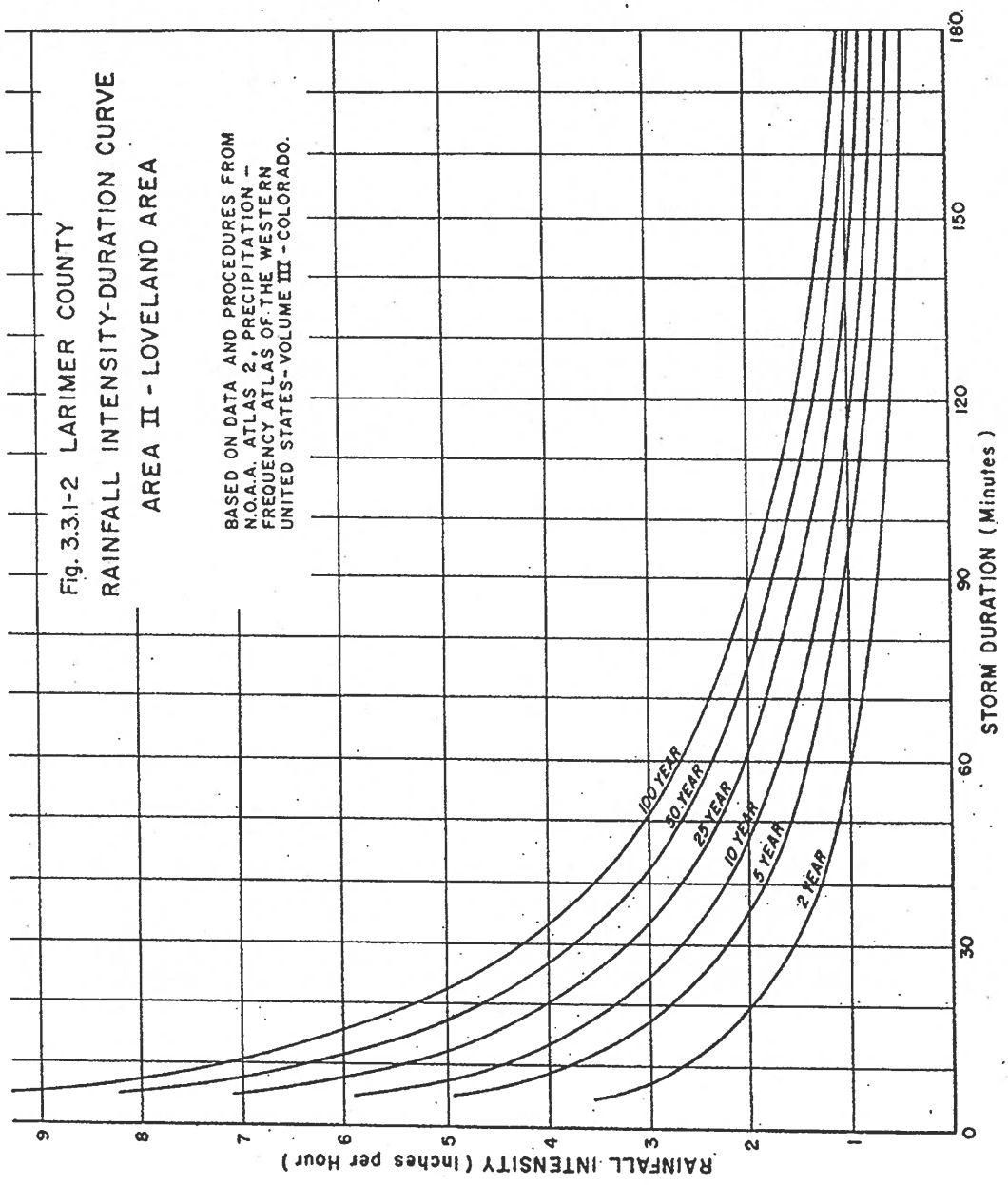
WRC ENG.

REFERENCE:

-508-

LOVELAND STORM DRAINAGE CRITERIA MANUAL	FIGURE 502

RAINFALL INTENSITY - DURATION CURVE



WRC ENG.	REFERENCE:

Chapter 6 Runoff

1.0 Overview

Paragraph 1:
Change …are described in the Urban Storm Drainage Criteria Manual (USDCM):
To …are described as follows:

Paragraph 5:
Delete Statistical analyses may be used in certain situations outside the UDFCD boundary. The use of this approach requires the availability of acceptable, appropriate, and adequate data.

Table 6-1:
Change In first cell of "Is CUHP Applicable?" Column for watershed size of 0 to 90 acres, change "Yes" to "No"

Add Under sub-note under Table 6-1: "The Rational Method shall be used to determine runoff rates for all drainage basins 90 acres or less in size and the calculations submitted in the drainage report. CUHP may be used, in addition to the Rational Method calculations, to determine runoff rates from design points consisting of smaller, combined sub-basins that fall under 90 acres for the purpose of routing flows through detention ponds.

Last Paragraph:
Change …Volume 3 of the USDCM.
To …Volume 3 of the LSDC.

2.5 Rainfall Intensity

Paragraph 2:
Delete entire paragraph

Add Refer to the LSDC Rainfall chapter for City of Loveland rainfall intensity data.

2.5.1 Runoff Coefficient

Paragraph 5:
Change …recommendations in Section 2.4.
To …recommendation in Section 2.4 and are valid for the COL area.

Delete Use of these coefficients and this procedure outside of the semi-arid climate found in the Denver region may not be valid.

3.2 Effective Rainfall for CUHP

Change …of the USDCM.
To …of the LSDC.

3.2.1 Pervious-Impervious Areas

Change …of the USDCM Volume 3.
To …of the LSDC Volume 3.

3.2.3 Infiltration

Paragraph 3:

Change …portions of UDFCD.

To …portions of COL.

Paragraph 6:
Change …use within UDFCD with CUHP.
To …use within COL with CUHP.

Change …frequently within UDFCD;
To …frequently within the COL;

Paragraph 7:
Change …watershed in the Denver metropolitan…
To …watershed in the COL metropolitan…

3.3.1 Rainfall

Change …chapter of the USDCM.
To …chapter of the March 1986 Loveland Storm Drainage Criteria Manual.

Add See Table 502 within the Rainfall Chapter for 1-hour rainfall depths. See Table 503 within the Rainfall Chapter for detailed hyetograph distributions.

3.3.2 Catchment Description

DCIA Level:
Change …Volume 3 of the USDCM.
To …Volume 3 of the LSDC.

Last Paragraph:
Change …studies within UDFCD, the…
To …studies within COL, the…

3.3.3 Catchment Delineation Criteria

Paragraph 1:

Change	UDFCD recommends an…
To	The COL recommends an…

4.0 EPA SWMM and Hydrograph Routing

Paragraph 1:

Change	In 2005, UDFCD adopted the use of EPA's SWMM 5.0 model and recommends its use for all future hydrology studies.
To	COL has adopted the use of EPA's SWMM 5.0 model and recommends its use for all future master plan hydrological studies only.

4.1 Software Description

Paragraph 1:

Change	…not used by UDFCD because…
To	…not used by the COL because…
Change	…calibrated to UDFCD regional…
To	…calibrated to COL regional…

4.2.1 Step 1: Method of Discretization

Blue section labeled "Discretizing large catchments into smaller ones"

Change	…Chapter of the USDCM by…
To	…Chapter of the LSDC by…

5.1 Published Hydrologic Information

Delete	Entire paragraph
Add	Master drainage plans are available on the City of Loveland website. Hard copies of the master drainage plans can be ordered at the Stormwater Engineering office.

5.2 Statistical Methods

Delete	Entire section

6.0 Software

Paragraph 1:
Change …protocols in the USDCM.
To …protocols in the LSDC.

Paragraph 5:
Delete entire paragraph
Add Refer to LCDS Rainfall Chapter for rainfall information within the City of Loveland.

7.1 Rational Method Example 1

Add Example 1 is based upon rainfall for a location in Denver, Colorado. For the COL, the rainfall intensity is to be obtained from the COL Rainfall Chapter 5 and not from Equation 4.3 as presented in this example.

7.2 Rational Method Example 2

Add Example 2 is based upon rainfall for a location in Denver, Colorado. For the COL, the rainfall intensity is to be obtained from the COL Rainfall Chapter 5 and not from Equation 4.3 as presented in this example.

Chapter 7 Streets, Inlets, and Storm Drains

1.4 Minor and Major Storms

Change …is established by local ordinances or criteria, and…
To …for the COL is…

Delete "or-5-"

Change …are commonly specified, based on many factors including street function, traffic load, vehicle speed, etc.
To …event.

Change Local ordinances often also establish…
To The…

Change …, generally...
To …in the COL is…

Delete "(although it may be a lesser event for some retrofit projects with site constraints)"

2.1 Street Function and Classification

Paragraph 1:
Change The four street…
To The five street…

Second Bullet: Collector
Change Collector… and arterials
To Residential Collector… and arterials in residential areas.

Add as Third Bullet
Commercial Collector: Low/moderate-speed traffic providing services between local streets and arterials in commercial areas.

Third Bullet: Arterial
Change Arterial… through urban areas and accessing freeways.
To Minor Arterial... through urban areas.

Add as Fourth Bullet
Major Arterial: Moderate/high-speed traffic moving through urban areas.

Delete Fifth bullet "Freeway: Highspeed…"

Change "Table 7-1 provides additional information on the classification of streets for drainage purposes."
To Table 7-1 provides the allowable street flow depths in the COL

Delete Table 7-1

Add The following Table 7-1

Table 7-1 Allowable Street Flow Depths

TRAFFIC CLASSIFICATION	DRAINAGE CLASSIFICATION	ALLOWABLE FLOW DEPTH	ALLOWABLE FLOW DEPTH
		MINOR STORM (FT)	MAJOR STORM (FT)
Local	A	0.46	0.67
Residential Collector	B	0.47	0.67
Commercial Collector	B	0.5	0.75
Minor Arterial	C	0.5	0.78
Major Arterial	C	0.5	0.75

Note: Allowable flow depth is measured vertically from the gutter flowline at the curb face.

2.2 Design Considerations

Change …UDFCD has established encroachment and inundation standards for…
To …the COL has established the allowable street flow depths presented in section 2.1 for…

Delete These standards were presented in the Policy chapter and are repeated in Table 7-2 for convenience.

Delete Table 7-2

Change …UDFCD has established street inundation standards during the…
To …The COL has established the allowable street flow depths presented in section 2.1 for the…

Delete These standards were given in the *Policy* chapter and are repeated in Table 7-3 for convenience.

Delete Table 7.3

Paragraph 3:
Delete ….intersections, sump locations, and for

Change …were given in the Policy chapter and are repeated in Table 7-4 for convenience.
To …are presented in Chapter 11, Section 2.0.

Add At intersections, the maximum depth of flow in crosspans is as presented in Table 7-1.

Delete These allowable street cross-flow standards were given in the *Policy* chapter and are repeated in Table 7-4 for convenience.

Delete Table 7-4

Paragraph 4:
Delete …spread (pavement encroachment) and allowable…

2.3 Street Hydraulic Capacity (Inset)

Change …from the face of the curb to the crown (for the minor event).
To …based upon the allowable depth of flow in the gutter flowline

2.3.1 Curb and Gutter

Delete UDFCD prescribes a minimum longitudinal slope of 0.4% for positive drainage (Write-McLaughlin 1969).

Add COL prescribes a minimum longitudinal slope for positive drainage that is specified by the City of Loveland. The City utilizes the Larimer County Urban Area Street Standards (LCUASS) for minimum longitudinal slope guidelines.

Change UDFCD recommends…
To The COL uses…

Change …1% for positive drainage; however, a cross slope of 2% is more typical.
To …2% for positive drainage.

Delete "1. Calculate the street capacity based upon the allowable spread for the minor storm as defined in Table 7-2."

Change 2…Table 7-2.
To 1…Table 7-1.

Change 3…two…
To 2…one…

Change 3…in Figure 7-3
To 2…in Figure 7-4

Delete 3…"The lesser value (limited by allowable spread or by depth with a safety factor applied) is the allowable street capacity."

Change 4…through three… Table 7-3
To 3…and two… Table 7-1

Under Section "Allowable Capacity"
Delete "the lesser of:"

Delete Equation 7-11 in its entirety

Delete "or"

Delete "Q_T = street hydraulic capacity where flow spread equals allowable spread (cfs)"

Change There are two sets of safety reduction factors developed for the UDFCD region (Guo 2000b).
To There are two sets of safety reduction factors developed for the UDFCD region (Guo 2000b) and they shall also be utilized for the Loveland area.

2.3.2 Swale Capacity

Third paragraph
Change …Examples 7.4 and 7.5…
To …Examples 6.4 and 6.5…

At end of fifth paragraph
Add For larger storm events, the Froude number shall not exceed 0.5 and the velocity shall not exceed 5 fps.

3.1 Inlet Function and Selection

Table 7-5
Delete "Slotted" inlet row.

Below Table 7-5 Add The standard inlets permitted for use in City of Loveland streets are:

INLET TYPE	**PERMITTED USE**
Curb Opening Inlet Type R	All street types with 6" Vertical curb
Grated Inlet Type C	All streets with a roadside Ditch
Grated Inlet Type 13	Alleys or private drives with a valley gutter
Combination Inlet Type 13	All street types with 6" Vertical curb

Add The maximum ponding over inlets in parking lots is 12 inches.

3.2 Allowable Street Capacity (insert)

Delete "the lesser of:"

Delete "Capacity determined by the allowable spread for the minor event"

Change UDFCD region (in photograph 7-3 reference)
To COL region

3.2.3 Combination Inlets on a Continuous Grade

Change …UDFCD region.
To …COL.

3.2.4 Slotted Inlets on a Continuous Grade

Delete Entire Section

3.2.5 Grate Inlets in a Sump (UDFCD CSU Model)

Delete …(the most common grated street inlets in the UDFCD region),…

3.2.7 Other Inlets in Sump (Not Modeled in the UDFCD-CSU Study)

Table 7-8. Sump inlet discharge variables and coefficients.
Delete "Slotted Inlets" rows

3.2.8 Inlet Clogging

Delete As a common practice for street drainage, 50% clogging is considered for the design of a single grate inlet and 10% clogging is considered for a single curb-opening inlet.

Add Table 7-9, "Allowable Inlet Capacity" provides allowable inlet capacity percentages to be used with standard inlets that are permitted within the City. These values are to be used to determine the allowable clogging factors for each inlet type.

Delete The sentence beginning with "To address this phenomenon…"

Delete The remaining section starting with "With the concept…"

Add To account for effects which decrease the capacity of the various types of inlets, such as debris plugging, pavement overlaying and variations in design assumptions, the theoretical capacity calculated for the inlets is reduced by the factors presented in Table 7-9 for the standard inlets permitted for use in the COL streets.

Table 7-9. Allowable Inlet Capacity

CONDITION	**INLET TYPE**	**PERCENT OF ALLOWABLE CAPACITY ALLOWED**
Sump or continuous Grade	CDOT Type R 5' Length 10' Length 15' Length	 88 92 95
Continuous Grade	Combination Type 13	66
Sump	Grated Type C Grated Type 13	50 50
Sump	Combination Type 13	65

3.3 Inlet Location and Spacing on Continuous Grades

Change …so does the spread and depth.
To …so does the depth.

Change Since the spread (encroachment) and depth…
To Since the depth…

3.3.1 Design Considerations

First Paragraph:
Delete "encroachment and"
Change …Section 2.2.
To …Section 2.1.

Delete "Table 7-2 lists pavement encroachment and inundation standards for minor storms in the UDFCD region."

Second Paragraph:
Delete "spread (encroachment)"

Delete "encroachment and"

Delete "spread and/or"

3.3.2 Design Procedure

First Paragraph:
Delete "encroachment and"Delete "Equation 7-11 and"

Third Paragraph:
Delete "allowable spread and"

Delete "allowable spread and"

Fourth Paragraph:
Delete "spread or"

4.1 Introduction

After Paragraph 1:
Add Refer to the COL Storm Drainage Standards, Specifications, and Details on the COL website for allowable storm sewer pipe materials and manhole details and specifications.

Paragraph 4:
Delete The first two sentences

4.2 Design Process, Considerations, and Constraints

Paragraph 3:
Change "Pipe diameters less than 15 inches are not recommended for storm drains, and many communities have adopted an 18 inch diameter minimum standard."

To The minimum size storm sewer pipe within a Public Right-of-Way or Public Drainage Easement shall be 18 inches in diameter.

Paragraph 4:
Change …depth 100%...
To …depth at 100%...

Delete The last two sentences of the fourth paragraph

Paragraph 5:
Delete The two sentences that begin with "Manholes are also…"
Add Refer to the COL Storm Drainage Standards, Specifications, and Details on the COL website for manhole spacing, etc.

4.3 Storm Drain Hydrology—Peak Runoff Calculation

Change of the USDCM
To of the LSDC

4.4.1 Flow Equations and Storm Drain Sizing

Add The Manning's roughness coefficient "n" for all storm sewer pipe capacity calculations shall be 0.013 regardless of pipe material (i.e. Concrete, PVC, or HDPE)

4.4.2 Energy Grade Line and Head Loss

After first sentence:

Add Storm sewer energy loss coefficient tables, manhole and junction loss coefficient tables, and an example illustration are included on the following four pages and herein referenced as Figures 7-16, 7-17, 7-18, and 7-19.

Add The hydraulic grade line and energy grade line shall be calculated for each storm sewer system and included in the Final Drainage Report. Each storm sewer system shall be profiled on the Final Construction Drawings and shall include the design flow hydraulic grade line. The energy grade line for the design flow shall be 6 inches below the final finished elevation of the manhole rims and inlet flowlines.

Losses at the Upstream Manhole, Section 3 to Section 4:

Change K_e = entrance loss coefficient between 0.2 to 0.5
To K_e = entrance loss coefficient from Figure 7-16

Add Figure 7-16

Bend/Deflection losses:

Change K_b = bend loss coefficient
To K_b = bend loss coefficient from Figure 7-16

Change As shown in Figure 7-15 and Table 7-11, the…
To As shown in Figure 7-13 and Table 7-11, the…

Change Figure 7-16 illustrates…
To Figure 7-14 illustrates…

Change curve on Figure 7-15 labeled…
To curve on Figure 7-13 labeled…

Lateral Junction Losses:

Change K_j = lateral loss coefficient
To K_j = lateral loss coefficient from Figure 7-13

Transitions:

Change …Table 7-12…
To Figure 7-17

Add Figure 7-17

Delete Table 7-12 in its entirety

Change …contraction coefficient.
To …contraction coefficient from Figure 7-17.

Delete Typically, $K_c = 0.5$ provides reasonable results.

Curved Pipes
Change …coefficient from Figure 7-15.
To …coefficient from Figure 7-18.

Add Figure 7-18

5.0 UD-Inlet Design Workbook

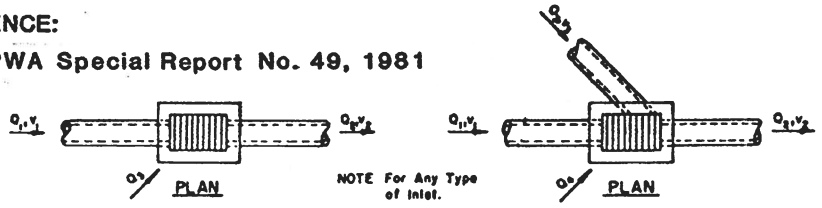
Add Only UD-Inlet is allowed in the COL for inlet capacity calculations.

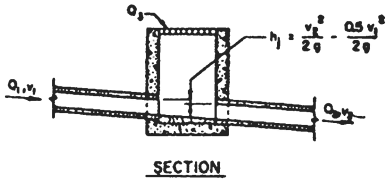
Figure 7-16

MANHOLE AND JUNCTION LOSSES

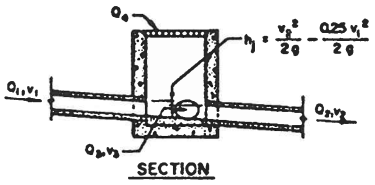
REFERENCE:

APWA Special Report No. 49, 1981

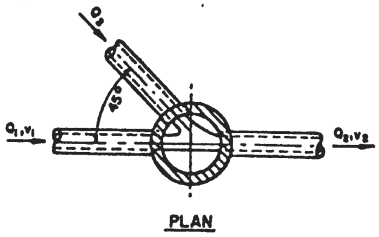


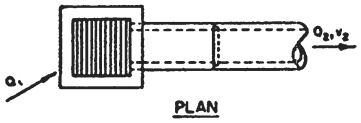


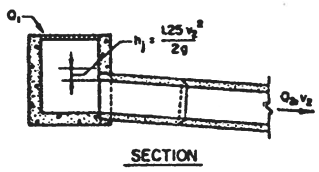
CASE I
INLET ON MAIN LINE



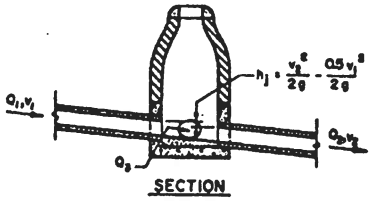
CASE II
INLET ON MAIN LINE
WITH BRANCH LATERAL







CASE IV
INLET OR MANHOLE AT
BEGINNING OF LINE



CASE III
MANHOLE ON MAIN LINE
WITH 45° BRANCH LATERAL

EQUATION:

$$H_L = \left(\frac{V_2^2}{2g}\right) - K_j\left(\frac{V_1^2}{2g}\right)$$

CASE NO.	K_j
I	0.50
II	0.25
IV	1.25

CASE III θ°	K_j
22-1/2	0.75
45	0.50
60	0.35
90	0.25
No Lateral	0.50

Figure 7-17

STORM SEWER ENERGY LOSS COEFFICIENT

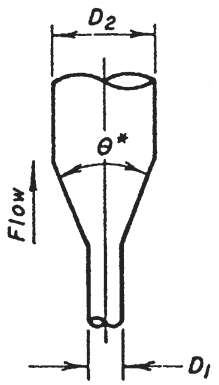
(EXPANSION, CONTRACTION)

REFERENCE: Linsley and Franzini, "Water Resources Engineering", McGraw-Hill, 1964

(a) Expansion (K_e)

θ*	$\frac{D_2}{D_1} = 3$	$\frac{D_2}{D_1} = 1.5$
10	0.17	0.17
20	0.40	0.40
45	0.86	1.06
60	1.02	1.21
90	1.06	1.14
120	1.04	1.07
180	1.00	1.00

*The angle θ is the angle in degrees between the sides of the tapering section.



(b) Pipe Entrance from Reservoir

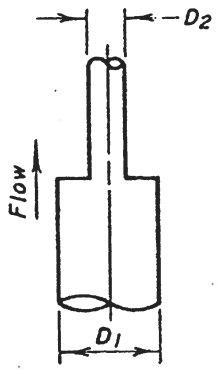
Bell-mouth $H_L = 0.04 \frac{V2}{2g}$

Square-edge $H_L = 0.5 \frac{V2}{2g}$

Groove and U/S For Concrete Pipe $H_L = 0.2 \frac{V^2}{2g}$

(c) Contractions (K_c)

$\frac{D_2}{D_1}$	K_c
0.1	0.5
0.4	0.4
0.6	0.3
0.8	0.1
1.0	0



EQUATIONS:

$$H_L = K_e \left(\frac{V_1^2}{2g}\right)\left[1-\left(\frac{A_1}{A_2}\right)\right]^2$$

$$H_L = K_c \left(\frac{V_2^2}{2g}\right)\left[1-\left(\frac{A_2}{A_1}\right)^2\right]^2$$

Figure 7-18

STORM SEWER ENERGY LOSS COEFFICIENT

(BENDS)

$$H_L = K_j(V^2/2g)$$

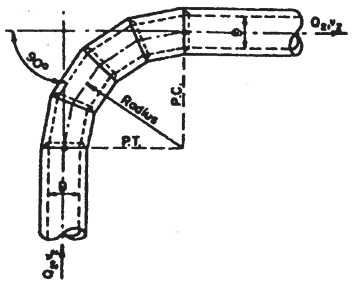
REFERENCE:

APWA Special Report No. 49, 1981

CASE I
CONDUIT ON 90° CURVES*

NOTE: Head loss applied at P.C. for length

RADIUS	K_b
1 X D	0.50
(2 to 8) X D	0.25
(8 to 20) X D	0.04
>20 X D	0



* When curves other than 90° are used, apply the following factors to 90° curves
60° curve 85%
45° curve 70%
22-1/2° curve 40%

CASE II
BENDS WHERE RADIUS IS EQUAL TO DIAMETER OF PIPE

NOTE: Head loss applied at begining of bend

θ°BEND	K_b
90	0.50
60	0.43
45	0.35
22-1/2	0.20

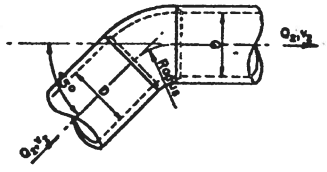
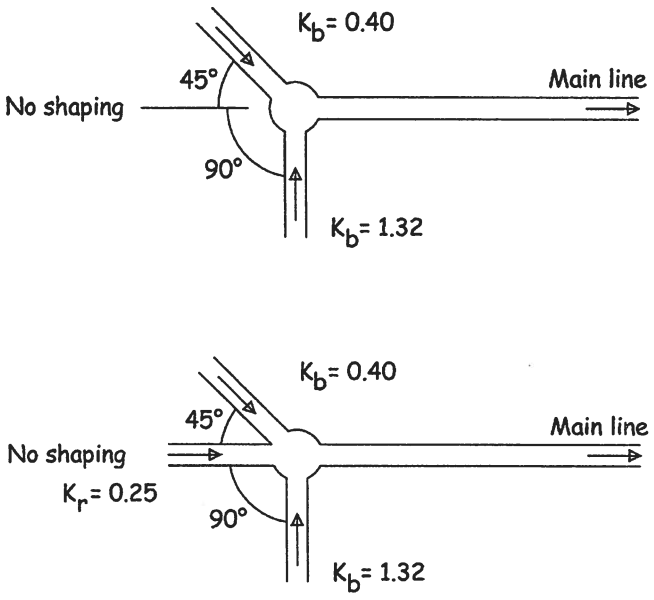


Figure 7-19



at θ = 45°, K_r^1 = 0.50

at θ = 90°, K_r^2 = 0.25

$K_r = \min(K_r^1, K_r^2) = 0.25$

Manhole

Sewer

Example Illustration

Chapter 8 Open Channels

3.2 Provide Ample Space for Stream and Floodplain

Provide Ample Freeboard:

Change "Urban Drainage and Flood Control District (UDFCD) recommends providing 18 inches"…

To The COL requires 12 inches…

3.3 Manage Increase Urban Runoff

Paragraph 1:

Change …Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM)>

To …Volume 3 of the LSDC.

Paragraph 4:

Delete Entire paragraph (beginning with "Master plan modeling…")

4.3.2 Sizing of Bankfull Channel

Based on return period:

Change …UDFCD recommends using…

To …the COL recommends using…

Last Paragraph

Change …streams within the UDFCD area.

To …streams within the COL area.

4.3.4 Floodplain Terraces

Paragraph 7:

Delete See the *Stream Access and Recreational Channels* chapter for these criteria.

Add The City of Loveland and the design engineer shall work together to provide access to all major drainageways as determined appropriate at the time of preliminary and final design.

4.5 Develop Grade Control Strategy to Manage Longitudinal Slope

Number 3:

Change …have been estimated in an UDFCD master plan.

To …have been estimated in the LMDP.

Number 4:

Change …within UDFCD boundaries

To …within COL boundaries

4.6 Address Bank Stability

After third bullet

Add In addition, consideration should be given to using structural methods at the channel bottom and vegetative / bioengineering methods on the upper banks of the channel.

4.6.1 Bioengineering Techniques

Paragraph 1:

Change …restoration within UDFCD has…

To …restoration within the COL has…

Paragraph 1:

Change UDFCD promotes the integration…

To The COL promotes the integration…

4.6.2 Bank Protection Approaches

Paragraph 4:

Change UDFCD recommends using purely vegetative…

To The COL recommends using purely vegetative…

Paragraph 5:

Change UDFCD experience has shown…

To The COL experience has shown…

Blue Box

Item 3.

Change …hydraulic calculations…

To hydraulic and shear stress calculations…

Add 4. Provide sufficient evidence of high groundwater table or a proposed temporary irrigation plan to support the establishment of roots and vegetation for the proposed bioengineered system.

4.8 Evaluate Stream Hydraulics of over a Range of Flows

Paragraph 7:

Change …with the owner and local jurisdiction,…

To …with the owner and COL,…

5.0 Naturalized Channels

2nd Paragraph:

Add Manufactured channel linings such as gabions, interlocked concrete blocks, synthetic linings, etc. are not recommended for new developments, but will be considered on a case-by-case basis by the City of Loveland.

5.3 Establish Effective Cross-Sectional Shape

Paragraph 2:

Delete In addition to the minimum dimensions shown in Table 8-2, a maintenance access path with a minimum per the geometry listed in Table 9-3 of the *Stream Access and Recreational Channels* chapter.

Add In addition to the minimum dimensions shown in Table 8-2, the City of Loveland and the design engineer shall work together to provide access to all major drainageways as determined appropriate at the time of preliminary and final design.

Paragraph 3:

Change …a freeboard of 18 inches or more

To …a freeboard of 12 inches or more

Add Grass-lined open channels conveying ≤ 50 cfs may reduce the minimum 1.0-foot freeboard requirement to the freeboard required to convey 1.33 times the 100-year design flow. The reduced freeboard may only occur if a 1.0-foot minimum freeboard is not physically or reasonably possible and a variance request is submitted.

5.6 Address Bank Stability

Add The City of Loveland is open to review and accept alternate bioengineering methods that provide protection to toe of bank slopes (i.e. riprap, etc.)

5.8 Evaluate Storm Hydraulics Over a Range of Flows

Add Water surface profiles shall be computed for all open channels conveying > 50 cfs within the City of Loveland. Hydraulic grade lines shall be shown on the Final Construction Drawing profiles of open channels conveying > 50 cfs within the City of Loveland. It is not necessary to show energy grade lines on Final Construction Drawing profiles, but encouraged. The energy grade line for the design flow shall be at or below the final finished top of channel bank elevation.

Table 8-3:

Add Note: The 5-year design parameters in this table are not the same as the 2-year design storm event.

6.1 Design Criteria for Swales

After Paragraph 1:

Add To the greatest extent possible, smaller swales with smaller flows shall be designed so that the Froude Number for the 100-year stormwater flows does

not exceed 0.80. If the Froude Number exceeds 0.80, then the use of a permanent turf reinforcement mat within the swale may be used in lieu of riprap lining. The permanent turf reinforcement mat shall be installed up to the freeboard elevation of the 100-year storm flow and shall withstand the velocity and shear stress created by the 100-year storm flows within the swale.

Item 1:
Change …5:1 or flatter.
To …4:1 or flatter.

Add 3. Grass-lined open channels conveying ≤ 50 cfs may reduce the minimum 1.0-foot freeboard requirement to the freeboard required to convey 1.33 times the 100-year design flow. The reduced freeboard may only occur if a 1.0-foot minimum freeboard is not physically or reasonably possible and a variance request is submitted.

Add 4. The City of Loveland and the design engineer shall work together to provide access to all major drainageways as determined appropriate at the time of preliminary and final design.

Add 5. At a minimum, all swales shall be designed to convey the 100-year storm event.

6.3 Soil Riprap and Void-Filled Riprap Swales

Add For soil riprap, vegetation must be established in accordance with Section 6.2.1 above.

8.0 Rock and Boulders

Paragraph 3:
Change UDFCD recommends review…
To The COL recommends review…

8.1.1 Mild Slope Conditions

Paragraph 1:
Change …UDFCD recommends…
To …COL recommends…

Paragraph 2:
Change …chapter of the USDCM, and protection…
To …chapter of the LSDC, and protection…

8.1.2 Steep Slope Conditions

First paragraph after bullets:
Change …standard UDFCD riprap gradations.
To …standard COL riprap gradations.

Change …in UDFCD specifications.
To …in COL specifications and standard details.

8.2 Boulder and Riprap Specifications

Change …for riprap and boulders can be found in UDFCD's Construction Specifications, available at www.udfcd.org.
To …for riprap can be found on the COL's website. Boulder classifications and grout specifications can be found in the following Table 8-8 and Table 8-9.

Add The following Table 8-8 and Table 8-9

Table 8-8
Classification of Boulders

Boulder Classification	Nominal Size and [Range in Smallest Dimension of Individual Rock Boulders (inches)]	Maximum Ratio of Largest to Smallest Rock Dimensions of Individual Boulders
B18	18 [17-20]	2.5
B24	24 [22-26]	2.0
B30	30 [28-32]	2.0
B36	36 [34-38]	1.75
B42	42 [10-44]	1.65
B48	48 [45-51]	1.50

Table 8-9

Structural Grout Requirements for Grouted Boulders

Item	Type A[1]	Type B[2]
Cement	Type II, 7 Sack	Type II, 7 Sack
Concrete Aggregate Mix – Max Diameter	½ inch	¾ inch
Compressive Strength	3,200 psi at 28 days	3,200 psi at 28 days
Slump	4 to 6 inches	4 to 6 inches
Air Entrainment	7.5% ± 1.5%	7.5% ± 1.5%
Fiber Mesh	1.5 lbs/cy	1.5 lbs/cy
Fly Ash (Class C) – Max Allowable Substitute	25%	25%
Color Additive	As Required	As Required

1 Type A grout can be used for most applications.

2 Type B grout is appropriate for waterways such as streams and rivers that have a substantial flow that could scour Type A grout.

8.2.2 Soil Riprap

Change …UDFCD frequently specifies…
To …the COL frequently specifies…

8.2.3 Void-filled Rip Rap

Number 3, Paragraph 5:
Change UDFCD recommends construction…
To The COL recommends construction…

Volume 2

Chapter 9 Hydraulic Structures

1.0 Structures in Streams

Paragraph 5:
Change …discussed herein govern design of all structures
To … discussed herein should be followed.

2.1 Overview

Paragraph 4:
Change …fully developed future basin conditions, in accordance with zoning maps, master plans, and other relevant documents.
To …the major storm as presented in the LMDP.

Blue box labeled Key Considerations…:
Change …master plan…
To …LMDP…

Change …or less to avoid…
To …or less, if possible, to avoid…

2.2.2 Geometry

Table 9-1, Footnote 1:
Change Urban Drainage and Flood Control District (UDFCD)…
To The COL…

2.3.5 Hydraulic Jump Length

Paragraph 2:
Change …in the UDFCD region.
To …in the COL.

Paragraph 3:
Change UDFCD recommends…
To COL recommends…

2.4.1 Introduction

Paragraph 2:
Change …the Urban Storm Drainage Criteria Manual (USDCM)…
To …LSDC…

2.6.1 Description

Paragraph 2:
Delete Entire paragraph

Add In the COL, grouted boulders shall be left exposed.

2.6.3 Design Criteria

Number 3:
Change …UDFCD…
To …COL…

Table 9-4:
Add A row above the “”Less than 5.00” cell. Within this row, the cell under the “Rock Sizing Parameter, Rp” column shall contain the wording, “Less than 4.50” The cell under the “Boulder Classification” column shall contain the term “B18”.

Table 9-4 Cell containing the wording “Less than 5.00”:
Replace “Less than 5.00”
With “4.5 to 4.99”

2.6.4 Construction Guidance

Paragraph 6:
Change …UDFCD…
To …COL...

2.7.1 Description

Paragraph 2:
Change …UDFCD…
To …COL…

2.7.4 Decorative Elements (Finishing)

Examples in Nature:
Change …UDFCD…
To …COL…

Change …UDFCD…
To …COL…

Top Dressing with Sand…:
Change …UDFCD…
To …COL…

2.8 Vertical Drop Structure Selection

Delete Entire Section

2.9 Low-Flow Drop Structures and Check Structures

2nd Bullet:
Delete (depending on local criteria)

3.0 Pipe Outfalls and Rundowns

Delete 2nd Paragraph

Add When a pipe outfall conveys stormwater down an embankment, permanent erosion protection in the form of a concrete or grouted riprap rundown is needed to protect the embankment from erosion. The rundown needs to be designed to contain the 100-year runoff plus freeboard and be in the shape of a swale. Rundowns conveying > 50 cfs shall have a minimum 1.0 foot freeboard above the 100-year water depth. Rundowns conveying ≤ 50 cfs may reduce the freeboard requirement to the freeboard required to convey 1.33 times the 100-year design flow.

3.1.1 Flared End Sections and Toe Walls

Paragraph 2:
Change …UDFCD…
To …COL…

Change …UDFCD…
To ….COL…

Paragraph 3:
Delete Figure 9-29 and… … for a cutoff wall.

3.1.2 Concrete Headwall and Wingwalls

Delete Entire section

Delete Figure 9-29 through Figure 9-33

3.2.4 Outfalls and Rundowns

Section Title
Change "Outfalls and Rundowns"
To "Grouted Boulder Outfalls

Paragraph 1:
Change …outfall or "rundown"can…
To …outfall can…

Change …the South Platte.
To …Big Thompson River.

3.2.5 Rundowns

Paragraph 1:
Delete The use of rundowns is discouraged due to their high rate of failure which results in unsightly structures that become a maintenance burden.

Change …alternative is to …
To …alternative, for low flow rates, is to …

Design Flow paragraph
Change …full design flow
To …100-year design flow

Delete Cross-section paragraph

Add **Cross-Section**
Rundowns shall be designed to contain the 100-year runoff plus freeboard and be in the form of a swale. The rundown shall be constructed of either grouted riprap (with no fines), grouted boulders or concrete.
Design Capacity
The capacity of the channel rundown is dependent on the allowable flow depth at the entrance to the rundown. Since many rundowns begin at a curb in a parking lot or street, capacity limitations are based on maximum ponding depth at the curb equal to the curb height. The maximum depth is taken as the specific energy of the flow as it passes through critical depth at the entrance to the rundown. The minimum rundown width should equal the width of the upstream curb cut or storm sewer or as required to convey the major storm runoff, whichever is greater. At no time should the rundown width be less than 12 inches. **Outlet Configuration**
The channel rundown outlet shall enter the drainageway at the trickle channel. Erosion protection of the opposite channel bank shall be provided by a layer of grouted riprap. The width of this riprap erosion protection shall be at least three times the channel rundown width. Riprap protection shall extend up the opposite bank to the minor storm flow depth in the drainageway or 2 feet, whichever is greater.

Freeboard
For rundowns conveying > 50 cfs, provide a minimum 1 foot of freeboard above the critical depth of the flow. For rundowns conveying ≤ 50 cfs, the freeboard requirement may be reduced to the freeboard required to convey 1.33 times the 100-year design flow.

Appendix A. Force Analysis for Grade Control Structures

Overall Analysis, Paragraph 2:
Change …USDCM…
To …COL…

Chapter 10 Stream Access and Recreational Channels

1.0 Introduction and Overview

Delete Paragraph starting with "Boatable channels represent a subset of recreational channels…"

Delete Paragraph starting with "Some boatable channel criteria may also be appropriate…"

Delete The three bulleted items.

2.0 Public Safety Project Review

Blue Box labeled Public safety criteria…
Change …in the Urban Storm Drainage Criteria Manual (USDCM):
To …in the LSCM:

From the storage Chapter, Paragraph 2:
Delete "Check requirements of the local jurisdiction."

Change UDFCD…
To COL…

3.0 Shared-Use Paths Adjacent to Streams

Change ...adhere to local jurisdiction…
To …adhere to COL…

Change …adhere first to local jurisdiction criteria…
To …adhere first to COL criteria…

3.1 Path Use

Bullet 1:
Change …into an existing master plan where…
To …into an existing plan where…

3.2 Frequency of Inundation

Third Paragraph
Change …In this case UDFCD…
To …In this case COL…

3.3.1 Typical Sections

First Paragraph
Change …is ten feet…
To …is twelve feet…

Delete This is also consistent with AASHTO's width recommendations for two-directional shared-use paths.

Delete …to 12 or even 14 feet…

Change …path meets that of Cherry Creek.
To …path meets that of Cherry Creek in Denver, Colorado.

3.3.4 Vertical Clearance in an Underpass

Delete Minimum values may be lower than those published by local communities within the UDFCD boundary.

Delete Always check local criteria and conform to their vertical clearance requirements.

Delete Table 10-3

Add When designing paths within City of Loveland property or rights-of-way, the current City of Loveland requirements for path geometry shall be used instead of the geometry parameters presented in Table 10-3.

3.4.2 Pumped Systems

Change …UDFCD…
To …COL…

Blue box labeled Underpass Safety:
Third Bullet:
Change UDFCD encourages…
To COL encourages…

Change …in Photo 10-17 as a regional standard.
To …in Photo 10-17.

3.5.2 Path Underpass in a Culvert

Paragraph 2:
Change UDFCD…
To COL…

Change …in Photo 10-17 to promote consistency throughout the region.
To …in Photo 10-17.

3.6.1 Crossing Type and Materials

Change …UDFCD…
To …COL…

3.7.3 Asphalt

Change UDFCD…
To COL…

3.7.4 Concrete

Add When the path is constructed on City of Loveland property or rights-of-way, the current City of Loveland criteria shall be used to determine the minimum allowable depth of the concrete.

3.7.5 Proprietary Surfaces

Change …UDFCD…
To …COL…

4.3 Minimum Criteria

Paragraph 1:
Change …UDFCD…
To …COL…

Chapter 11 Culverts and Bridges

1.0 Introduction and Overview

Paragraph 4:
Change ...the Urban Storm Drainage Criteria Manual (USDCM)…
To …the LSDC…

2.0 Required Design Information

Drainage Master Plan:
Change Drainage Master Plan
To Planning

First Bullet:
Change …the relevant major drainageway master plan, and…
To …the relevant LMDP, and…

Second Bullet:
Delete Assure consistency with existing master plans and/or outfall studies.

Design Flood Frequency and Discharge:
Delete Bullet starting with "The design flood frequency for culverts…"
Add

DRAINAGE CLASSIFICATION	**MINIMUM CAPACITY (RECURRANCE INTERVAL)**
Local	10-Year
Residential Collector & Commercial Collector	10-Year
Minor Arterial & Major Arterial	100-Year

When the flow in a roadside ditch exceeds the capacity of the culvert and overtops the cross street, the flow over the street crown shall not exceed the limits established in Chapter 7, Section 2.1.

Allowable Headwater Depth for Culverts:
Delete Items 1 through 3. Add The maximum culvert headwater to diameter ratios are:

STORMWATER FREQUENCY	**HEADWATER TO DIAMETER**
10-Year	HW/D ≤ 1.0
100-Year	HW/D ≤ 1.5

Allowable Outlet Velocities for Culverts:
Change Use UD Culvert, available at www.udfed.org to…
To Refer to Section 3.0 in Chapter 9 to…

Culvert Details:

Add To second bullet: Refer to the "City of Loveland, Colorado Storm Drainage Standards", latest edition, for allowable culvert pipe materials. The storm drainage standards can be found on the City of Loveland Public Works Stormwater Engineering Stormwater Standards page.

3.1 Key Hydraulic Principles

Add Culvert hydraulic analysis must include analysis of both inlet and outlet control conditions as steady state open channel flow calculations do not apply to culvert hydraulics.

Change Manning roughness coefficient (See Table 11-1)
To Manning roughness coefficient

Delete Table 11-1. Manning's roughness coefficients with 3.5.3 page 53 (last paragraph)
Add The Manning's roughness coefficient "n" for all culvert pipe sizing calculations shall be 0.013 regardless of pipe material (Concrete, PVC, or HDPE).

3.1.1 Energy and Hydraulic Grade Lines

Add The hydraulic grade line and energy grade line shall be determined for each culvert system and included in the Final Drainage Report. Each culvert system shall be profiled on the Final Construction Drawings and shall include the design flow hydraulic grade line.

4.1 Capacity Charts

Paragraph 2: Delete Sentence starting with "Perhaps most important to recognize…"

Delete Sentence starting with "This is important because…"

4.1.2 Culverts Under Outlet Control

Paragraph 1:
Delete Sentence that begins with "In addition, the hydraulic roughness of the culvert material…"

Paragraph 2:
Delete Sentence starting with "Also, as stated in section 2.2, UDFCD…"

4.3 Computer Applications

Paragraph 1:
Change …UDFCD…
To …COL…

Delete Paragraph starting with "In addition to the public domain…"

4.4.3 Minimum Culvert Diameter

Delete Sentence starting with "Since smaller diameter pipes…"

Add Culverts smaller than 18 inches in diameter may only be used to convey roadside ditches under driveways where basin location, site grading, and roadside ditch depths do not make an 18 inch diameter culvert practical. A variance shall be requested for use of culverts smaller than 18 inches in diameter.

4.4.6 Minimum Slope

Delete Entire section

5.1.1 Inlets with Headwalls

Corrugated Metal Pipe:
Delete Entire Section

5.1.2 Special Inlets

Corrugated Metal Pipe:
Delete Entire Section

Concrete Pipe:
Delete As is the Case with Corrugated Metal Pipe, concrete end-sections….

Mitered Inlets:
Delete They are most commonly used with corrugated metal pipe.

5.1.3 Projecting Inlets

Delete …metal or…

Add At a minimum all culvert entrances and outlets shall include a flared end section or headwall.

5.2.2 Buoyancy

3rd Paragraph:
Delete …particularly on corrugated metal pipe with mitered, skewed, or projecting ends.

5.3 Safety Grates

Delete 2nd Bullet.

Paragraph 6:
Change …the USDCM to size the grate…
To …the LSDC to size the grate…

Blue box labeled Safety Grate Design:
Change …the USDCM to size the grate.
To …the LSDC to size the grate.

5.3.1 Collapsible Grating

Delete Entire Section.

6.0 Outlet Protection

Paragraph 4:
Change …the USDCM and...
To …the LSDC and…

7.1 General

Last Paragraph:
Change …owner and local jurisdiction.
To …owner and COL.

Change Contact the local government to…
To Contact the COL to…

7.3 Freeboard

Delete Criteria for bridge freeboard vary from 1 foot to 4 feet in Colorado depending on the jurisdiction and risk of debris specific to the channel.

Add The bridge low chord elevation shall be a minimum of 1-foot above the 100-year water course energy grade line.

Delete Sentence starting with “Additionally, some criteria define freeboard based…”

Delete Sentence starting with “When the local jurisdiction does…”

9.0 Checklist

Delete Sentence starting with “HW/D ratio…”

Delete Second bullet starting with “The culvert…”

Chapter 12 Storage

1.0 Overview

Paragraph 1:
Change …USDCM.
To …LSDC.

Bullet 1:
Change Regional sub-regional, and onsite detention facilities,
To Regional and onsite detention facilities,

Last Paragraph:
Change UDFCD…
To COL…

2.0 Implementation of Regional, Sub-regional, and On-site Detention Facilities

Section Title
Change Implementation of Regional, Sub-regional, and On-site Detention Facilities
To Implementation of Regional and On-site Detention Facilities

Paragraph 1:
Change There are three basic …
To There are two basic …

Bullet 2:
Delete Subregional Detention

Last sentence:
Change These three approaches …
To These two approaches …

2.1 Regional Detention

Paragraph 1:
Change …watershed areas ranging from about 130 acres to one square mile.
To …watershed areas.

Paragraph 2:
Delete Sentence starting with "In some cases, regional detention has been shown…"

Paragraph 3:
Delete Sentence starting with "Regional detention facilities may be…"

Add Regional Master Planned detention ponds, designed and constructed by or on behalf of the City of Loveland, shall be owned and maintained by the City of

Loveland Stormwater Utility. All other detention ponds shall be considered privately owned and privately maintained.

Paragraph 5:
Delete Entire paragraph
Add Release rates for master planned regional detention facilities shall be as identified in the LMDP or as determined by the COL.

2.2 Subregional Detention

Delete Entire section including Figure 12-2.

2.3 Onsite Detention

Paragraph 1:
Change …one lot, generally commercial or industrial sites draining areas less than 20 to 30 acres.
To …one lot, or development.

Paragraph 2:
Delete On-site facilities are usually designed to control runoff from a specific land development site and are not typically located or designed to effectively reduce downstream flood peaks along the receiving stream.

Figure 12-3:
Change Onsite drainage area generally <20AC
To Onsite drainage area

Change "Minor drainage"
To "Drainageway"

Change "Major drainage"
To "Drainageway"

Change Onsite detended facility
To Onsite detention facility

Delete Applicable to certain commercial, multi-family, and industrial land uses

Paragraph 3:
Change …is that developers can be required to build them as a condition of site approval.
To …is that development can occur before master planned facilities are fully constructed.

Delete Sentence starting with "Approximately 100 onsite facilities built…"

2.4 Detention and UDFCD 100-Year Floodplain Management Policy

Delete Entire section

3.2 Excess Urban Runoff Volume

Paragraph 1:
Change …UDFCD…
To …COL…

Paragraph 3:
Delete The upper portion of volume in a full spectrum detention facility is designed to reduce the developed condition 100-year peak discharge down to 90 percent of the pre-development 100-year peak flow rate from the tributary sub-watershed.
To The upper portion of volume in a full spectrum detention facility is designed to reduce the developed condition 100-year peak discharge down to the historic rate as presented in Table 12-6 in Section 4.1.2.

Blue Box labeled Benefits of Implementing…:
Change …UDFCD…
To …COL…

3.3 Compatibility of Full Spectrum Detention with Minor and Major Event Detention

Paragraph 1:
Change …in magnitude to 10-year/100-year detention…
To …in magnitude to traditional 10-year/100-year detention…

Change …based on past criteria provided in this manual.
To …based on traditional design criteria.

Paragraph 2:
Delete Sentence starting with "Where existing master plans recommend…"

Paragraph 3:
Delete Sentence starting with "There may be opportunities to convert existing…"

3.4 Water Quality Capture Volume and Full Spectrum Detention

Bullet 2:
Delete Retention ponds,

Bullet 4:
Delete Sand filters, and

Paragraph 2:
Change …UDFCD does not recommend adding any part…
To …COL does not add any part…

Add Within the City of Loveland the water quality capture volume shall be considered a portion of the total 100-year detention pond volume obtained using the simplified full spectrum detention pond design method.

Table 12-1, Maximum Release Rate for Zone 3:
Change 0.9 (predevelopment Q100)
To Based on the 100-year release rates in Table 12-6.

Paragraph 4:
Delete Sentence starting with "The design of a retention pond…"

Delete Figure 12-7

Delete Table 12-2

Table 12-3, Maximum Release Rate for Zone 3:
Change 0.9 (predevelopment Q_{100})
To Based on the 100-year release rates in Table 12-6.

Delete Paragraph starting with "The design of a sand filter combined with full…"

Delete Figure 12-9

Delete Figure 12-10

Delete Figure 12-11

Table 12-4, Title
Change Sand Filter or bioretention facility combined with full spectrum detention
To Bioretention facility combined with full spectrum detention

Table 12-4, Maximum Release Rate for Zone 3:
Change 0.9 (predevelopment Q100)
To Based on the 100-year release rates in Table 12-6.

4.0 <u>Sizing of Full Spectrum Detention Storage Volumes</u>

Change …USDCM…
To …LSDC…

Item 2:
Change UD-Detention workbook
To Modified FAA Method

Add The excess urban runoff and 100-year storm shall be the design parameters for all detention pond designs within theCOL, unless so dictated by COL.

Add Hydrograph Routing through the CUHP and SWMM method is mainly used for master planning purposes.

Add The Rational Method and Modified FAA Method is required for all detention volume sizing calculations.

Delete Table 12-5

4.1.1 Full Spectrum Detention Volume

Delete Entire section.

4.1.2 100-year Release Rates

Delete All paragraphs, equations, and tables

Add The maximum allowable unit flow release rates in COL are presented in Table 12-6

Table 12-6:
Maximum Allowable Unit Flow Release Rates (cfs/acre) of Tributary Catchment

Design Return Period (Years)	NRCS Hydrologic Soil Group		
	A	B	C & D
2	0.02	0.03	0.04
5	0.07	0.13	0.17
10	0.13	0.23	0.30
25	0.24	0.41	0.52
50	0.33	0.56	0.68
100	0.50	0.85	1.00

4.2 UD-Detention Workbooks

Delete Entire Section

Add 4.2 Modified FAA Method
The Modified FAA Method shall be used to design all detention pond 100-year volumes for drainage basins that contain 160 acres or less. The City of Loveland does not have better values to use for the C1, C2, C3 coefficients within the "Detention Volume by Modified FAA Method" spreadsheet. Please use the Denver area values. When utilizing the spreadsheet provided on the City of Loveland website, do not alter the default values for C1, C2, and C3 provided in the spreadsheet. Use the values from Table 12-6 to insert into

the Allowable Unit Release Rate input cell and do not use the default "q" provided in the button in the "Modified FAA" tab.

4.2.1 Hydrograph Routing using CUHP and SWMM

Paragraph 2:
Change …USDCM…
To …LSDC…

Paragraph 3:

Delete The maximum allowable 100-year release rate should not exceed 90 percent of the approved predevelopment release rate determined through CUHP/SWMM modeling of the upstream watershed (this may vary slightly from the predevelopment discharge values presented in Section 4.1.2), or maximum flow rates recommended in an accepted master plan.

Add The 100-year release rate should not exceed the maximum allowable release rates presented in Table 12-6.

5.0 Design Considerations

Paragraph 2:
Change …USDCM…
To …LSDC

Change UDFCD…
To COL…

Paragraph 3:
Change …USDCM.
To …LSDC.

5.2 Storage Volume

Change …three…
To …two…

5.3 Embankments

Side Slope bullet:
Add Embankments within Regional Detention Ponds shall be no steeper than 4(H):1(V).
Delete …with no trees or shrubs above the basin floor.
Delete …especially in retention ponds.

Freeboard bullet:

Change …minimum of 1 foot above the water surface elevation when the emergency spillway is conveying the maximum design or emergency flow.

To …minimum of 1 foot above the 100-year water surface elevation in the detention pond.

Delete Sentence starting with "When the embankment is designed to withstand…"

5.4 Emergency Spillways

Paragraph 1:

Delete Sentence beginning with "Generally, embankments should…"

Add After the second paragraph:

- Spillway Sizing – Each detention pond shall contain an emergency spillway capable of conveying the peak 100-year storm discharge draining into the detention pond. The invert of the emergency spillway shall be set equal to or above the 100-year water surface elevation. The depth of flow out the emergency spillway shall be ≤6 inches or 50% of the spillway height, if the spillway height is greater than one foot.

- Emergency Spillway Downstream Protection – From the emergency spillway downhill to the embankment toe of slope, protection shall consist of either riprap or soil riprap in order to protect the emergency spillway from catastrophic erosion failure. The riprap shall be sized at the time of final engineering design.

- Concrete Cutoff Wall – A concrete cutoff wall, 8 inches thick, 3 foot deep, extending 5 feet into the embankment beyond the emergency spillway opening, is encouraged on all private detention ponds and required on all public regional detention ponds. A concrete cutoff wall will permanently define the emergency spillway opening. The emergency spillway elevation shall be tied back into the top of embankment using a maximum slope of 4:1.

Paragraph 3:

Change soil riprap…

To Riprap or soil riprap…

5.4.1 Soil Riprap Spillway

Paragraph 2:

Delete (based on local jurisdiction criteria)

Delete Sentence starting with "A concrete wall is recommended…"

5.5 Outlet Structure

Paragraph 1:
Change USDCM
To LSDC

Paragraph 2:
Change …USDCM…
To …LSDC…

Last Paragraph:
Change …USDCM…
To …LSDC…

5.5.4 Raised Grate with Offset Vertical Openings

Paragraph 1:
Change …USDCM).
To …LSDC).

After 5.5.5 Outlet Pipe Hydraulics:

Add 5.5.6 Outlet Pipe:
The outlet pipe of a regional detention pond shall contain a minimum of two (2) concrete cutoff walls embedded a minimum of 18" into undisturbed earthen soil. The cutoff walls shall be 8 inches thick. The outlet pipe bedding material shall consist of native earthen soil and not granular bedding material to at least the first downstream manhole or daylight point.

5.7 Inlets

Change …USDCM…
To …LSDC…

5.8 Vegetation

Change UDFCD…
To COL…

5.9 Retaining Walls

Paragraph 1:
Delete The use of retaining walls within detention basins is generally discouraged due to the potential increase in long-term maintenance access and costs as well as concerns regarding the safety of the general public and maintenance personnel.

Delete Where walls are used, limit the length of the retaining walls to no more than 50 percent of the basin perimeter.

Change Check requirements of the local jurisdiction.
To Check requirements of the COL

Change UDFCD…
To COL…

Add Before second paragraph: The COL requires all retaining walls to be designed by a licensed structural engineer and comply with COL codes for fall protection.

5.10 Access

Add Drivable access applies only to Regional Detention facilities within the City of Loveland. Each regional detention pond will be considered on a case-by-case basis at the time of final design.

Change USDCM
To LSDC

5.12 Linings

2nd Sentence
Delete …and retention…

Delete An impermeable liner may also be warranted for a retention pond where the designer seeks to limit seepage from the permanent pool.

Delete See the Retention Pond Fact Sheet in Volume 3 of the USDCM for guidance and benefits associated with the constructing a safety wetland bench.

5.13 Environmental Permitting and Other Considerations

Paragraph 2:
Change UDFCD…
To COL…

5.14.2 Weirs

Figure 12-21:
Delete "1' min Freeboard" label from "Emergency Spillway Profile"

Delete "Top of footing at or below bottom of soil riprap" label from "Emergency Spillway Profile"

Delete "1' Min Freeboard" label from "Emergency Spillway Section and Spillway Channel"

Delete "3" to 4" Topsoil cover" label from "Emergency Spillway Section and Spillway Channel"

Change Cross-Slope Label "≥2.5" from "Emergency Spillway Section and Spillway Channel
To Cross-Slope Label; "≥4" from "Emergency Spillway Section and Spillway Channel

6.1 Water Storage Reservoirs

Delete Entire section

6.3 Side-Channel Detention Basins

Change …limited application, but may be one of the storage alternatives considered during watershed master planning studies.
To …limited application.

6.4 Parking Lot Detention

Paragraph 2:
Delete Sentence starting with "If 100-year parking lot detention is allowed…"

Add Above ground parking lot detention ponds may be utilized when land area for a grassed lined detention pond is not available. To prevent damage to and floatation of automobiles, parking lot detention ponds shall not exceed 12 inches in depth at any point. Parking lot detention ponds shall be signed as such to inform the general public about the potential for flooding. A parking lot detention pond shall not encroach into a public street.

6.5 Underground Detention

Change … UDFCD.
To …COL.

Delete 2nd Sentence

Add Underground detention is discouraged but will be considered if a variance is requested. The variance request will need to explain why the engineer is proposing to use the method of underground detention and why it is a hardship for the owner to not provide an above-ground detention system. In addition, the owner's written permission to maintain the underground detention system will need to be provided to the COL.

6.6 Blue Roofs

Delete Entire section including image

6.7 Retention Facilities

Delete Entire section

7.0 Designing for Safety, Operation, and Maintenance

Item 2:
Change Easements and/or rights-of-way are required to allow access to the facility by the owner or agency responsible for maintenance.
To Easements and/or rights-of-way are required for all access to all regional facilities by the COL.

Delete Bullet starting with "3. Permanent ponds should have provisions…"

Delete Bullet staring with "6. Use of fertilizer, pesticides…"

Change …USDCM…
To …LSDC…

Add Regional Master Planned detention ponds, designed and constructed by or on behalf of the City of Loveland, shall be owned and maintained by the City of Loveland Stormwater Utility. All other detention ponds shall be considered privately owned and privately maintained.

8.2 Example – Design of a Full Spectrum Detention Sand Filter Basin using UD-Detention

Paragraph beginning with "Enter the depth…":
Change …per USDCM criteria.
To …per LSDC criteria.

Chapter 13 Revegetation

This chapter is for reference purposes and no additional changes shall be made to this chapter.

VOLUME 3

Preface

2.0 Purpose

Change Urban Storm Drainage Criteria Manual (USDCM)
To Loveland Storm Drainage Criteria (LSDC)

3.0 Overview

Chapter 1: Stormwater Management and Planning:
Change …UDFCD's approach to reducing the impacts of urban runoff through implementation of a holistic…
To …the four step process to minimize adverse impacts of urbanization

Change UDFCD
To The COL

Remove …only minimally…

Blue Box Titled "The Four Step Process for Stormwater Quality Management"
Change The Four Step Process for Stormwater Quality Management
To The Four Step Process to Minimize Adverse Impacts of Urbanization

Step 2
Add The COL does not require a WQCV be implemented in every detention pond. If other stormwater quality devices and methods are implemented throughout the development that efficiently clarify the stormwater before it leaves the site, then a WQCV may not be needed.

Step 3 Stabilize Drainageways:

Delete Sentence beginning with "Many drainageways within…"
Add Channel stabilization measures are either included in the LMDPs or are as identified by the COL at the time of development.

Delete Entire fourth sentence beginning with "If this can be done early, it is far…"

Chapter 3: Calculation the WQCV and Volume Reduction:
Change incentive
To incentives

Chapter 4: Treatment BMPs
Add This section also includes discussion of the COL's Stormwater Quality BMP Point System Checklist.

Chapter 5: Source Control BMPs:
Add Provided for information purposes only. Not a part of the LSDC.

Blue box titled “Volume 3 BMPs”
Treatment BMPs
Delete Retention Pond

4.0 Revisions to USDCM Volume 3

Title
Change USDCM
To LSDC

Paragraph 1:
Change USDCM
To LSDC

Change UDFCD
To the COL

Bullet 1:
Delete Second Sentence beginning with, “Although UDFCD has previously included….”

Bullet 2:
Change UDFCD
To COL

Bullet 4:
Change UDFCD
To COL

5.0 Acronyms and Abbreviations

Insert “COL - City of Loveland” between COD and CRS

Insert “LMDP - Loveland Master Drainage Plan” between LEED and LID

Insert “LSDC - Loveland Storm Drainage Criteria” between LID and MCM

Chapter 1 Stormwater Management and Planning

1.0 Introduction

Bullet 3:
Change UDFCD's
To COL's

Change …reduce the impacts of urban runoff.
To …minimize adverse impacts of urbanization.

Last Paragraph:
Change UDFCD
To The COL

2.0 Urban Stormwater Characteristics

Paragraph 2:
Change …primary focus.
To …primary focus due to its proximity to the COL and similar climatic conditions.

3.2 Colorado's Stormwater Permitting Program

Paragraph 3:
Change …area communities.
To …area communities as well as the COL.

Change MS4 permit holders are…
To The COL is…

Within Blue Box Titled "Common Stormwater Management Terms":
Minimizing Directly Connected Impervious Area (MDCIA):
Change UDFCD
To the COL

Water Quality Capture Volume (WQCV):
Change UDFCD
To COL

Change 0.6
To 0.64

3.2.2 Post-construction Stormwater Management

Paragraph 1:
Delete …and Chapter 5, Source Control BMPs,…

Last Paragraph:
Change UDFCD
To the COL

Change USDCM
To LSDC

Remove …in 1992.

4.0 Four Step Process to Minimize Adverse Impacts of Urbanization

Paragraph 1:
Change UDFCD has long recommended a…
To The COL recommends a…

4.1 Step 1. Employ Runoff Reduction Practices

Permeable Pavement:
Add Currently, where fire protection vehicles need to access streets, alleys or driveway and parking aisles, permeable pavement shall not be used. Permeable pavement may be used in parking spaces and other paved areas that do not need to be accessed by fire protection vehicles.

Last Paragraph:
Change UDFCD
To COL

4.2 Step 2. Implement BMPs That Provide a Water Quality Capture Volume with Slow Release

Change …wetland ponds, and retention ponds.
To …wetland ponds.

Change …Denver metropolitan area…
To …COL…

4.3 Step 3. Stabilize Streams

Change Many streams within UDFCD boundaries are included in major drainageway or outfall systems plans…
To Several streams within the COL boundaries are included in the LMDP's,…

Add Streams requiring stream stabilization are either shown in the LMDPs or are as identified by the COL. The developer is responsible for implementing these improvements at the time of development.

5.0 Onsite, Subregional and Regional Stormwater Management

Delete "Subregional" from title

2nd Paragraph:
Delete …subregionally (serving two or more development parcels with a total drainage area less than 130 acres),…

Delete …or subregional…

Delete …subregional,…

Change ….regional/subregional…
To …regional…

5th Paragraph:
Delete …or subregional…

Change …regional/subregional…
To …regional…

Change …regional/subregional…
To …regional…

Delete Last sentence

6th Paragraph:
Delete …subregional…

6.0 Conclusion

Change UDFCD
To The COL

Chapter 2 BMP Selection

1.1 Physical Site Characteristics

Watershed Size Bullet:
Delete As a practical limit, the maximum drainage area contributing to a water quality facility should be no larger than one square mile.

Base Flows Bullet:
Delete retention ponds

1.3 Targeted Pollutants and BMP Processes

Pollutant Removal/Treatment Processes:
Number 1: Sedimentation
Delete …, retention ponds, …

Number 4: Adsorption/Absorption:
Delete …, retention ponds, …

Number 5: Biological Uptake:
Change …bioretention, constructed wetlands and retention ponds…
To …bioretention and constructed wetlands…

Number 1 beginning with "Be designed according to…":
Change UDFCD
To COL

1.4 Storage-Based Versus Conveyance-Based

Delete …retention ponds,…

1.5 Volume Reduction

Paragraph 1:
Change UDFCD has developed a…
To The COL has a…

Paragraph 3:
Delete …retention and…

1.6 Pretreatment

Change …constructed wetland basins, and retention ponds.
To …and constructed wetland basins.

1.8 Online Versus Offline Facility Locations

Paragraph 1:
Change Outfall system plans and other reports
To The LMDP

Change …a master planning study has been completed that…
To …the LMDP…

Paragraph 2:
Change …a master plan identifying…
To …the LMDP identifies…

Paragraph 3:
Delete The maximum watershed recommended for a water quality facility is approximately one square mile.
Add These on-line facilities must be constructed on-site.

1.9 Integration with Flood Control

Paragraph 1:
Delete …sub-regional or…

Paragraph 2:
Delete This manual does not stipulate or recommend which policy should be used. When a local policy has not been established, UDFCD suggests the following approach:
Add For the COL the following approach shall be used:

Delete Entire bullet named "Minor Storm (not EURV):"

Delete Entire bullet named "100-year Storm:"

1.9.1 Sedimentation BMP's

Delete "and retention ponds."

1.11 Maintenance and Sustainability

Paragraph 1:
Change MS4 permit holder may also require
To COL requires

3.0 Life Cycle Cost and BMP Performance Tool

Change To do so, UDFCD has developed an…
To To do so, COL has an…

3.1 BMP Whole Life Costs

Paragraph 1:
Change UDFCD
To COL

Paragraph 3:
Change UDFCD's
To COL's

Bullet 2:
Change …Denver-area…
To …Loveland-area…

Bullet 5:
Change …Denver-area…
To …Loveland-area…

3.2 BMP Performance

Change …UDFCD…
To …the COL…

Chapter 3 Calculating the WQCV and Volume Reduction

2.1 Development of the WQCV

Blue Box titled "Using and Flood Control Hydrology":
Change UDCFD…
To The COL…

2.3 Attenuation of the WQCV (BMP Drain Time)

First Paragraph:
Delete …,retention ponds…

Change Retention ponds and constructed…
To Constructed…

3.0 Calculation of the WQCV

Equation 3.1
Delete Equation 3-1

Add Equation 3-1:
$WQCV=a\ (0.91I^3 - 1.19I^2 + 0.78I)\ b$
Where b = 1.067 (COL adjustment factor for the 0.64 inch, 80^{th} percentile of COL runoff producing storms)
And I =Imperviousness (percent expressed as a decimal).

Paragraph below Table 3-2:
Delete Sentence starting with "For areas beyond this region…"

Add For COL, use a precipitation depth of 0.64 inches for the WQCV event.

4.2 CUHP-SWMM Modeling of Volume Reduction

Change …MHFD…
To …COL…

Delete CUHP-SWMM can be applied to a lot or block scale as well, but simplified modeling methods, including UD-BMP, UD-Rational and/or UD-Detention (all of which are available at MHFD.org, are more common at the finer scales.

Add Simplified modeling methods, including UD-BMP, UD-Rational (both of which are available at MHFD.org) and the Modified FAA Method Spreadsheet (which is available on the COL website) shall be used at the finer scale.

5.0 Example Calculation of WQCV

Add Example 5.0 is based on the WQCV for Denver, Colorado. For the COL, the WQCV in this example will need to be adjusted per Equation 3.1 in Section 3.0

Chapter 4 Treatment BMPs

Contents

Remove T-7 Retention Pond

1.0 Overview

Blue box

Delete Retention Pond bullet

After third paragraph

Add COL discourages the design of micropools within detention ponds, due to safety and maintenance issues which have arisen within the community. Therefore, all references to micropools in Chapter 4 of the UDSCM are removed from the LSDC.

Add The COL does not recommend the use of well-screens that are placed in front of Water Quality Capture Volume orifices due to Homeowners Association and Business Owners Association maintenance issues. Therefore, all references to well-screens and trash racks in front of the Water Quality Capture Volume orifices in Chapter 4 of the UDSCM are removed from the LSDC.

Add A narrative of the permanent stormwater quality best management practices (BMPs) shall be included as a subsection in the drainage and erosion control report. The narrative shall provide a description of each permanent water quality BMP and how each practice will provide stormwater quality prior to the stormwater leaving the site. An 11" x 17" schematic drawing shall be inserted into the drainage and erosion control report and SWMP documents titled "Permanent Stormwater Quality BMPs" that clearly identifies where each of the proposed Permanent Stormwater Quality BMPs are located within the development site, i.e., Grass Swales (GS), Grass Buffers (GB), Extended Detention Basins (EDB), etc. The extent of each BMP shall be lightly shade or hatched. The purpose of the Permanent Stormwater Quality BMP schematic is to include it in a maintenance notebook that COL prepares to provide guidance for the property owner to easily identify the BMPs that need to be maintained in the future.

Add In compliance with the COL MS4 permit, COL requires all development applicants who's sites contain Stormwater Permanent Control Measures to submit Standard Operating Procedures (SOPs) for all Stormwater Permanent Control Measures at the time of Site Plan Review. This is in an effort to establish the maintenance needs of a site/structure prior to acceptance of plans, building of structures and transfer of ownership of said structures to owners. The SOP should be brief and written in simple "layperson" terms so that the persons assigned the maintenance responsibilities can easily

understand how each measure should be maintained and cleaned. The following needs must be outlined in the criteria:

- Requirements for standalone SOP submittals for all sites where there are proposed Stormwater Permanent Control Measures
- Within the SOP's the following must be included:
- Documentation of operation and maintenance procedures to ensure the long term observation, maintenance, and operation of the control measures. The documentation shall include frequencies for routine inspection and maintenance.
- Inspection and maintenance forms
- Owner acknowledgement form (a form in which the Engineer and Owner of structure signs acknowledging the prescribe inspection and maintenance of all Control Measures
- Contact Verification form – The City of Loveland Verification form shall be included as the first page within the SOP which spells out owner name, address, phone number and email address.
- Submittal of a plan sheet showing location of all Stormwater Permanent Control Measures. Verbiage that if any in field changes are made to plan that a new plan/as built must be submitted to City and owner prior to issuance of Certificates of Occupancy. The plan sheet shall be presented as an 11" x 17" schematic drawing and titled "Permanent Stormwater Quality BMPs". The schematic shall clearly identify where each of the proposed Permanent Stormwater Quality BMPs are located within the development site, i.e., Grass Swales (GS), Grass Buffers (GB), Extended Detention Basins (EDB), etc. The extent of each BMP shall be lightly shade or hatched.

*SOPs must be standalone documents not included in drainage report or SWMP.

Add

The City of Loveland requires Permanent Stormwater Quality Control Measures on all development and redevelopment within COL including those under 1 acre of disturbance. These Permanent Stormwater Quality Control Measure(s) must meet a Base Design Standard as outline within the Colorado Department of Public Health and Safety (CDPS) Permit No. COR090000. The "base design standard" is the minimum design standard for new development and redevelopment. The applicant shall complete and submit to COL a worksheet, provided on the City website, which outlines "base design standard" criteria. The purpose of this worksheet is to demonstrate which of the "minimum base standards" are being met on the development/redevelopment and to demonstrate to the COL how the minimum base design standards were met. The worksheet shall address each requirement set forth in the most recent modification of the Colorado Department of Public Health and Safety (CDPS) Permit No. COR090000. The COL refers to the Colorado Department of Public Health and Safety (CDPS) Permit No. COR090000 for definition of development/redevelopment and for exclusions to this requirement.

2.0 Treatment BMP Fact Sheets

3rd Paragraph:
Change …UDFCD…
To …COL…

Table 4-1
Delete Retention Pond Column

Fact Sheet T-0 Quantifying Runoff Reduction

Table RR-1, Parameters for quantifying runoff reduction
Underdrain Row
Change …UDFCD…
To …COL…

Design Procedure
Item 4, "Characterize on-site topsoil and determine suitability of topsoil for the RPA"
2nd Paragraph
Change UDFCD…
To COL…

Item 5, "Calculate Runoff from each UIA:RPA Pair"
First Paragraph
Add The WQCV event precipitation depth in COL is 0.64 inches.

Item 6, "Compare runoff from each UIA:RPA pair to runoff from UIA alone"
Add The example in Item 6 is based on the WQCV for Denver, Colorado. For the COL, the WQCV in this example will need to be adjusted per Equation 3.1 in Section 3.0 of Chapter 3, "Calculating the WQCV and Volume Reduction."

Design Example
Add The design example is based on the WQCV for Denver, Colorado. For the COL, the WQCV in this example will need to be adjusted per Equation 3.1 in Section 3.0 of Chapter 3, "Calculating the WQCV and Volume Reduction."

Fact Sheet T-2 Grass Swale

Design Procedure and Criteria
Item 7, Design Flow Depth

Add The 100-year flow plus freeboard shall be fully contained within the swale.

Fact Sheet T-3 Bioretention (Rain Garden or Porous Landscape Detention)

Description
Add The Bioretention Specifications available in the Loveland Storm Drainage Standards, located on the COL website, must be followed for construction of

all bioretention facilities. If conflicts arise between the Bioretention Specifications and the LSDC, then the Bioretention Specifications shall govern.

Designing for Maintenance
2nd Bullet:
Delete 2nd Sentence beginning with "Use rock mulch sparingly…"

Add COL does not allow the use of rock mulch in rain gardens.

Delete Some municipalities may not allow wood mulch for this reason.

Add COL does not allow wood mulch for this reason. COL requires the use of triple shredded mulch.

Design Procedure and Criteria
Item 1, Subsurface Exploration and Determination of No-Infiltration, Partial Infiltration, or full Infiltration Section
Bullet 3, Full Infiltration Section:
Change UDFCD
To COL

Add The design of full infiltration sections in bioretention facilities requires a variance and proof by a licensed professional engineer that appropriate soils at each bioretention facility are present to the minimum depth equal to the bottom of the bioretention facility.

Item 3, Basin Geometry
Change UDFCD
To COL

Item 4, Growing Medium
Delete All paragraphs and Table B-1, "Material specification for bioretention/rain garden facilities"

Add Refer to the Bioretention Specifications available in the Loveland Storm Drainage Standards for the growing medium specifications.

Item 5, Underdrain System

Add "Refer to the Bioretention Specifications available in the Loveland Storm Drainage Standards for the underdrain specifications.

Delete 3rd Paragraph

Delete 4th Paragraph

Add Reference the Bioretention Specifications within the COL Storm Drainage Standards for the underdrain bedding material and reservoir storage layer.

Item 6, Impermeable Geomembrane Liner and Geotextile Separator Fabric
Delete 1st Paragraph

Delete Table B-2, Physical Requirements for Separator Fabric

Add Refer to the Bioretention Specifications available in the Loveland Storm Drainage Standards for the impermeable liner specifications.

Item 7, Inlet/Outlet Control
Delete …or can be designed without an underdrain (provided the subgrade meets the requirements above).

Item 8, Vegetation
Delete 1st Paragraph

Delete 2nd Paragraph

Delete Table B-3, Native Seed Mix for Rain Gardens

Add Refer to the Bioretention Specifications available in the Loveland Storm Drainage Standards for the vegetation specifications.

Aesthetic Design
Delete No-Infiltration Section Detail

Delete Full Infiltration Section Detail

Delete Section C Detail

Delete Section D Detail

Delete Section E Detail

Fact Sheet T-4 Green Roof
Design Procedure and Criteria
8th Bullet
Change …in Denver.
To …in Loveland.

Construction Considerations
1st Bullet

Change …in the local jurisdication.
To …in Loveland.

Fact Sheet T-5 Extended Detention Basin (EDB)

1st Paragraph
Delete Fourth Sentence beginning with "Soluble pollutant removal…"

Designing for Maintenance
1st Bullet
Delete Entire Sentence.

2nd Bullet
Delete …or toward the micropool…

5th Bullet
Change …spillway, and micropool…
To …and spillway…

6th Bullet
Delete Entire Bullet.

Add The COL does not recommend the use of well-screens due to Homeowners Association and Business Owners Association maintenance issues.

Design Procedure and Criteria

Item 5, Forebay Design

1st Paragraph
Delete Sentence beginning with "Refer to Table EDB-4…"

Delete Sentence beginning with "When using this table,…"

Delete 2nd Paragraph

Add Forebays need to be proportional to the detention pond in which they are located. Forebay volumes shall be determined using the following equation:

Volume Required (cubic feet) = 0.000265 x Tributary Area (square feet)

The forebay outlet shall be designed to release 2% of the 100-year peak inflow. Forebay dimensions shall be proportional to each other, e.g. the length and width should be similar.

Item 6, Trickle Channel

Add A concrete trickle pan may be designed in the flowline of the extended detention basin. The City of Loveland Stormwater Detail SW-21 provides design guidelines for concrete trickle pans options within extended detention basins.

Change …to the micropool…
To …to the EDB outlet structure…

2nd Bullet
Change …UDFCD…
To …COL…

Change …of the local jurisdiction.
To …of the COL.

Change …to micropool…
To …to the EDB outlet structure…

Item 7, Micropool and Outlet Structure
Section Title
Delete "Micropool and…"

1st Paragraph:
Delete …and provide a permanent micropool directly in front of the structure.

Delete Remainder of first paragraph after the first sentence

Delete 2nd Paragraph

Add The COL does not require nor desire micropools within extended detention basins due to safety and liability issues.

3rd Paragraph:
Delete Fourth, Fifth, Sixth, Seventh and Eighth Sentences.

Item 8, Initial Surcharge Volume
1st Paragraph
Change …the micropool…
To …the pond bottom located at the outlet structure…

Delete Third Sentence beginning with "The initial surcharge…"

Change …the micropool…
To …the pond bottom located at the outlet structure…

Second Paragraph
Delete First sentence beginning with "The initial surcharge volume…"

Delete …micropool…

Item 9, Trash Rack
Add Screens placed over the WQCV orifices are discouraged by COL due to Homeowners Association or Business Owners Association maintenance difficulties.

Item 12, Access
Delete …an micropool.

Blue Box "Designing for Baseflows"
1st Bullet
Delete …or retention pond.

Delete Table EDB-4, EDB Component Criteria

Fact Sheet T-6 Sand Filter

Delete Entire Section.

Fact Sheet T-7 Retention Pond

Delete Entire Section.

Fact Sheet T-8 Construction Wetland Pond

Design Procedure and Criteria
1st Paragraph:
Delete Last Sentence.

Item 7, Inlet
Change …UDFCD…
To …COL…

Fact Sheet T-10 Permeable Pavement Systems

Site Selection
Add Permeable Pavement Systems are prohibited in fire access drives or other areas that will be accessed by fire vehicles, unless otherwise approved by the Fire Code Official.

Design Procedure and Criteria
Item 1, Subsurface Exploration and Determination of a No-Infiltration, Partial Infiltration, or Full Infiltration Section
3rd Bullet, Full Infiltration Section

Change …UDFCD…
To …COL…

Add the design of full infiltration sections in permeable pavement requires a variance and proof that appropriate soils are present on the site.

Item 3, Depth of Reservoir
Change UDFCD…
To COL…

Item 6, Filter Material and Underdrain System

Third Paragraph
Change …USDCM…
To …COL…

Fact Sheet T-10.1 Permeable Interlocking Concrete Pavement

Site Selection
Delete First Bullet

Second Bullet
Add …with the exception of the parking lot areas that will be accessed by fire vehicles,

Delete Third Bullet

Delete Fifth Bullet

Add Permeable Interlocking Concrete Pavement is prohibited in fire access drives or other areas that will be accessed by fire vehicles, unless otherwise approved by the Fire Code Official.

Fact Sheet T-10.2 Concrete Grid Pavement Site Selection

Site Selection
First Bullet
Add …with the exception of the parking lot areas that will be accessed by fire vehicles,

Delete Second Bullet

Delete Third Bullet

Add Concrete Grid Pavement is prohibited in fire access drives or other areas that will be accessed by fire vehicles, unless otherwise approved by the Fire Code Official.

Fact Sheet T-10.3 Pervious Concrete

Delete Entire paragraph

Add The COL allows pervious concrete in areas that do not need to be accessed by fire vehicles or are located within rights-of-ways. Pervious Concrete is prohibited in fire access drives or other areas that will be accessed by fire vehicles, unless otherwise approved by the Fire Code Official.

Fact Sheet T-10.4 Porous Gravel

Site Selection
First Bullet
Add …with the exception of the parking lot areas that will be accessed by fire vehicles,

Second Bullet
Add …with the exception of the driveway areas that will be accessed by fire vehicles,

Delete Fourth Bullet

Add Porous Gravel is prohibited in fire access drives or other areas that will be accessed by fire vehicles, unless otherwise approved by the Fire Code Official.

Fact Sheet T-10.5 Reinforced Grass

Description
Delete Fifth Sentence starting with "This BMP is frequently used to…"

Add Reinforced Grass is prohibited in fire access drives or other areas that will be accessed by fire vehicles, unless otherwise approved by the Fire Code Official.

Site Selection
Second Bullet
Delete "Maintenance roads including…"

Delete Third Bullet

Selection Considerations
Delete Fourth Bullet

Fact Sheet T-11 Underground BMPs

Delete Second Paragraph

Site Selection
Third Bullet
Delete …and some communities may not allow pumped systems.

Delete Third Sentence beginning with, "If a pumped system must be used…"

Underground BMPs Based on a Surface BMP Design
First Paragraph
Delete …and retention facilities…

Delete …and the difficulty of creating an effective underground micropool.

Underground Proprietary BMPs
Second Paragraph
Delete …or retention ponds.

Item 3:
Change …UDFCD…
To …LSDC…

Last Paragraph
Change UDFCD…
To COL…

Change Local governments should reserve the right…
To COL reserves the right…

Delete Fifth Sentence beginning with, "In addition, a local government may require collection…"

Delete Sixth Sentence, "Finally, local governments may require agreements…"

Fact Sheet T-12 Outlet Structures

First Paragraph
Delete …retention ponds…

Second Paragraph
Change …UDFCD recommends…
To …COL recommends…

Photograph OS-1
Delete …with a screen (or grate) protecting the orifice plate from clogging,…

Outlet Design
Large Watershed Considerations
Change UDFCD recommends…
To COL recommends…

Change UDFCD recommends…
To COL recommends…

Orifice Plates, Trash Racks, and Safety Grates
Section Title
Delete , Trash Racks,…

Orifice Sizing
Change …UDFCD…
To ...COL…

Trash Rack Sizing
Delete Entire Section.
Add COL does not recommend screens or trash racks in front of the WQCV orifice plates due to Homeowners Association or Business Owner Association maintenance issues.

Delete Figure OS_1

Outlet Geometry
Second Paragraph
Delete …and sometimes a vertical barrier from the micropool of an EDB,…

Micropools with the Outlet Structure
Delete Entire Section.

Delete Figure OS-2

Delete Figure OS-3

Figure OS-4
Delete EURV and WQCV Trash Racks Items 1 through 4.

Figure OS-5
Delete Micropool configuration

Delete Well screen and associated graphic information in front of WQCV orifice plate

Delete Outlet pipe (optional location)

Figure OS-6:
Delete Micropool configuration

Delete Well screen and associated graphic information in front of WQCV orifice plate

Delete Outlet pipe (optional location)

Figure OS-7

Delete Micropool configuration

Delete Well screen and associated graphic information in front of WQCV orifice plate

Delete Outlet pipe (optional location for vertical constraints)

Figure OS-8

Delete Micropool configuration

Delete Well screen and associated graphic information in front of WQCV orifice plate

Delete Outlet pipe (optional location for vertical constraints)

Chapter 5 Source Control BMPs

Add This Chapter 5 is provided only for information purposes.

Chapter 6 BMP Maintenance

2.0 Defining Maintenance Responsibility for Public and Private Facilities

Delete Entire second bullet starting with "Publicly owned regional drainage…"

Third bullet:
Add The COL will periodically inspect these facilities and will require any deficiencies be corrected by the property owner.

Delete Entire fourth bullet starting with "Privately owned BMPs may be…"

After the paragraph beginning with "MS4 permittees can utilize…":
Add The COL's authority for BMP maintenance is included in the COL Municipal Code, Chapter 13.20.

Delete Entire paragraph (including bullets) from "Examples of some of the specific requirements…" through the bullet titled "Remedies".

3.0 Developing a Maintenance Plan

Delete Entire first paragraph
Add The Col has developed Standard Operation Procedures (SOPs) for BMP maintenance. These SOPs are available for reference for use on the COLs website. For BMPs that do not have SOPs, the COL will advise on the developer's preparation of a SOP for the specific BMP.

A Sediment / Erosion Control BMP agreement is also required to be executed prior to construction of the selected BMP. The standard COL agreement and associated Sediment /Erosion Control BMP documents are available on the COL website.
Add As part of the development application, a Standard Operating Procedure (SOP) for the development shall be completed per the specifications provided in LSCDC Volume 3, Chapter 4, "Treatment BMPs", Section 1.0, and submitted to the COL.

Number 5:
Delete (For BMPs maintained by UDFCD, the owner, rather than UDFCD, should be contacted).

Paragraph beginning with "On a general note…":
Change UDFCD
To COL

5.6 Sediment Removal and Growing Media Replacement

Delete Sentence beginning with "To date UDFCD is not aware…"

6.1 Inspection

4th Bullet
Change …of 0.6 inches or more.
To of 0.64 inches or more.

8.0 Sand Filters

Delete Entire Section.

9.0 Retention Ponds and Constructed Wetland Ponds

Title
Delete Retention Ponds and…

9.3 Aquatic Plant Harvesting

First Paragraph
Delete 2nd sentence beginning with, "Additionally, the plants growing on the safety wetland bench…"

Change …UDFCD…
To …COL…

10.3 Aquatic Plant Harvesting

First Paragraph
Change UDFCD…
To COL…

Chapter 7 Construction BMPs

1.0 Introduction

Add Within the COL, an Erosion and Sediment Control Plan must be developed and submitted to the COL as part of a development application process.

Add The final Erosion and Sediment Control Plan must be consistent with the Drainage Report.

Add The City of Loveland Stormwater Utility Senior Civil Engineer or designated representative thereto, may grant variances from the criteria of the Construction BMPs chapter by his/her acceptance of the Final Drainage Report in which the variance request is well documented.

Add For all construction projects, a written narrative shall be included in the drainage report that provides a brief summary of the temporary sediment and erosion control measures implemented throughout the site to mitigate sedimentation and erosion on and off the site. The narrative shall include the following information:

1. Sediment and Erosion Control Techniques
    a. A description of the methods presented in the Construction BMPs chapter used to mitigate erosion and sediment on the site.
2. Stormwater Management
    a. An explanation of how the stormwater runoff on the site will be managed on and off the site.
3. Maintenance
    a. A discussion of how and when the sediment and erosion control devices will be inspected, repaired and replaced throughout the duration of construction, after each storm event and after construction until the time that all vegetation is established.
4. Calculations
    a. All calculations that are used to size the various construction BMPs shall be included in the appendix of the drainage and erosion control report.
5. Additional Information
    a. Any additional information that is necessary to describe the sediment and erosion control BMPs or may be required by the COL to fully describe how the site is being treated.

Add Sediment and erosion control construction drawings shall be prepared and included in the Public Improvement Construction Plan set. The drawings shall divide the sedimentation and erosion control BMPs into phases of implementation in order to adequately reflect each of the four major development phases:
Phase 1 - Grading Phase – BMPs for initial installation of perimeter controls.

Phase 2 - Infrastructure Phase – BMPs for utility; paving; curb & gutter installation.
Phase 3 - Vertical Construction Phase – BMPs for individual lot construction.
Phase 4 - Permanent BMPs & Final Stabilization.
A minimum of two sediment and erosion control construction drawings shall be provided. The first sediment and erosion control construction drawing needs to show details for Phases 1 and 2 of construction and include all BMPs necessary for these phases and only these phases of construction. The second sediment and erosion control construction drawing needs to show details for Phases 3 and 4 of construction and only Phase 3 and 4 of construction.

Add When a development will create construction disturbance within an irrigation ditch, a water body or waterway, a Water Quality Control Plan shall be prepared and submitted as part of the development application process. The Water Quality Control Plan shall describe the methods that will be used during construction to avoid sedimentation, erosion and to maintain the water quality within the irrigation ditch, water body, or waterway

3.0 Colorado Construction Stormwater Discharge Permits

First Paragraph:
Change …UDFCD's…
To …the COL's…

Second Paragraph:
Change …most local governments require…
To …the COL…

Change …the local government and…
To …the COL and…

Change …the local government…
To …COL…

Delete Many local governments require documentation that goes beyond the state permit requirements

Table 7-1
Add Table 7-1 is provided only for information purposes.

3.1 Preparing and Implementing a Stormwater Management Plan (SWMP)

Add For disturbed areas of 1 acre or larger, the SWMP shall be submitted to the COL for review and acceptance.

3.1.1 General SWMP Recommendations

Bullet beginning with “Implement the provisions…”:
Change UDFCD recommends…
To The COL requires…

Change UDFCD…
To The COL…

3.1.2 SWMP Elements

Final Bullet: Inspections and Maintenance
Change UDFCD recommends providing…
To The COL requires…

3.2.1 Inspection Frequency

First Paragraph:
Change UDFCD…
To The COL…

3.4 Disposition of Temporary Measures

Last Paragraph
Change …by the local jurisdiction…
To …by COL…

4.0 Overview of Construction BMPs

After paragraph 2:
Add The COLs standard details as presented on the COL website must be followed for all source control BMPs. If conflicts arise between the details on the COL website and the LSDC, the details on the COL website shall govern. Additional information regarding the COLs Sediment / Erosion Control requirements may be found on the COLs website.

4.2 Sediment Control Measures

First Paragraph:
Change UDFCD…
To The COL…

7.0 Construction in Waterways

Second Paragraph:
Change Other UDFCD criteria…
To COL criteria…

First Three Bullets Below Second Paragraph:
Change UDFCD…
To COL…

8.1 General Considerations

"Jurisdictional Considerations" Bullet:
Change …municipalities…
To …entities…

Change …municipalities…
To …entities…

Change …municipality…
To …entity…

Fact Sheet EC-2 Temporary and Permanent Seeding (TS/PS)

Design and Installation
2nd Paragraph
Change …USDCM…
To …LSDC…

3rd Paragraph
Delete Last sentence beginning with, "Some jurisdictions do not allow…"

Seed Mix for Permanent Revegetation
1st Paragraph
Delete …or the local jurisdiction…

Fact Sheet EC-4 Mulching (MU)

Appropriate Uses
Change …in most jurisdictions…
To …in COL…

Delete …; however, hydromulching may not be allowed in certain jurisdictions or may not be allowed near waterways.

Fact Sheet EC-7 Temporary Slope Drain (TSD)

Maintenance and Removal
Last Paragraph
Change …by the local jurisdiction.
To …by COL.

Fact Sheet EC-10 Earth Dikes and Drainage Swales (ED/DS)

Maintenance and Removal
Last Paragraph
Change …by the local jurisdiction.
To …by COL.

Fact Sheet EC-12 Check Dams (CD)

Design and Installation
5th Paragraph
Delete Many jurisdictions also prohibit or discourage use of straw bales for this purpose.
Add COL prohibits the use of straw bales for this purpose.

Fact Sheet SC-3 Straw Bale Barriers (SBB)

Delete Entire Section.

Fact Sheet SC-6 Inlet Protection (IP)

Design and Installation
2nd Paragraph
Change …for use by local governments.
To …for use by COL.

Fact Sheet SM-1 Construction Phasing/Sequencing (CP)

Design and Installation
Delete 3rd Sentence
Delete 4th Sentence

Change Some local governments require…
To COL requires…

Chapter 8 Glossary

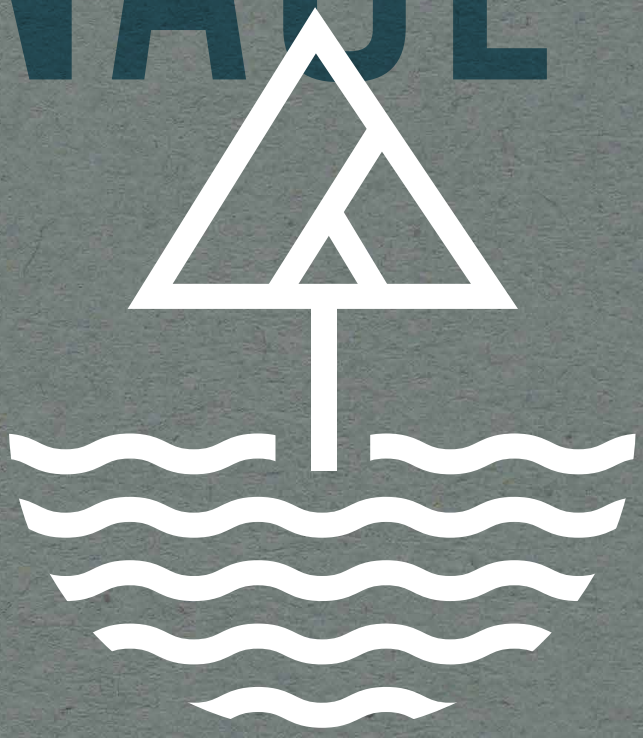
This chapter is for reference only.

URBAN STORM DRAINAGE

CRITERIA MANUAL

VOLUME

1



MANAGEMENT, HYDROLOGY, AND HYDRAULICS

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Management, Hydrology, and Hydraulics

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Disclaimer

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Preface

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1.0 Acknowledgements

Contributors to Original (1969) Version of the Urban Storm Drainage Criteria Manual (USDCM)

Residents of the Urban Drainage and Flood Control District (UDFCD) and many communities beyond the UDFCD boundary have benefited significantly from the pioneering vision of those who were responsible for the original (1969) version of the USDCM, including D. Earl Jones, Jr., P.E., Dr. Jack Schaeffer, Dr. Gilbert White and Kenneth R. Wright, P.E. (lead author). The vast majority of the policies, principles, and criteria in the 1969 USDCM are found in this updated (2015) version—a true testament to the wisdom of these leaders.

UDFCD wishes to acknowledge and thank all individuals and organizations that contributed to development and publication of the 2015 update of Volumes 1 and 2 of the USDCM. The lists of individuals and organizations that follow are our best effort to acknowledge all of the organizations and individuals that were directly involved in the UDSCM's preparation.

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2.0 Purpose

Volumes 1 and 2 of the USDCM provide guidance for engineers, planners, landscape architects, developers, and contractors in selecting, designing, constructing, and maintaining stormwater drainage and flood control facilities. Volumes 1 and 2 focus primarily on stormwater quantity management for drainage and flood control purposes. Volume 3 focuses on smaller, more frequently occurring events that have a greater overall impact on the quality of receiving waters.

3.0 Overview

This manual is organized according to the following:

- **Chapter 1: Drainage Policy.** Adequate drainage for urban areas is necessary to preserve and promote the general health, welfare, and economic well-being of the region. The *Policy* chapter lists the 12 principles that guide all the criteria in this manual. Additionally, the chapter includes several policies that support good stormwater and floodplain management as well as the goals and actions of UDFCD.

- **Chapter 2: Drainage Law.** This chapter deals with the general principles of drainage law along with local government drainage actions, financing, floodplain management, and special matters. The information provided in this chapter is specific to the State of Colorado.

- **Chapter 3: Planning.** The urban storm drainage system is a subsystem of the total urban infrastructure system and should be integrated with other subsystems including transportation, parks, open space, and utilities. This chapter identifies and discusses key considerations in the planning process. The chapter also describes types of master plans and outlines the master planning process.

- **Chapter 4: Flood Risk Management.** This chapter addresses programs and policies adopted by UDFCD to manage flood risks and reduce potential losses from flood events. This chapter also provides guidance for specific physical measures that can be implemented to help protect individual structures from flood damage.

- **Chapter 5: Rainfall.** The *Rainfall* chapter provides rainfall depth, duration, intensity, and frequency data and analytical methods used to develop the rainfall information needed to carry out the hydrological analysis described in the *Runoff* chapter of the USDCM. This chapter also provides guidance for development of rainfall distributions for use with the Colorado Urban Hydrograph Procedure (CUHP) and Depth Reduction Factor (DRF) adjustments for use when analyzing watersheds in of 5 square miles or more. There is also a companion workbook, UD-Rain, available at www.udfcd.org that allows the user to perform calculations in accordance with these criteria.

- **Chapter 6: Runoff.** The *Runoff* chapter presents five methods for hydrologic analysis. Peak rate of runoff, runoff volume, and the time distribution of flow provide the basis for all planning, design, and construction of drainage facilities. There is also a companion workbook, UD-Rational, available on the UDFCD website, that applies the Rational Method to estimate stormwater runoff and peak flows from small urban catchments.

- **Chapter 7: Streets, Inlets, and Storm Drains.** This chapter presents design for both stormwater collection and conveyance utilizing streets and storm drains. Inlet capacity, as presented in this chapter, is based on FHWA Hydraulic Circular No. 22 (HEC-22) methodology which was subsequently refined through a multijurisdictional partnership led by UDFCD, where hundreds of

- physical model tests of inlets commonly used in Colorado were performed at the Colorado State University (CSU) hydraulics laboratory. UD-Inlet, available on the UDFCD website, is a companion workbook that allows the user to calculate inlet capacity in accordance with these criteria.

- **Chapter 8: Open Channels.** This chapter presents principles of stream restoration along with special design considerations for constrained urban streams. There is a focus on preservation, enhancement, and restoration of stream corridors. The chapter also includes design of new channels and swales, methods for bank stabilization, and rock sizing.

- **Chapter 9: Hydraulic Structures.** This chapter includes design of various types of grade control structures including check structures, grouted stepped (or sloped) boulder drop structures, sculpted concrete drop structures, and vertical drop structures. Pipe outfalls and rundowns are also included in this chapter.

- **Chapter 10: Stream Access and Recreational Channels.** This chapter provides criteria related to the design of shared-use paths adjacent to streams and criteria for responsible design of recreational channels including boatable channels. The topics in this chapter are largely related to safety; therefore, this chapter also summarizes all criteria related to safety elsewhere in the USDCM and includes guidance for reviewing a project from the standpoint of public safety.

- **Chapter 11: Culverts and Bridges.** This chapter addresses the hydraulic function of culverts and bridges, i.e., conveyance of surface water through embankments such as roadways and railroads. UD-Culvert is a companion workbook available on the UDFCD website that aids in analyzing the flow conditions in circular and box culverts.

- **Chapter 12: Storage.** This chapter provides guidance for the analysis and design of storage facilities that are implemented independently or in combination with stormwater quality facilities. UD-FSD and UD-Detention, both available on the UDFCD website, are companion workbooks to this chapter that allow the user to design or review almost any type and configuration of detention storage facility.

- **Chapter 13: Revegetation.** This chapter provides guidelines and recommendations for revegetation efforts associated with drainage and water quality facilities. The guidance addresses three habitat types: uplands, riparian areas, and wetlands. For each habitat type, guidance is provided with regard to site preparation, plant material selection and installation, maintenance and post-construction monitoring.

A reference section is provided for each chapter, and additional materials and insight on the topics presented in the USDCM may be found by studying the papers and documents listed at the end of each chapter.

The USDCM provides criteria and standards recommended by UDFCD. Designing facilities that go beyond minimum criteria is encouraged. In addition, there may be other requirements by local, state and federal agencies that may have to be met in addition to the minimum criteria provided herein.

4.0 List of Abbreviations

Commonly Used Abbreviations

ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BFE	Base flood elevation
BMP	Best management practice
CDOT	Colorado Department of Transportation
CDPHE	Colorado Department of Public Health and Environment
CMP	Corrugated metal pipe
CRS	Colorado Revised Statute(s)
CUHP	Colorado Urban Hydrograph Procedure
CWCB	Colorado Water Conservation Board
DCIA	Directly connected impervious area
DRCOG	Denver Regional Council of Governments
EGL	Energy grade line
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHAD	Flood Hazard Area Delineation
FHWA	Federal Highway Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FPE	Flood protection elevation
GSB	Grouted stepped or sloping boulder drop structure
HGL	Hydraulic grade line
HUD	U.S. Department of Housing and Urban Development

H:V	Horizontal to vertical ratio of a slope
ICC	Increased cost of compliance
LID	Low impact development
MDCIA	Minimized directly connected impervious area
NAVD	North American Vertical Datum
NFIA	National Flood Insurance Act
NFIP	National Flood Insurance Program
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PMP	Probable maximum precipitation
RCP	Reinforced concrete pipe
SBA	Small Business Administration
SEO	Colorado State Engineer's Office
SFHA	Special Flood Hazard Area
SFIP	Standard Flood Insurance Policy
SWMM	EPA Stormwater Management Model
TABOR	Taxpayer Bill of Rights
UDSWM	Urban Drainage Stormwater Management Model
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WEF	Water Environment Federation
WQCV	Water quality capture volume

Commonly Used Units

cfs	cubic feet per second
cfs/ft	cubic feet per second per foot
ft	foot
ft^2	square feet
ft/ft	foot per foot
ft/sec	feet per second
ft/sec^2	feet per second squared
hr	hour
in	inch
in/hr	inches per hour
in/hr/ac	inches per hour per acre
lbs	pounds
lbs/cy	pounds per cubic yard
lbs/ft^2	pounds per square foot
lbs/ft^3	pounds per cubic foot
lbs PLS/acre	pounds pure live seed per acre
min	minute
psi	pounds per square inch
psf	pounds per square foot

Chapter 1
Drainage Policy

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1.0 Policies and Principles

Photograph 1-1. Local grass channel after 35 years of service. Ann Spirn of the Massachusetts Institute of Technology refers to this channel as "urban poetry" in her publications.

Adequate drainage for urban areas is necessary to preserve and promote the general health, welfare, and economic well-being of the region. Drainage is a regional phenomenon that affects all governmental jurisdictions and all parcels of property. This characteristic of drainage makes it necessary to formulate a program that balances both public and private involvement (Wright-McLaughlin Engineers 1969). Overall, the governmental entities most directly involved must provide coordination and master planning, but drainage planning must also be integrated on a regional level (FEMA 1995).

The underlying principles in this chapter provide direction for planning drainage facilities. These principles are made operational through a set of policy statements. The application of the policy is, in turn, facilitated by technical drainage criteria, which are the focus of this manual. When considered in a comprehensive manner, at a regional level and with public and private involvement, drainage facilities can enhance the general health and welfare of the region and assure optimum economic and social relationships while avoiding uneconomic flood losses and disruption (White 1945).

Urban Storm Drainage Criteria Manual (1969 – present)

"The time is ripe in the Denver Region for implementation of a new and more thorough approach to storm drainage as it relates to urban problems. This manual was written in an attempt to provide the various techniques, methodology, and guidelines to achieve that objective." --Kenneth Wright, March 15, 1969

"To the best of our knowledge, the USDCM is the first such standard prepared for implementation throughout an American metropolitan area. Its adoption will permit consistent reactions to basic problems that are independent of political subdivision boundaries. Its philosophy provides for flexible approaches to realization of necessary drainage control and total water resources objectives, and at the same time encourages improved sensitivity to the total ecology. We believe these approaches will save your region many millions of dollars through the years to come by reducing drainage construction costs and flood hazard exposure, at the same time enhancing the quality of urban life." --D. Earl Jones, U.S. Department of Housing and Urban Development (HUD), February 10, 1970

All residents of the area have benefited significantly from the pioneering vision of those who were responsible for the original (1969) version of the Urban Storm Drainage Criteria Manual, including Kenneth R. Wright, P.E., D. Earl Jones, Jr., P.E., Dr. Jack Schaeffer, Joe Shoemaker, and Dr. Gilbert White. The vast majority of the policies, principles, and criteria in the 1969 manual were retained in the 2001 and 2016 updates—a true testament to the wisdom of these leaders. This 2016 update builds upon the foundation that they provided more than 40 years ago.

UDFCD's principles and policies for urban storm drainage and floodplain management are briefly summarized in this section, followed by discussion of these policies in the remainder of the chapter.

1.1 Principles

Since 1969, UDFCD has embraced principles of drainage planning that guide the criteria in this manual. When these principles are followed, drainage planning and decisions are made in a consistent manner, considering both public safety and environmental protection. These time-tested principles include:

1. **Drainage is a regional phenomenon that does not respect the boundaries between government jurisdictions or between properties.** This makes it necessary to formulate programs that include both public and private involvement. Overall, the governmental entities most directly involved must provide coordination and master planning, but drainage planning must be integrated on a regional level if optimum results are to be achieved. The manner in which proposed drainage systems fit into existing regional systems must be quantified and discussed in the master plan.

2. **A storm drainage system is a subsystem of the total urban water resource system.** Stormwater system planning and design for any site must be compatible with comprehensive regional plans and should be coordinated with planning for land use, open space and transportation. Erosion and sediment control, flood control, site grading criteria, and water quality all closely interrelate with urban stormwater management. Any individual master plan or specific site plan should normally address all of these considerations.

3. **Every urban area has an initial (i.e., minor) and a major drainage system, whether or not they are actually planned and designed.** The initial drainage system, sometimes referred to as the "minor system," is designed to provide public convenience and to accommodate moderate, frequently occurring flows. The major system carries more water and operates when the rate or volume of runoff exceeds the capacity of the minor system. Both systems should be carefully considered.

4. **Runoff routing is primarily a space allocation problem.** The volume of water present at a given point in time in an urban region cannot be compressed or diminished. Channels and storm drains serve both conveyance and storage functions. If adequate provision is not made for drainage space demands, stormwater runoff will conflict with other land uses, result in damages, and impair or disrupt the functioning of other urban systems.

5. **Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another.** Urbanization tends to increase downstream peak flow by increasing runoff volumes and velocities. Stormwater runoff can be stored and slowly released via detention facilities to manage peak flows, thereby reducing the drainage capacity required immediately downstream.

6. **An urban storm drainage strategy should be a multi-objective and multi-means effort.** The many competing demands placed upon space and resources within an urban region argue for a drainage management strategy that meets a number of objectives, including water quality enhancement, groundwater recharge, recreation, wildlife habitat, wetland creation, protection of landmarks/amenities, control of erosion and sediment deposition, and creation of open spaces.

7. **Design of the storm drainage system should consider the features and functions of the existing drainage system.** Every site contains natural features that may contribute to the management of stormwater without significant modifications. Existing features such as natural streams, depressions, wetlands, floodplains, permeable soils, and vegetation provide for infiltration, help control the velocity of runoff, extend the time of concentration, filter sediments and other pollutants, and recycle

nutrients. Each development plan should carefully map and identify the existing natural system. Techniques that preserve or protect and enhance the natural features are encouraged. Good designs improve the effectiveness of natural systems rather than negate, replace or ignore them.

8. **In conjunction with new development and redevelopment, coordinated efforts should be made to minimize increases in, and reduce where possible, stormwater runoff volumes, flow rates, and pollutant loads to the maximum extent practicable.** Key practices include:

   - The perviousness of the site and natural drainage paths should be preserved to the extent feasible. Areas conducive to infiltration of runoff should be preserved and integrated into the overall runoff management strategy for the site.

   - The rate of runoff should be slowed. Preference should be given to stormwater management systems that maximize vegetative and pervious land cover. These systems will promote infiltration, filtering and slowing of the runoff. It should be noted that, due to the principle of mass conservation, it is virtually impossible to prevent increases in post-development runoff volumes for all storm events when an area urbanizes. Existing stormwater regulations typically require control of peak flows to predevelopment levels to the maximum extent practicable, and increasingly, regulatory agencies are implementing requirements focused on the control of runoff volumes for smaller, frequently occurring events. Increased flow volumes may not cause flooding problems if a watershed has a positive outfall to a stream or river; however, increases in runoff volumes may cause problems for small, enclosed watersheds (i.e. draining to a lake) or into streams of limited capacity. Increases in runoff volumes, if not appropriately managed, can also adversely affect stream stability.

   - Pollution control is best accomplished by implementing a series of measures, which can include source controls, minimizing directly connected impervious area, and construction of on-site and regional facilities to control both runoff and pollution. Implementing measures that reduce the volume of runoff produced by frequently occurring events through infiltration and disconnection of impervious areas is one of the most effective means for reducing the pollutant load delivered to receiving waters.

9. **The stormwater management system should be designed beginning with the outlet or point of outflow from the project, giving full consideration to downstream effects and the effects of off-site flows entering the system.** The downstream conveyance system should be evaluated to ensure that it has sufficient capacity to accept design discharges without adverse upstream or downstream impacts such as flooding, stream bank erosion, and sediment deposition. In addition, the design of a drainage system should take into account the runoff from upstream sites, recognizing their future development runoff potential (e.g., imperviousness).

10. **The stormwater management system requires regular maintenance.** Failure to provide proper maintenance reduces both the hydraulic capacity and pollutant removal efficiency of the system. The key to effective maintenance is clear assignment of responsibilities to an established entity and a regular schedule of inspections to determine maintenance needs and to ensure that required maintenance is conducted. Local maintenance capabilities should be a consideration when selecting specific design criteria for a given site or project.

11. **Floodplains should be preserved whenever feasible and practicable.** Nature has claimed a prescriptive easement for floods, via its floodplains, that cannot be denied without public and private cost. Floodplain encroachment must not be allowed unless competent engineering and planning have proven that flow capacity is maintained, risks of flooding are defined, and risks to life and property are strictly minimized. Preservation of floodplains is a policy of UDFCD to manage flood hazards,

preserve habitat and open space, create a more livable urban environment, and protect the public health, safety, and welfare (White 1945).

12. **Reserve sufficient right-of-way for lateral movement of incised floodplains.** Whenever an urban floodplain is contained within a narrow non-engineered channel, its lateral movement over time can cause extensive damage to public and private structures and facilities. For this reason, whenever such a condition exists, it is recommended that, at a minimum, the channel be provided with grade control structures and a right-of-way corridor be preserved of a width corresponding to normal depth calculations for the future stable channel geometry, plus maintenance access requirements.

1.2 Basic Hydrologic Data Collection Policies

1. A program for collecting and analyzing storm runoff and flood data should be maintained so that intelligent and orderly planning may be undertaken for storm drainage facilities.

2. A program should be maintained to delineate flood hazard areas along all waterways in urbanized areas and in areas that may be urbanized in the future. This program should make full use of the information and data from the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), private consulting engineers, and the Colorado Water Conservation Board (CWCB). This information should be regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, climate change, and the occurrence of extraordinary hydrologic events.

3. Before commencing design of any drainage project, comprehensive facts and data should be collected and examined for the particular watershed and area under consideration, and the basis for the design should then be agreed upon by the governmental entities affected.

1.3 Planning Policies

1. Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design must be compatible with comprehensive regional plans. A master plan for storm drainage should be developed and maintained in an up-to-date fashion at all times for each urbanizing drainage watershed.

2. The planning for drainage facilities should be coordinated with planning for open space and transportation. By coordinating these efforts, new opportunities may be identified that can help solve drainage problems. Natural streams should be used to convey storm runoff wherever feasible. Major consideration must be given to the floodplains and open space requirements of the area (White 1945).

3. Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another.

4. Storage of runoff in detention and retention reservoirs can reduce the drainage conveyance capacity

Accessing UDFCD Hydrologic Data, Floodplain Maps and Flood Alert System

Much of the hydrologic data originally envisioned in the 1960s is now readily available on the UDFCD website (www.udfcd.org) and is accessible for developers, engineers, local governments, and the general public.

requirement immediately downstream. Acquisition of open space adjacent to streams provides areas where storm runoff can spread out and be stored for slower delivery downstream.

5. Runoff from small, frequently occurring storms should be managed to reduce runoff peak flows, volumes (where feasible) and pollutant loading to streams. Management of these frequently occurring events helps to protect beneficial uses of streams and promotes channel stability.

1.4 Technical Criteria

- Storm drainage planning and design should follow the criteria developed and presented in this Urban Storm Drainage Criteria Manual (USDCM).

- Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. To provide for orderly urban growth, reduce costs to future generations and avoid loss of life and major property damage, both systems must be properly planned, engineered and maintained.

- The determination of runoff magnitude should be by the Rational Formula, the Colorado Urban Hydrograph Procedure (CUHP), or statistical analyses based on an adequate record of actual measured flood occurrences as set forth in the Runoff chapter of this manual. The method of statistical analysis is very problematic for watersheds that lack stationarity, (i.e., have been altered via urbanization or other physical changes over the record of measured floods).

- Use of streets for urban drainage should fully recognize that the primary use of streets is for traffic. Streets should not be used as floodways for initial storm runoff. Usability of the street during minor storms and reduction of street maintenance costs should be objectives of urban drainage design.

- Irrigation ditches should not be used as outfall points for initial or major drainage systems, unless such use is shown to be without unreasonable hazard, as substantiated by thorough hydraulic engineering analysis, and written approval of the ditch owner(s) is obtained. In addition, irrigation ditches cannot be relied on to mitigate upstream runoff.

- Proper design and construction of stormwater detention basins and retention ponds is necessary to minimize future maintenance and operating costs and to avoid public nuisances, health hazards, and safety hazards. This is particularly important, given the many detention and retention facilities in an urban area.

- Management of runoff from frequently occurring storm events should include four steps: 1) employing runoff reduction practices, 2) implementing best management practices (BMPs) that provide a water quality capture volume with slow release and/or infiltration, 3) stabilizing streams and 4) implementing site-specific and other source control BMPs, as needed. See Chapter 1, Volume 3 of the USDCM for additional information on the four-step process.

- The various governmental entities within the UDFCD boundary have adopted floodplain management programs, which must be maintained over the long-term. Floodplain management must encompass comprehensive criteria designed to encourage the adoption of permanent measures that will lessen the

- Exposure of life, property and facilities to flood losses, improve the long-range land management and use of flood-prone areas, and inhibit, to the maximum extent feasible, unplanned and economically unjustifiable future development in such areas.

1.5 Flood Insurance Policy

Flood insurance is an integral part of the strategy to manage flood losses. UDFCD encourages the continued participation of local governments in the National Flood Insurance Program, as set forth in the National Flood Insurance Act (NFIA) of 1968, as amended.

1.6 Levee Policy

1. UDFCD strongly discourages local governments from authorizing or permitting the use of levees in regard to new development in flood hazard areas.

2. UDFCD will consider levees to protect existing development only as a last resort when no other mitigation option is feasible.

1.7 Criteria Implementation Policies

1. The USDCM should continue to be adopted by all governmental entities operating within the UDFCD boundary (Figure 1-1).

2. Each level of government is encouraged to participate in a successful drainage program.

3. Problems in urban drainage administration encountered by governmental entities can be reviewed by UDFCD to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments. The financing of storm drainage improvements is fundamentally the responsibility of the affected property owners—both those directly affected by the water and those from whose land the water flows.

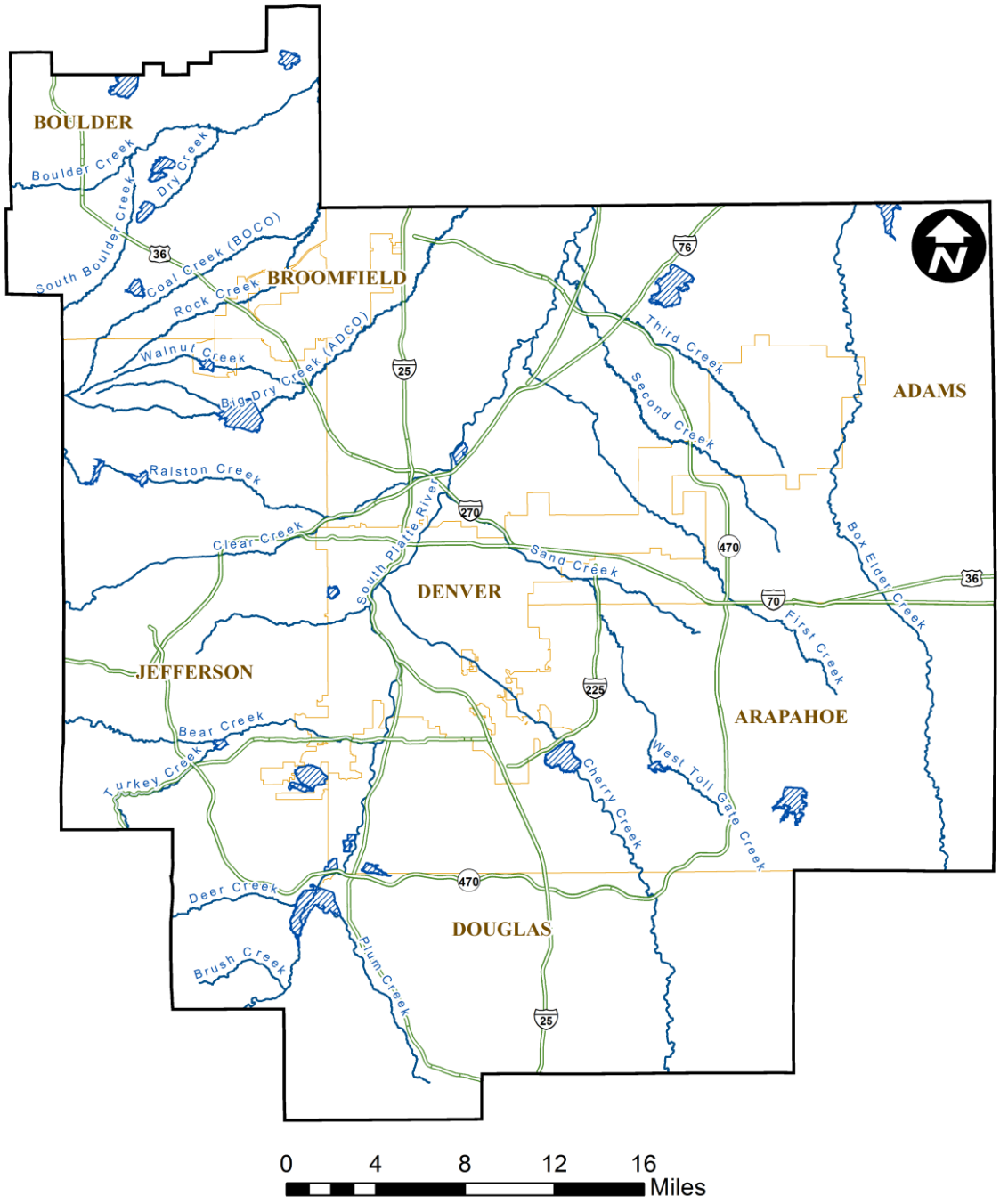

Figure 1-1. Urban Drainage and Flood Control District (UDFCD) boundary

2.0 UDFCD Hydrologic Data Collection

A well developed and systematic inventory of basic hydrologic data and knowledge provides the foundation for sound decision making that protects the public health, safety and welfare and results in effective use of public funds. Prior to the commencement of any drainage project, comprehensive facts and data are collected and examined for the particular watershed and area under consideration. The following key information leads to scientifically-based and cost-effective drainage planning:

- **Data Collection Program**. An important step in a drainage program is to get the facts. A program for collecting and analyzing storm runoff and flood data is maintained to promote intelligent and orderly planning (Jones 1967).

- **Storm Runoff and Flood Damage Data**. Storm runoff and flood damage data should be collected in a systematic and uniform manner.

- **Rainfall-Runoff Characterization**. A program is maintained to collect and analyze rainfall-runoff relationships in urbanized portions of the UDFCD boundary.

- **Inventory of Successful Projects**. Some drainage projects function better than others. It is important to determine why, so that key features may be identified for use on future projects.

- **Publically Accessible UDFCD Library**. As a key component of UDFCD's education and outreach program, UDFCD actively maintains an electronic library of drainage master planning studies, as-built drawings, maps, hydrologic data and guidance documents, which is available for use by all governmental entities, planners, and engineers. The public is encouraged to access this library through the UDFCD website (www.udfcd.org). Additionally, archived material (hydrologic and hydraulic models, master planning study technical appendices, etc.) may be made available by email request to udfcd@udfcd.org.

- **Runoff Magnitude Records**. Where practical, the magnitude of computed and measured runoff peaks is tabulated for UDFCD streams and gulches so that comparisons may be readily made between watersheds and erroneous values may be more easily identified.

- **Floodplain Data**. A program to delineate flood hazard areas along all waterways within the UDFCD boundary is maintained by UDFCD. This program makes full use of UDFCD's Flood Hazard Area Delineation (FHAD) studies, FEMA Flood Insurance Studies, Natural Resources Conservation Service and USGS data, and floodplain studies by others. This information is regularly reviewed and updated to reflect changes due to urbanization, changed stream conditions, and the occurrence of extraordinary hydrologic events.

    - **Small Streams**. Small streams and other waterways, which are often overlooked, have a large damage potential. These waterways should receive early attention in areas subject to urbanization. Floodplain information should be shown on preliminary and final subdivision plats, including the areas inundated by major storm runoff and areas of potential erosion.

    - **Central UDFCD Database**. Floodplain data and mapping is stored in a central UDFCD depository available to all planners, developers, and engineers. All floodplain mapping, master planning documents, and FHADs, as well as many, design reports, as-builts and other UDFCD documents, are now available online in a database that is searchable by waterway, document type, keywords, etc.

- **Floodplains**. Floodplain management efforts should focus on developing information in areas that have a one percent chance of being inundated in any given year—that is, the 100-year floodplain. Local governmental entities may choose to regulate floodplains for other frequencies of flooding; however, the 100-year floodplain based on runoff from the projected fully urbanized watershed must be defined and is the minimum basis for regulation.

- **Priority for Data Acquisition**. UDFCD has established priorities for data acquisition because it recognizes that not all of the desired data can be collected at one time. When setting priorities, consideration is given to 1) areas of rapid urban growth, 2) drainage problem areas, 3) local interest and capabilities in floodplain management, and 4) the potential for developing high-quality, robust data sets.

3.0 Planning

3.1 Total Urban System

Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design should be compatible with comprehensive regional plans. Master plans for storm drainage have been developed and are maintained in an up-to-date fashion for most of the watersheds in the UDFCD region. An effort to complete the coverage of master plans for yet unplanned areas of UDFCD should be continued until full coverage is achieved.

Evolution of UDFCD Master Planning Program

"Initially, master planning was aimed at reducing flood potential in areas already developed. Now, much of our time is also spent on growth areas, working to prevent flood problems from ever occurring."

—Ben Urbonas, UDFCD Master Planning Program Manager from 1976 to 2008.

3.1.1 Planning Process Elements

Good urban drainage planning is a complex process. Fundamentals include:

1. **Major Drainage Planning:** Local and regional planning should consider the major drainage system necessary to manage the 100-year runoff; that is the runoff having a one percent probability of occurrence in any given year. Implementation of major drainage plans will reduce loss of life and major damage to the community and its infrastructure.

2. **Outfall System Planning:** Outfall system planning efforts identify detention, water quality and conveyance practices within a watershed that ultimately discharges to a receiving stream. Outfall system plans typically address storm drain improvements, stream crossing improvements, stream enlargement, stabilization, and floodplain preservation.

3. **Initial Drainage System Planning:** All local and regional planning should consider the initial drainage system to transport the runoff from 2-year to 5-year storms; these storms have a 50% to 20% respective probability of occurrence in any given year. The planner of an initial system must strive to minimize future drainage problems from these more frequently occurring storms.

4. **Water Quality and Environmental Design:** All planning efforts should address stormwater quality treatment requirements, opportunities for the development to mimic natural hydrology and preserve natural features, enhance habitat, and evaluate impacts of new facilities. When convened early in the planning and design process, a multi-disciplinary design team can help to ensure that the benefits to total urban systems are considered in the drainage planning effort.

5. **Long-term Maintenance and Operation**: Future operation and maintenance by private and public entities needs to be considered during the planning stages to ensure that the facility functions as designed over the long-term.

3.1.2 Master Planning

Drainage design does not lend itself to a piecemeal approach; therefore, master plans for drainage should be prepared on a prioritized basis. Such plans already cover most of the developed watersheds within in the UDFCD boundary. Additional plans will be developed for areas yet unplanned. In addition, existing master plans will be updated as needed to reflect conditions that change over time.

Initial steps include the planning of major drainage systems from the point of outfall, proceeding in an upstream direction. Major drainage systems, which are defined as servicing an area of at least 130 acres, are typically well defined and often dictate the design of the initial drainage system, including storm drains, detention facilities, and stormwater quality BMPs.

Master planning must be based upon potential future upstream development, taking into consideration both upstream and downstream existing and future regional publicly owned and operated (or controlled) detention and retention storage facilities. Assurances for construction and perpetual operation and maintenance of detention and retention facilities must be provided for the effects of the facilities to be considered in master planning. In the absence of such detention and retention facilities, the basis of design for both the initial and major systems is fully developed upstream conditions without storage.

Each municipality and county within UDFCD's boundary is responsible for master planning urban storm drainage facilities within its jurisdiction. UDFCD can help to coordinate efforts. Cooperation between governmental entities is needed to solve drainage problems, and joint city, county and UDFCD efforts are encouraged. Master planning is best accomplished on a systematic priority basis so that the most demanding problems, such as areas of rapid urbanization, are addressed first.

UDFCD has established a standard format for master plan reports and drawings so that a uniform planning approach and coordination of efforts can occur more easily. Master planning should be completed in adequate detail to provide a clear drainage framework for future development in a particular watershed. Generalized concepts based on rough hydrological analyses should not be used as master plans; a more rigorous analysis is necessary.

3.1.3 Floodplain Easements

A master plan should be prepared prior to development in a watershed. Where development occurs in a watershed in advance of a master plan, flood easements should be retained for the 100-year floodplain. If available the future conditions 100-year floodplain should be used for this purpose. Where an existing master plan recommends the preservation of a defined floodplain, every effort should be made to acquire and/or preserve an easement or property right (ownership) for such a floodplain.

Photograph 1-2. National Medal of Science winner, Dr. Gilbert White, recommended naturalistic floodplains because they save people from damages and are good for the economy and the environment.

On any floodplain, nature possesses an

intrinsic easement for intermittent occupancy by runoff waters. Humans can deny this easement only with difficulty. Encroachments upon, or unwise land modifications within this easement can adversely affect upstream and downstream flooding occurrences during nature's inevitable periodic occupancy of this easement. Floodplain regulations, therefore, must define natural easements and boundaries and must delineate floodplain and floodways that are consistent with the overall public interest.

3.1.4 Local and Regional Planning

Local and regional planning, whether performed under federal or state assistance programs or under completely local auspices, should consider and evaluate opportunities for multi-objective water resources management.

3.1.5 Development and Site Planning

All land development proposals should receive full site planning and engineering analyses. In this regard, professional consideration must be given to the criteria outlined in this manual. Development of an area without the provision of adequate drainage multiplies the cost to the public because the drainage problem must be corrected later, usually at public expense. Where flood hazards are involved, local planning boards should consider proposed land use so that it is compatible with the flood hazard risks involved with the property, and appropriate easements should be provided to preclude encroachment upon waterways or flood storage areas.

A development plan should consider broad goals such as:

- Drainage and flood control problem alleviation,
- Economic reasonableness,
- Broader regional development context,
- Environmental preservation and enhancement, considering water quality and stream stability,
- Social and recreational objectives.

Photograph 1-3. An urban storm drainage strategy should be a multi-objective and multi-means effort.

These goals have the potential to influence the type of drainage subsystem selected. Planning for drainage facilities should be related to the goals of the urban region, should be looked upon as a subsystem of the total urban system, and should not proceed independent of these considerations (Wright 1967).

3.1.6 Managing Runoff from Frequently Occurring Storms

Protecting and enhancing the water quality of streams is an important objective of drainage planning. Erosion control, maintaining stream stability, and reducing pollutant loading from stormwater runoff must be considered. Volume 3 of the USDCM provides criteria for stormwater runoff BMPs that help to reduce runoff volumes for frequently occurring storm events and provide treatment of the water quality capture volume (WQCV), which is based on the 80th percentile runoff-producing event.

The first step in managing runoff from frequently occurring storms is implementing runoff reductions

Common Stormwater Quality Terms and Concepts

Best Management Practice (BMP): A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters. (Some entities use the terms "Stormwater Control Measure" or "Stormwater Control.")

Low Impact Development (LID): LID is a comprehensive land planning and engineering design approach to managing stormwater runoff with the goal of mimicking the pre-development hydrologic regime. LID emphasizes conservation of natural features and use of engineered, on-site, small-scale hydrologic controls that infiltrate, filter, store, evaporate, and detain runoff close to its source.

Minimizing Directly Connected Impervious Area (MDCIA): MDCIA includes a variety of runoff reduction strategies based on reducing impervious areas and routing runoff from impervious surfaces over grassy areas to slow runoff and promote infiltration. MDCIA is recommended as a key technique for reducing runoff peaks and volumes for frequently-occurring storms following urbanization. MDCIA is a key component of LID.

Green Infrastructure: Planning and design of systems intended to benefit from the services and functions provided in the natural environment. In regard to wet weather management, and on a regional scale, preservation of riparian floodplains and channel stabilization that allows for vital habitat and wildlife passage through techniques similar to those found in nature, preserves ecological function and creates balance between built and natural environments. On an urban level, wet weather management practices that include infiltration, evapotranspiration, and reuse to help restore natural hydrology.

Water Quality Capture Volume (WQCV): This volume represents runoff from frequent storm events such as the 80th percentile runoff-producing event. The volume varies depending on local rainfall data. Within the UDFCD boundary, the WQCV is based on runoff from 0.6 inches of precipitation.

Excess Urban Runoff Volume (EURV): EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff (generally greater than the 2-year event for pervious land surfaces). The EURV is relatively constant for a given imperviousness over a wide range of storm events.

Full Spectrum Detention: This practice utilizes capture and slow release of the EURV. UDFCD has found this method better replicates historic peak discharges for the full range of storm events compared to multi-stage detention practices.

practices, also known as *minimizing directly connected impervious area* (MDCIA), which reduces the amount and connectivity of impervious surfaces in a development. This can be accomplished through a variety of techniques such as functional grading, wide and shallow surface flow sections, disconnection of hydrologic flow paths, and the use of bioretention and permeable pavements. The extent to which MDCIA and runoff reduction can be implemented on a development site is dependent on the site conditions (e.g., soil type, groundwater depth, depth to bedrock) and development type (e.g., new development, redevelopment, ultra urban, infill,). Opportunities for runoff reduction should be evaluated in each development. Once this step has been completed, then BMPs designed to treat the remaining WQCV can be implemented. An alternative to treating the WQCV is use of an integrated detention and water quality detention facility based on capture and treatment of the Excess Urban Runoff Volume (EURV). Design criteria for these facilities, described as full spectrum detention facilities, are provided in the *Storage* chapter.

3.1.7 Separation of Stormwater and Sanitary Flows

Sanitary sewage systems that overflow or bypass untreated sewage into surface streams are not permitted in Colorado. Drainage planning should prevent inflow to sanitary sewers resulting from street flow and channel flooding. In cases where sanitary sewers are flooded by urban storm runoff, engineers and planners should work together to correct these problems. Additionally, illegal connections of sanitary sewers to the storm drain system or conditions where storm drains intercept flows from leaking sanitary sewers must be corrected to protect public health.

3.2 Multiple-Objective Considerations

Planning for drainage facilities should be coordinated with planning for open space, recreation and transportation. By coordinating these efforts, new opportunities can be identified which can assist in the solution of drainage problems (Heaney, Pitt and Field 1999).

1. **Lower Drainage Costs**. Planning drainage works in conjunction with other urban needs results in more orderly development and lower costs for drainage and other facilities.

2. **Open Space**. Open space provides significant urban social and environmental benefits. Use of stabilized, natural streams is often less costly than constructing artificial channels. Combining the open space needs of a community with the major drainage system is a desirable combination of uses that reduces land costs and promotes riparian zone protection and establishment over time.

3. **Transportation**. Design and construction of new streets and highways should be fully integrated with drainage needs of the urban area for better streets and highways and better drainages and to avoid creation of flooding hazards. The location of borrow pits needed for road construction should be integrated with broad planning objectives, including storm runoff detention.

4. **Natural Channels**. Natural streams should be used in lieu of storm drains for stormwater runoff wherever practical. Preservation and protection of natural streams are encouraged; however, significant consideration must be given to their stability as the tributary area urbanizes.

5. **Channelization**. Natural streams within an urbanizing area are often deepened, straightened, lined, and sometimes put underground. A community loses a natural asset when this happens. Channelizing a natural waterway usually speeds up the flow, causing greater downstream flood peaks and higher drainage costs, and does nothing to enhance the environment. Natural streams within an urbanizing area require stabilization, not channelization.

6. **Channel Storage**. Streams having "slow-flow" characteristics, vegetated bottoms and sides, and wide water surfaces provide significant floodplain storage capacity. This storage is beneficial because it reduces downstream runoff peaks and provides an opportunity for groundwater recharge. Wetland channels, wide natural streams, and adjacent floodplains provide urban open space.

7. **Major Runoff Capacity**. Streams and their residual floodplains should be capable of carrying the 100-year storm runoff, which can be expected to have a one percent chance of occurring in any given year.

Photograph 1-4. Streams having "slow-flow" characteristics with vegetated bottoms and sides can provide many benefits.

8. **Maintenance and Maintenance Access**. Urban streams require both scheduled and unscheduled maintenance activities such as removal of sediment, debris and trash; mowing, and repair of hydraulic structures. Assured long term maintenance is essential, and it must be addressed during planning and design. UDFCD assists with drainage facility maintenance, provided that the facilities are designed and constructed in accordance with the UDFCD's Maintenance Eligibility Guidelines. The most current version of these guidelines may be obtained from UDFCD's website (www.udfcd.org). Designers are strongly encouraged to adhere to the design criteria listed in the Maintenance Eligibility Guidelines. Waterways, detention facilities, and other drainage facilities must have permanent access for routine and major maintenance activities.

3.3 Avoiding Transfer of Problems

Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another. Both intra-watershed and inter-watershed transfers

Multi-purpose Values of Urban Stream Corridors

"Urban stream corridors provide many critical functions in the life of a community. During storm events, they function as conveyance systems for storm runoff. Floodplain managers have a keen interest in making this function as reliable and safe as possible. But, urban stream corridors are much more. Their linear nature is well suited to trails and a variety of recreational activities. Human beings are naturally drawn to water and the natural environment. Moreover, Coloradoans seek an active outdoor lifestyle and value natural areas for beauty and the appreciation of wildlife. Urban streams also provide an immense ecological resource and are central to the natural processes that support the environment. Thus, thoughtful treatment of these natural systems creates community assets that are important to local governments and developers as they plan new projects and especially to the future residents. Therefore, trails, recreational activities, floodplain, wetland, and riparian preservation are critical community values."

—Bill DeGroot, UDFCD Floodplain Management Program Manager (1974- 2014)

should be avoided and appropriate assumptions should be made during master planning to avoid transfer of problems. Key principles include:

1. **Intra-Watershed Transfer**: Channel modifications that create unnecessary problems downstream should be avoided, both for the benefit of the public and to avoid damage to private parties. Problems to avoid include land and channel erosion and downstream sediment deposition, increase of runoff peaks, and debris transport, among others.

2. **Inter-Watershed Transfer:** Diversion of storm runoff from one watershed to another introduces significant legal and social problems and should be avoided unless specific and prudent reasons justify and dictate such a transfer and no measurable damages occur to the natural receiving water or urban systems or to the public.

3.4 Detention and Retention Storage

Stormwater runoff can be stored in detention basins and retention ponds. Such storage, when properly designed, constructed, and maintained with adequate assurances for the long-term, can reduce the peak flow drainage capacity required, thereby reducing the land area and expenditures required downstream. Retention ponds, both on and off-line, require a legal right to store water in Colorado. Consultation with the State Engineer's Office is needed in such cases.

Photograph 1-5. Retention ponds with permanent ponding have many benefits, including flood reduction, water quality and land values.

3.4.1 Upstream Storage

Provide temporary storage of storm runoff close to the points of rainfall occurrence to the extent practical. Opportunities for storage include on-site detention basins and retention ponds, parking lots, ball fields, property line swales, parks, road embankments, and borrow pits. Wherever reasonably acceptable from a social standpoint, parks should be used for short-term detention of storm runoff. Such use may help justify park and greenbelt acquisition and expenditures. This "Blue-Green" concept was introduced in the 1960's (Jones 1967) and remains an effective strategy in drainage planning.

Parking lots create more runoff volume and higher runoff rates than natural conditions. Where practical, parking lots should be designed to provide temporary storage of runoff during infrequent events (e.g., 5-year or greater).

Due to the difficulty in quantifying the cumulative effects of very large numbers of small (i.e., on-site) detention/retention facilities (Malcomb 1982; Urbonas and Glidden 1983) and the challenge of assurance of their continued long-term performance or existence (Debo 1982; Prommersberger 1984), UDFCD recognizes only regional, publicly owned (or controlled) facilities in its floodplain management program.

3.4.2 Downstream Storage

Detention and retention of storm runoff is desirable in slow-flow channels, in storage facilities located in the stream, in off-line facilities, and by using planned channel overflow ponding in park and greenbelt areas. Lengthening the time of concentration of storm runoff to a downstream point is an important goal of storm drainage and flood control strategies.

3.4.3 Reliance on Privately Controlled Facilities and Water Storage Reservoirs

Privately controlled facilities cannot be used for flood mitigation purposes in master planning because their perpetuity cannot be reasonably guaranteed. Additionally, publicly owned water storage reservoirs (city, state, water district, irrigation company, etc.) should be assumed to be full for flood planning purposes and only the detention storage above the spillway crest considered in the determination of downstream flood peak flows. Exceptions may occur where legal agreements are in place ensuring flood storage in perpetuity.

3.4.4 Reliance on Embankments

The detention of floodwaters behind embankments created by railroads, highways or roadways resulting from hydraulically undersized culverts or bridges should not be utilized for flood peak mitigation when determining the downstream flood peaks for channel capacity purposes unless such detention has been established in perpetuity through a legally binding agreement.

4.0 Technical Criteria

4.1 Intended Use of Design Criteria

Storm drainage planning and design should adhere to the criteria developed and presented in this manual. The design criteria presented herein represent current best engineering practice, and their use in the region is recommended. The criteria are not intended to be an ironclad set of rules that the planner and designer must follow; they are intended to establish guidelines, standards and methods for sound planning and design. UDFCD revises and updates the criteria as necessary to reflect advances in the field of urban drainage engineering and urban water resources management.

Governmental entities and engineers should utilize the USDCM in planning new facilities and in their reviews of proposed works by developers, private parties, and other governmental entities, including the Colorado Department of Transportation and other agencies of the state and federal governments.

4.2 Initial and Major Drainage Criteria

Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. Both systems must be planned and properly engineered to provide for orderly urban growth, reduce costs to future generations, and avoid loss of life and major property damage.

4.2.1 Design Storm Return Periods for Initial and Major Drainage Systems

Storm drainage planning and design should fully recognize the need for two separate and distinct storm drainage systems: the initial drainage system and the major drainage system. Recommended design storms for the initial and major drainage systems are specified in Table 1-1. Local governments should not be tempted to specify larger than necessary design runoff criteria for the initial drainage system

because of the direct impact on the cost of urban infrastructure.

Normally, the initial drainage system cannot economically carry major storm runoff, though the major drainage system can provide for the initial runoff. A well-planned major drainage system will reduce or eliminate the need for storm drain systems (Jones 1967). Systems consisting of underground pipes are a part of initial storm drainage systems.

Table 1-1. Design storms and purposes of initial and major drainage systems

Drainage System	Design Storm	Purposes
Initial Drainage System	2- to 5-year floods (depends on local criteria)	Reduce the frequency of street flooding and maintenance costs, provide protection against regularly recurring damage from storm runoff, help create an orderly urban system, and provide convenience to urban residents.
Major Drainage System	100-year flood (1% probability of occurrence for any given year)	Avoid major property damage and loss of life for the storm runoff expected to occur from an urbanized watershed.

There are many developed areas within the UDFCD boundary that predate and do not fully conform to the drainage standards in Table 1-1. Flooding problems experienced in such areas were a key reason for the original development of the USDCM. UDFCD recognizes that upgrading already developed areas to conform to all of the policies, criteria, and standards contained in the USDCM will be difficult, if not impractical to obtain, short of complete redevelopment or renewal. However, flood risk management techniques can be applied to these areas.

Strict application of the USDCM in the overall planning of new development is practical and economical; however, when planning drainage improvements and designating floodplains for developed areas, the use of the policies, criteria, and standards contained in the USDCM should be adjusted to provide for economical and environmentally sound solutions consistent with other goals of the area. Where the 100-year storm is not chosen for design purposes, the residual impact of the 100-year storm should be investigated and made known.

4.2.2 Critical Facilities

Drainage engineers and planners should consider that certain critical facilities may need a higher level of flood protection. For instance, hospitals, police, fire stations and emergency communication centers should be designed in a manner so that their functioning will not be compromised, even during a 100-year flood. The use of a 500-year flood level for such facilities may be justified (and required by State floodplain regulations) in many instances.

4.2.3 Runoff Computations

The determination of runoff magnitude should be made using the techniques described in the *Runoff* chapter.

Master Plan Hydrology

Published peak flows should only be changed when it is clear either an error was made or a recalibration of the regional hydrologic model impacts the area of study and, in either case, when continued use of the published flows is not in the public's interest.

The peak discharges determined by any method are approximations. Rarely will drainage works operate at the design discharge. In actual practice, flow will always be more or less, as the hydrograph rises and falls during a storm event. Thus, the engineer should not overemphasize the detailed accuracy and precision of computed discharges but should emphasize the design of practical and hydraulically balanced drainage infrastructure based on sound logic and engineering, as well as dependable hydrology. The use of more than three significant figures for estimating peak discharges conveys a false sense of precision and should be avoided.

Because of the public's reliance on published peak flow estimates, these values should be changed only when it is clear either an error was made or a recalibration of the regional hydrologic model impacts the area of study and, in either case, when continued use of the published flows is not in the public's interest.

4.2.4 Joint Probability Computations

The depth of flow in the receiving stream must be taken into consideration for backwater computations for both the initial and major storm runoff. An analysis of the joint probability of occurrence may be warranted. FEMA recommends modeling a 10-year water surface in the receiving stream for a 100-year tributary discharge. HEC-22 also provides guidance based on the ratio of main stream watershed area to that of the tributary stream.

4.2.5 Open Channels for Major Drainage

Open channels for transporting major storm runoff are more desirable than underground conduits, and use of such is encouraged. Open conveyance planning and design objectives are often best met by using naturalized streams (as described in the *Open Channels* chapter), which characteristically have slower velocities and large width-to-depth ratios. Additional benefits can be obtained by incorporating parks and greenbelts with the naturalized stream layout. Use of naturalized streams (and other storm runoff features) should be considered in the early planning stages of a new development.

When evaluating existing natural water courses (perennial, intermittent and ephemeral), straightening, fill placement, and other alterations should be minimized and carefully evaluated. Such actions tend to reduce flood storage and increase the velocity to the detriment of those downstream of and adjacent to the channel work. Effort should be made to reduce flood peaks and control erosion so that the natural channel regime is preserved as much as practical. Some type of structural stream stabilization is almost always necessary to stabilize the stream against increased flows associated with urbanization. For example, grade control structures and structural protection at the stream toe and on the outer banks at bends are normally required. Riparian buffer zones can be used to accommodate future meandering and bank sloughing, at least in part.

4.3 Use of Streets

Streets are a significant component of the urban drainage system, and use of streets for storm runoff should be made within reasonable limits, recognizing that the primary purpose of streets is for traffic. Reasonable limits of the use of streets for conveyance of storm runoff should be governed by design criteria summarized in Table 1-2 for initial storm runoff, Table 1-3 for major storm runoff and Table 1-4 for allowable maximum cross-street flow for initial and major design storm runoff. These criteria are

consistent with the intent that major storm runoff will be removed from public streets at frequent and regular intervals and routed into streams, as well as the recognition that runoff tends to follow streets and roadways; therefore, streets and roadways may be aligned to provide a specific runoff conveyance function.

Table 1-2. Reasonable use of streets for initial storm runoff in terms of pavement encroachment

Street Classification	Maximum Encroachment
Local	No curb overtopping. Flow may spread to crown of street.
Collector	No curb overtopping. Flow spread must leave at least one lane free of water.
Arterial	No curb overtopping. Flow spread must leave at least one lane free of water in each direction but should not flood more than two lanes in each direction.
Freeway	No encroachment is allowed on any traffic lanes.

Table 1-3. Major storm maximum street ponding depth

Street Classification	Maximum Ponding Depth
Local and Collector	Residential dwellings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of a building. The depth of water over the gutter flow line should not exceed 12 inches for local and collector streets.
Arterial and Freeway	Residential dwellings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of a building. The depth of water should not exceed the street crown to allow operation of emergency vehicles. The depth of water over the gutter flow line should not exceed 12 inches.

Table 1-4. Maximum allowable cross-street flows

Street Classification	Initial Design Runoff	Major Design Runoff
Local	6 inches of depth in cross pan	12 inches of depth above gutter flow line.
Collector	Where cross pans allowed, depth of flow should not exceed 6 inches	12 inches of depth above gutter flow line.
Arterial/Freeway	None	No cross flow. 12 inches of maximum depth at upstream gutter or roadway. edge

Initial and major drainage planning should go hand-in-hand. When maximum allowable street encroachment will be exceeded, a storm drain system based on the initial storm should be planned. Development of a major drainage system that can also drain the initial runoff from the streets is encouraged; this enables the storm drain system to commence further downstream.

Other design criteria for use of streets include:

- An arterial street crossing will generally require a storm drain system.
- Bubblers (inverted siphons which convey flows beneath roadways) are discouraged because of plugging with sediment and difficulty in maintaining them. Additionally, these serve as a breeding ground for bacteria and mosquitos.
- Collector streets should have cross pans only at infrequent locations as specified by the governing entity and in accordance with good traffic engineering practices.
- The local street criteria for overtopping also apply to any private access road that serves commercial areas or more than one residence, for emergency access and safety reasons.
- Drainage design objectives for streets should include reducing street repair and maintenance costs, minimizing nuisance to the public, and minimizing frequent disruption of traffic flow.

4.4 Use of Irrigation Ditches

Use of irrigation ditches for collection and transport of either initial or major storm runoff should be prohibited unless specifically provided in a UDFCD master plan or approved by UDFCD and the ditch owner, following adequate hydraulic engineering analysis that demonstrates such use is without unreasonable hazard.

Irrigation ditches are typically characterized by flat slopes and limited carrying capacity. Experience and hydraulic calculations demonstrate that these physical limitations generally preclude use of ditches as an outfall point for the initial storm drainage system. Exceptions to the rule can occur when the capacity of the irrigation ditch is adequate to carry the normal ditch flow plus the initial storm runoff with adequate freeboard to avoid creating a hazard to those below the ditch. In such cases, written approval must be obtained from the ditch owner stating that the owner understands the physical and legal (i.e., liability) consequences of accepting such runoff.

Irrigation ditches are not suitable as an outfall for the major storm runoff. Without major reworking of irrigation ditches to provide major carrying capacity without undue hazard to those downstream or below the ditch, the ditches are almost always totally inadequate for such a use and should not be used as an outfall. Moreover, because ditches are normally privately owned, one cannot assume the perpetual existence or function of a ditch.

Other irrigation ditch-related considerations include:

- Land planners downhill from a ditch should ignore the effects of the ditch in hydrologic calculations, but should also plan for continued ditch seepage.
- Irrigation ditches are sometimes abandoned in urban areas after the agricultural land is no longer farmed. Provisions must be made for a ditch's perpetuation, defined as continued operation,

capacity, and serviceability, prior to its being chosen and used as an outfall for urban drainage.

4.5 Water Quality Treatment

Stormwater quality BMPs are designed based on either the Water Quality Capture Volume (WQCV) or the Excess Urban Runoff Volume (EURV):

- **WQCV**: The WQCV, as described in detail in Volume 3 of the USDCM, corresponds to approximately the 80th percentile runoff event and is used in BMPs designed for water quality purposes only. It is appropriate to size BMPs for the entire area tributary to the BMP. The release rate for the WQCV varies based on the type of BMP.

- **EURV**: The EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff (generally greater than the 2-year event from pervious land surfaces). The EURV is relatively constant for a given imperviousness over a wide range of storm events. The EURV is a greater volume than the WQCV and is detained over the minimum time necessary to allow for the recommended drain time of the WQCV, and is used to better replicate peak discharge in receiving waters for runoff events exceeding the WQCV. The EURV is associated with Full Spectrum Detention, a simplified sizing method for both water quality and flood control detention. EURV calculation procedures are provided in the *Storage* Chapter.

4.6 Maintenance of Storage and Water Quality Facilities

Long-term maintenance provisions must be arranged for storage and water quality facilities. Maintenance of detention or retention facilities includes the removal of debris, excessive vegetation from the embankment, and sediment. Maintenance requirements for water quality facilities (BMPs) vary, depending on the BMP type, as described in Chapter 6, Volume 3 of the USDCM. Without maintenance, detention, retention, and water quality facilities will become unsighty social liabilities and eventually become ineffective for their intended functions.

5.0 Floodplain Management

5.1 Purpose

Governmental entities within the UDFCD area should continue to implement floodplain management programs. Floodplain management includes comprehensive criteria designed to encourage, where necessary, the adoption of permanent state or local measures which will lessen exposure of life, property and facilities to flood losses, improve long-range land management and use of flood-prone areas, and inhibit, to the maximum extent feasible, unplanned future development in such areas.

Floodplain Management

"Preventing new flood damage potential is not only a critical function of any total flood control program, it is typically the surest, most cost-effective way to reduce total annual losses from flooding. Prevention requires adhering to a well-documented, well-understood drainage philosophy that encourages utilization of non-structural methods of flood damage mitigation. Sensible land use regulations coupled with defined floodplains and drainage master plans keep new flood damage potential from being introduced into the 100-year floodplains."—Bill DeGroot, UDFCD Floodplain Management Program Manager (1974 to 2014)

5.2 Goals

Floodplain management includes these two primary goals:

1. **Reduce the vulnerability of residents to the danger and damage of floods**. The dangers of flooding include threats to life, safety, public health, and mental well-being, as well as damage to properties and infrastructure and disruption of the economy. Protection from these hazards should be provided, by whatever measures are suitable, for floods having a one percent recurrence probability in any given year (100-year floods), at a minimum, based on projected build-out in the watershed. Protection from the effects of greater, less frequent flooding is also needed for critical facilities where such flooding would cause service interruptions or unacceptable damages.

2. **Preserve and enhance the natural values of the floodplain**. Natural floodplains serve society by providing floodwater storage, groundwater recharge, water quality enhancement, passive recreation, and habitat for plants and animals. Many floodplains also have cultural and historical significance. It is in the public's interest to avoid development that destroys these values or, in instances where the public good requires development, to ensure that measures are taken to mitigate the floodplain loss through replacement of floodplain functions or other means.

These two goals are achievable through coordinated floodplain management and drainage planning conducted in a coordinated manner by local governments and other entities.

5.3 National Flood Insurance Program

Flood insurance should be integral part of a strategy to manage flood losses. The cities and counties in the UDFCD area are encouraged to continue to participate in the National Flood Insurance Program (NFIP) set forth in the NFIA of 1968, as amended. A prerequisite for participation is the adoption of a floodplain management program by the local government that, where necessary, includes adoption of permanent state or local regulatory measures that will lessen the exposure of property and facilities to flood losses. Property owners should be encouraged to buy flood insurance, even outside the designated floodplain, to protect against local flooding where such potential exists.

5.4 Floodplain Management

The objectives of floodplain management are to:

1. Adopt effective floodplain regulations.

2. Improve local land use practices, programs, and regulations in flood-prone areas.

3. Provide a balanced program of measures to reduce losses from flooding.

4. Reduce the need for reliance on local and federal disaster relief programs.

5. Minimize adverse water quality impacts.

6. Foster the creation/preservation of greenbelts, with associated societal, water quality, wildlife and other ecological benefits, in urban areas.

The most successful and sustainable way to accomplish all of the above listed objectives is do so while promoting the natural and beneficial uses of the floodplain. The natural and beneficial uses of the floodplain hold political, social, and economic value. Although hydrologic data are critical to the development of a floodplain management program, a successful program is largely dependent on a series of policy, planning, and design decisions. These area-wide decisions provide the setting for floodplain

usage and, when combined with hydrologic considerations and augmented by administrative and other implemention devices, constitute a floodplain management program. The program must give high priority to both flood danger and public programs, such as urban renewal, open space, etc. See the Floodplain Preservation Brochure available at www.udfcd.org for additional discussion and good examples of developments designed and constructed with value placed on the natural and beneficial functions of the floodplain.

> "Floods are acts of God, but flood losses are largely acts of man."
>
> –Gilbert White, June 1945

5.5 Floodplain Filling

While floodplain management allows some utilization of the flood fringe (i.e., areas outside of the formal floodway), the planner and engineer should proceed cautiously when planning facilities on lands below the expected elevation of the 100-year flood. Flood peaks from urbanized watersheds are high and short-lived, which makes storage in the flood fringe important and effective. Filling the flood fringe tends to increase downstream peaks.

5.6 New Development

When deciding whether to 1) construct a major flood control project to enable new development or 2) maintain an open area within an urban floodplain, the following factors should be considered:

- Relative costs of the respective alternatives (not only financial, but also non-financial economic costs such as opportunities foregone).
- Opportunities for flood proofing and other measures in relation to the extent of flood hazard.
- Availability of land in non-floodprone areas for needed development.
- Location of the high flood hazard areas, namely, defined floodways.
- Potential adverse effect on others in or adjacent to the floodplain.
- The fact that floods larger than the design flood can and will occur (i.e., some level of risk exposure will still exist, even with well-designed facilities).

5.7 Floodplain Management Strategies and Tools

FEMA has developed a variety of floodplain management strategies and tools, as summarized in Table 1-5. Other strategies and tools may also be used.

Table 1-5. Floodplain management strategies and tools

Strategy	Brief Description
Reduce Exposure to Floods	Reduce exposure to floods and disruptions by employing floodplain regulations and local regulations. The latter includes zoning, subdivision regulations, building codes, sanitary and well codes, and disclosure to property buyers.
Development Policies	Development policies that include design and location of utility services, land acquisition, redevelopment, and permanent evacuation (purchase of properties).
Disaster Preparedness	Disaster preparedness is an important tool for safeguarding lives and property, and disaster assistance will reduce the impact to citizens from flooding.
Flood Proofing	Flood proofing of buildings is a technique that is wise and prudent where existing buildings are subject to flooding. Flood proofing can help a proposed project achieve a better benefit-cost ratio.
Flood Forecasting	Flood forecasting and early warning systems are important means to reduce flood losses, safeguard health, protect against loss of life and generally provide an opportunity for people to prepare for a flood event before it strikes.
Flood Modification	The use of methods to modify the severity of the flood is a floodplain management tool. These include regional detention, channelization, minimizing directly connected impervious area, and on-site detention.
Modification of Flood Impacts	The impact of flooding can be mitigated (or modified) though the education, flood insurance, tax adjustments, emergency measures, and a good post-flood recovery plan that can be initiated immediately following a flood.

6.0 Implementation of Urban Storm Drainage Criteria

6.1 Adoption and Use of the USDCM and Master Plans

The USDCM should be adopted and used by local governments operating within the UDFCD boundary, as a resource that:

1. Gives direction to public entity efforts to guide private decisions.
2. Gives direction to public entity efforts to regulate private decisions.
3. Provides a framework for a public entity when it seeks to guide other public entities.
4. Provides a framework to assist in coordinating a range of public and private activities.
5. Provides direction for development of master plans and designs and for implementation of drainage facilities.

Drainage master plans should be completed following the criteria in the USDCM and be adopted and implemented by all governmental entities within the master plan boundaries.

6.2 Governmental Participation

Each level of government must participate if a drainage program is to be successful.

6.3 Amendments to Criteria

Problems in urban drainage administration encountered by any governmental entity should be reviewed by UDFCD to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments. UDFCD should continually review the needs of the region in regard to urban runoff criteria and should recommend changes as necessary to the USDCM.

6.4 Financing Drainage Improvements

Financing storm drainage improvements is fundamentally the responsibility of the affected property owners (both the persons directly affected by the water and the person from whose land the water flows) as well as the local government. Every effort should be made to keep the cost of drainage solutions reasonable. This will involve careful balancing of storage and conveyance costs and the integration of drainage with other activities such as open space and transportation efforts. Funding must be established, and budgets should be prepared to assure proper maintenance of all new drainage and storage facilities.

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Chapter 2
Drainage Law

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1.0 Summary of Current General Principles of Drainage and Flood Control Law

1.1 Introduction

Photograph 2-1. Preserving a natural floodplain, including wetland areas, and using this area for flood control and conveyance, represents sound engineering in concert with established Colorado drainage law.

Drainage law not only has its basis in law made by the courts and the legislature but also relies to a large extent on the drainage facts that exist in each case. Therefore, a party with the most reliable facts and information will have a distinct advantage in court. Similarly, drainage engineering and design revolves around drainage law as well as the natural law of gravity.

This chapter deals with the general principles of drainage law along with local government drainage actions, financing, floodplain management, and special matters. This chapter is meant to provide an outline of the general principles of Colorado drainage law for the engineer and agency official. It is not meant to serve as a substitute for a lawyer's opinions, though this chapter may be of interest to practicing attorneys. Also, throughout this chapter cases from other jurisdictions are cited. Although they are from courts located in other states, they are cited since they provide the reasoning and law that most likely would be implemented by courts in the State of Colorado.

In using this chapter of the Urban Storm Drainage Criteria Manual (USDCM), the reader should be familiar with the entire USDCM and should pay particular attention to the *Policy* and *Planning* chapters. In the *Policy* chapter, 12 principles have been stated, with which the reader of this chapter should be familiar. Similarly, the following legal principles are summarized below for ready reference.

1.2 Legal Principles

1. The owner of upstream property possesses a natural easement on land downstream for drainage of surface water flowing in its natural course. The upstream property owner may alter drainage conditions so long as the water is not sent down in a manner or quantity to do more harm to the downstream land than formerly. Bittersweet Farms, Inc. v. Zimbelman, 976 P.2d 326 (Colo. App. 1998).

2. On July 1, 2003 the Colorado Legislature substantially changed the law in regard to the liability of governmental entities and the drainage, flood control, and stormwater facilities that they own or maintain. Governmental entities on and after July 1, 2003 have complete governmental immunity in regard to the drainage, flood control, and stormwater facilities that they own or maintain. The law in Colorado however did not change in regard to other facilities that a governmental entity owns and operates. In regard to those other facilities, a governmental entity's liability is determined as if it is a private party. However, the amount of its liability is limited by the Colorado Governmental Immunity Act.

3. A natural watercourse may be used as a conduit or outlet for the drainage of lands, at least where the augmented flow will not tax the stream beyond its capacity and cause flooding of adjacent lands. Ambrosio v. Pearl-Mack Construction Co., 351 P.2d 803 (Colo. 1960).

4. Ditch corporations that own ditches owe a duty to those property owners through which their ditches pass to maintain their ditches using ordinary care so as to prevent damage to adjoining real property. Oliver v. Amity Mut. Irrigation Co., 994 P.2d 495 (Colo. App. 1999). Further, ditch owners are not required under the law to accept stormwater runoff that is result of development that occurs after the ditch was constructed. The ditch owner would have a legal claim based upon trespass as well as a claim based upon the fact that the ditch is not a natural drainage and most likely the increased flows will be deposited into the ditch in a manner or quantity to do more harm than formerly. Hankins v. Borland, 431 P.2d 1007 (Colo. 1967).

5. Construction or enlargement of jurisdictional dams or reservoirs is subject to approval by the Colorado State Engineer's Office, which, depending on the size of the dam and the hazard classification, may include requirements for spillways to pass up to the Extreme Storm Precipitation (ESP) event[1]. A "jurisdictional dam" is defined as a dam that impounds water above the elevation of the natural surface of the ground creating a reservoir that meets one of the following conditions:

   i. Has a capacity of more than 100 acre-feet;

   ii. Has a surface area exceeding 20 acres at the high waterline; or

   iii. Exceeds 10 feet in height measured vertically from the elevation of the lowest point of the natural surface of the ground where that point occurs along the longitudinal centerline of the dam up to the flow line crest of the emergency spillway of the dam.

   Rules 4 & 5 of the Department of Natural Resources, Division of Water Resources, Office of the State Engineer, Rules and Regulations for Dam Safety and Dam Construction, 2-CCR 402-1, Effective Date: January 1, 2007.

6. The boundaries of the floodplain should be accurately determined and based on a reasonable standard. Mallett v. Mamarooneck, 125 N.E. 2d 875 (N.Y. 1955).

7. Adoption of a floodplain regulation to regulate flood-prone areas is a valid exercise of police power and is not a taking as long as the regulation does not go beyond protection of the public's health, safety, morals, and welfare. Hermanson v. Board of County Commissioners of Fremont, 595 P.2d 694 (Colo. App. 1979).

8. The adoption by a municipality of floodplain ordinances to regulate flood-prone areas is a valid exercise of police power and is not a taking. Morrison v. City of Aurora, 745 P.2d 1042 (Colo. App. 1987).

9. A zoning ordinance is not unconstitutional because it prohibits a landowner from using or developing his land in the most profitable manner. It is not required that a landowner be permitted to make the best, maximum or most profitable use of his property. Baum v. City and County of Denver, 363 P.2d 688 (Colo. 1961) and Sundheim v. Board of County Commissioners of Douglas County, 904 P.2d 1337 (Colo. App. 1995).

10. The Colorado Governmental Immunity Act (CGIA), in addition to providing complete immunity to

[1] The ESP event represents the greatest depth of precipitation for a given duration that is physically possible over a drainage basin through the application of modern meteorological techniques, based on Colorado extreme storm data approved by the State Engineer.

governmental entities for the drainage, flood control, and stormwater facilities that they own or maintain, also does not require a governmental entity to upgrade, modernize, modify, or improve the design or construction of a facility, including but not limited to the drainage, flood control and stormwater facilities that it owns or maintains. This same protection does not include private parties.

11. A "dangerous condition" constitutes an unreasonable risk to the health or safety of the public, which is known to exist or which in the exercise of reasonable care should have been known to exist and which condition is proximately caused by the negligent act or omission of the public entity in constructing or maintaining such facility. 24-10-103 (1.3) C.R.S. However, a dangerous condition shall not exist solely because the design of any facility is inadequate. Again, this protection does not extend to private parties.

12. Under the CGIA, a governmental entity is not protected by immunity in regard to the operation and maintenance of any "public water facility" or "sanitation facility." 24-10-106 (f) C.R.S.

13. However, under the CGIA, a "public water facility" does not include a "public sanitation facility;" a natural watercourse even if dammed, channelized, or used for transporting domestic water supplies; a drainage, borrow, or irrigation ditch even if dammed, channelized, or containing stormwater runoff or discharge; or a curb and gutter system. 24-10103 (5.7) C.R.S.

14. Also, under the CGIA, a "public sanitation facility" does not include a "public water facility;" a natural watercourse even if dammed, channelized, or containing stormwater runoff, discharge from a storm sewer; a drainage, borrow, or irrigation ditch even if the ditch contains stormwater runoff or discharge from storm sewers; a curb and gutter system or other drainage, flood control, and stormwater facilities. 24-10103 (5.5) C.R.S. Therefore, a public entity will be immune from liability in regard to all drainage and flood control facilities that it designs, constructs and maintains. Again, this protection does not extend to private parties.

15. Under the CGIA, a public entity will not be liable for its failure to upgrade, modernize, modify, or improve the design or construction of a drainage or flood control facility or any other facility that it owns or maintains whether it knows of a deficiency or not or whether it is a dangerous condition or not. 24-10-103 (2.5) C.R.S. The Colorado Legislature in enacting this law found that governmental entities ". . . provide essential public services and functions and the increased legal liability from not having this type of statutory protection poses the danger of disrupting or making prohibitively expensive the provision of such services and functions."

16. The CGIA has not been challenged in court since its adoption in 2003 although courts have considered whether its application was meant by the Colorado Legislature to be retroactive. Therefore, it is uncertain if the CGIA would withstand a legal challenge. Regardless, governmental entities should, to the best of their ability, attempt to construct, operate, and maintain the drainage, flood control, and stormwater facilities that they own to the same standard that private parties are required to meet.

17. CGIA does not protect a public entity from a claim based upon inverse condemnation. Inverse condemnation is defined as the taking of private property for a public or private use, without compensation, by a governmental or public entity which has refused to exercise its eminent domain power.

18. In imposing conditions upon the granting of land-use approvals, no local government shall require an owner of private property to dedicate real property to the public or pay money to a public entity in an amount that is determined on an individual and discretionary basis, unless there is an essential nexus between the dedication or payment and a legitimate local government interest and the dedication or

payment is roughly proportional both in nature and extent to the impact of the proposed use or development of such property. This law does not apply to any legislatively formulated assessment, fee, or charge that is imposed on a broad class of property owners by a local government. 29-20-203 C.R.S.

19. Public entities that own dams or reservoirs are not subject to strict liability for damages caused by water escaping from their dams or reservoirs. Further, those public entities have no duty to ensure that waters released from an upstream reservoir because of a dam failure would be contained by their facilities or would bypass those facilities without augmentation. Kane v. Town of Estes Park, 786 P.2d 412 (Colo. 1990).

20. A professional engineer is required not only to serve the interests of his or her employer/client but is also required, as his or her primary obligation, to protect the safety, health, property, and welfare of the public. Rule I 2. of The Colorado Rules of Professional Conduct of the State Board of Registration for Professional Engineers and Professional Land Surveyors.

21. Where a municipality imposes a special fee upon owners of property for purposes of providing a service and where the fee is reasonably designed to defray the cost of the service provided by the municipality, such a fee is a valid form of governmental charge within the legislative authority of the municipality. Bloom v. City of Fort Collins, 784 P.2d 304 (Colo. 1989).

2.0 General Principles of Drainage Law

> Very little is gained if the same act which dries up one tract of land renders the adjoining tract twice as difficult to redeem. Livingston v. McDonald, 21 Iowa 160, 170 (1866).

2.1 Private Liability

Traditionally, courts have analyzed the legal relations between parties in drainage matters in terms of such property concepts as natural easements, rights, privileges, and servitudes but have based liability for interfering with surface waters on tort principles. See Kenyon and McClure *Interferences With Surface Waters*, 24 Minn. L. Rev. 891 (1940). Drainage and flood control problems attendant with increased urbanization, the trend in tort law toward shifting the burden of a loss to the best risk-bearer, and complete or partial reinstitution of governmental immunity by the legislature will continue to change the traditional rules that have governed legal relations between parties in drainage matters. These changes are reflected in the three basic rules relating to drainage of surface waters that have been applied over a period of time in the United States: the common enemy rule, the civil law rule (later to be called a "modified civil law rule"), and the reasonable use rule.

2.1.1 Common Enemy Rule

Under the common enemy rule, which is also referred to as the common law rule, surface water is regarded as a common enemy, which each property owner may fight off or control as he or she will or is able, either by retention, diversion, repulsion, or altered transmission. Thus, there is no cause of action even if some injury occurs. All jurisdictions originally following this harsh rule have either modified the rule or adopted the civil law rule or reasonable use rule. 5 *Water and Water Rights,* §§450.6, 451.2 (R.E. Clark ed. 1972).

2.1.2 Civil Law Rule

The civil law rule, or natural flow rule, places a natural easement or servitude upon the lower land for the drainage of surface water in its natural course, and the natural flow of the water cannot be obstructed by the servient owner to the detriment of the dominant owner. 5 *Water and Water Rights*, §452.2A (R.E. Clark ed. 1972). Most states following this rule, including Colorado, have modified the rule. Under the modified rule, the owner of upper lands has an easement over lower lands for drainage of surface waters, and natural drainage conditions can be altered by an upper proprietor provided the water is not sent down in a manner or quantity to do more harm than formerly. Hankins v. Borland, 163 Colo. 575, 431 P.2d 1007 (1967); H. Gordon Howard v. Cactus Hill Ranch Company, 529 P.2d 660 (1974); Hoff v. Ehrlich, 511 P.2d 523 (1973); but see Ambrosio v. Perl-Mack Construction Company, 143 Colo. 49, 351 P.2d 803 (1960) and Bittersweet Farms, Inc. v. Zimbelman, 976 P.2d 326 (Colo. App. 1998).

2.1.3 Reasonable Use Rule

Under the reasonable use rule, each property owner can legally make reasonable use of his land, even though the flow of surface waters is altered thereby and causes some harm to others. However, liability attaches when the harmful interference with the flow of surface water is "unreasonable." Whether a landowner's use is unreasonable is determined by a nuisance-type balancing test. The analysis involves three inquiries:

1. Was there reasonable necessity for the actor to alter the drainage to make use of his or her land?

2. Was the alteration done in a reasonable manner?

3. Does the utility of the actor's conduct reasonably outweigh the gravity of harm to others?

Restatement Torts, §§822-831, 833 (1939); *Restatement (Second) Torts*, §158, Illustration 5. Alaska, Hawaii, Kentucky, Massachusetts, Minnesota, New Hampshire, New Jersey, North Carolina, North Dakota, Ohio and Utah have adopted this rule. Some states have restricted their application of the rule to urban areas (South Dakota and Texas). In Pendegast v. Aiken, 236 S.E. 2d 787 (1977), the North Carolina Supreme Court traces the common law rule to the civil law rule to adoption by that court of the reasonable use rule, starting at page 793:

> It is no longer simply a matter of balancing the interests of individual landowners; the interests of society must be considered. On the whole the rigid solutions offered by the common enemy and civil law rules no longer provide an adequate vehicle by which drainage problems may be properly resolved.

2.2 Municipal Liability

A municipality is generally treated like a private party in regard to the determination of negligence in matters other than drainage and flood control . Harbison v. City of Hillsboro, 103 Ore. 257, 204 P. 613, 618 (1922); City of Golden v. Western Lumber and Pole Company, 60 Colo. 382, 154 P. 95 (1916) (a municipality undertaking a public improvement is liable like an individual for damage resulting from negligence or an omission of duty); City of Denver v. Rhodes, 9 Colo. 554, 13 P. 729 (1887). With regard to drainage and flood control improvements, however, the Colorado legislature has legislatively changed the law to provide for immunity of municipalities and other public entities. Since 2003, public entities have been immune from liability in regard to the construction and maintenance of natural watercourses even if dammed, channelized, or containing stormwater runoff, discharge from a storm sewer; a drainage, borrow, or irrigation ditch even if the ditch contains stormwater runoff or discharge from storm sewers; a curb and gutter system or other drainage, flood control, and stormwater facilities. Although these statutes seem to protect public entities from lawsuits in regard to damage to citizens from drainage and flood control facilities that were negligently designed, constructed, or maintained, the prudent approach in designing, constructing, and maintaining these facilities is to assume such immunity is not available to a public entity. In that way, public entities will always be protecting the best interests of its citizens. However, governmental immunity does not protect a public entity from a claim made in inverse condemnation for the taking of property rights without compensation.

In the case of Jorgenson v. City of Aurora, 767 P.2d 756 (Colo. App. 1988), the Colorado Court of Appeals held that given the constitutional genesis of a claim for inverse condemnation, and considering the nature of the right upon which this action is founded, a claim in inverse condemnation is not subject to the Governmental Immunity Act.

It is becoming more and more common for private developers to design, construct, and maintain drainage and flood control facilities. Obviously, the governmental immunity laws do not apply to them.

2.2.1 Planning Drainage Improvements

As a general rule, municipalities are under no legal duty to construct drainage improvements unless public improvements necessitate drainage—as in those situations in which street grading and paving or construction of schools accelerates or alters storm runoff. Denver v. Mason, 88 Colo. 294, 295 P. 788 (1931); Denver v. Capelli, 4 Colo. 25, 34 Am. Rep. 62 (1877); Daniels v. City of Denver, 2 Colo. 669 (1875). This is because statutory provisions authorizing municipal drainage improvements and flood control are generally written in non-mandatory language. Thus, absent mandatory statutory language imposing a duty on municipalities or judicial imposition of an implied duty to avoid or abate injuries, municipalities are not liable for failing to provide drainage or flood control.

As noted earlier, public entities are immune from liability for the design, construction, and maintenance of drainage and flood control facilities unless a claim is based upon inverse condemnation. Therefore, those same public entities would also be immune from liability for the planning of drainage improvements.

In the case of Larry H. Miller Corporation-Denver v. Urban Drainage and Flood Control District, *et.al.* 64 P.3d 941 (Colo. App. 203), Urban Drainage and Flood Control District (UDFCD) was sued by a property owner (Miller) who was damaged by severe flooding on its property causing damages to motor vehicles exceeding $525,000. One of the Miller's claims was that UDFCD had produced a master plan including Miller's property which was intended to analyze the hydraulic, hydrologic, and existing stormwater systems' capacity and to develop alternative plans to handle stormwater flows to minimize safety hazards and damage resulting from flooding of streets and private property and UDFCD did not follow through

and construct the recommended drainage and flood control improvements. The Colorado Court of Appeals held that there was no requirement that UDFCD own, operate, or maintain any drainage facilities or to acquire property to protect it from flooding. Therefore, in most cases, unless there is a specific statutory requirement to act, public entities (even when aware of a potential problem) are not required to expend funds to remedy that problem. The Court's reasoning being that, in this case, UDFCD was in the best position to allocate its resources.

2.2.2 Construction, Maintenance, and Repair of Drainage Improvements

Although municipalities or other public entities can no longer be held legally responsible for damage caused to the public by their negligence, other legal theories have been used to impose liability on municipalities for faulty construction and maintenance of drainage improvements. Thus, a municipality may incur liability for trespass, Barberton v. Miksch, 128 Ohio St. 169, 190 N.E. 387 (1934) (casting water upon the land of another by seepage or percolation resulting from construction and maintenance of a reservoir was a trespass by the municipality); an unconstitutional taking, Mosley v. City of Lorain, 43 Ohio St. 2d 334, 358 N.E. 2d 596 (1976) (the city had effectively appropriated the plaintiff's property by constructing a storm sewer system which channeled a greater volume of water into the creek than the creek could reasonably be expected to handle without flooding); taking, Lucas v. Carney, 167 Ohio St. 416, 149 N.E. 2d (1958) (construction of a public improvement on county property, which greatly increased the amount and force of surface water that flowed onto the plaintiff's property, overflowing and inundating it, raised a claim of pro tanto appropriation); or nuisance, Mansfield v. Bolleet, 65 Ohio St. 451, 63 N.E. 8.6 (1902) (a municipality is liable if it causes drainage to be emptied into a natural watercourse and substantially damages a downstream landowner). Even in the absence of negligence, nuisance, trespass, or taking, the evolving doctrine of inverse condemnation is being used to permit landowners to obtain compensation from a municipality where storm runoff from municipal projects is diverted across another's land on the theory that the city has taken a drainage easement. Thus, like an easement for noise emanating from the municipal airport, physical entry by the public entity or statutory allowance of compensatory damages is not required in order for landowners to recover damages.

In several Colorado cases, however, municipalities have not incurred liability for faulty construction where they are found to be upstream proprietors with a natural easement for drainage—even when water is sent down in a manner or quantity to do more harm than formerly. City of Englewood v. Linkenheil, 362 P.2d 186 (1961) (the city's action in channeling water by a system of drains, catch basins, intakes, and pipes, from a higher place to a place contiguous to the land of the plaintiff, which was a natural drainage area, so as to overflow onto the land of plaintiff did not constitute a taking of property without just compensation); City and County of Denver v. Stanley Aviation Corporation, 143 Colo. 182, 352 P.2d 291 (1960) (plaintiff could not recover from the city for damage caused by flood waters which backed onto lower land on its theory that the city had been negligent or failed to use due care in installing a pipe adequate to carry the waters); Aicher v. Denver, 10 Colo. App. 413, 52 P. 86 (1897) (the city was not found liable for damage where street grade was changed, trolley tracks were permitted in a street, and a culvert was built too small, but the landowner was declared to be in the unfortunate position of having built below the grade of the street).

The CGIA provides in 24-10-103 (1) C.R.S. that maintenance does not include any duty to upgrade, modernize, modify, or improve the design or construction of a facility. Therefore, a public entity, under this statute, would not be found to have failed to maintain a facility if it failed to perform one or more of these enumerated actions. However, if a public entity fails to maintain a facility other than the excluded enumerated actions above, such failure could subject that entity to a claim that such failure was negligent, and such entity would not be protected by the CGIA.

2.2.3 Summary

In general, in the absence of negligence, a municipality will not be held liable for increased runoff occasioned by the necessary and desirable construction of drains and sewers. Denver v. Rhodes, 9 Colo. 554, 13 P. 729 (1887). Nor will a municipality be held liable for damages caused by overflow of its sewers or drains occasioned by extraordinary, unforeseeable rains or floods. 18 McQuillan, *Municipal Corporations*, §53.124 (3rd ed. 1971).

Municipal liability may attach when a claim is made alleging inverse condemnation or the taking of property rights without compensation and where a municipality:

1. Collects surface water and casts it in a body onto private property where it did not formerly flow.

2. Diverts, by means of artificial drains, surface water from the course it would otherwise have taken and casts it in a body large enough to do substantial injury on private land, where, but for the artificial drain, it would not go.

3. Fills up, dams back, or otherwise diverts a stream of running water so that it overflows its banks and flows on the land of another. A municipality is also liable if it fails to provide a proper outlet for drainage improvements constructed to divert surface waters or if it fails to exercise ordinary care in the maintenance and repair of drainage improvements.

This latter liability attaches when it is determined that a municipality has not exercised a reasonable degree of watchfulness in ascertaining the condition of a drainage system to prevent deterioration or obstruction. 13 McQuillan, *Municipal Corporations*, §37.254 (3rd ed. 1971). See, also, Malvernia v. City of Trinidad, 123 Colo. 394, 229 P.2d 945 (1951).

Thus, the best rule to follow in planning for the construction of drainage improvements, whether following the natural watercourse or artificially draining surface water, is that a municipality is liable if it actively injures private property as a result of improvements made to handle surface water. A municipality in Colorado appears to be in a much stronger position if it can establish that the improvement followed natural drainage patterns. Drainage District v. Auckland, 83 Colo. 510, 267 P. 605 (1928); City of Englewood v. Linkenheil, 362 P.2d 186 4961); City of Boulder v. Boulder and White Rock Ditch and Reservoir Company, 73 Colo. 426, 216 P. 553 (1923). See Kenworthy, "Urban Drainage: Aspects of Public and Private Liability," July-August 1962, *DICTA*, p. 197; Shoemaker, "An Engineering-Legal Solution to Urban Drainage Problems," 45 *Denver Law Journal* 381 (1968).

2.3 Municipal Liability for Acts of Others

2.3.1 Acts or Omissions of Municipal Officers, Agents, or Employees

The general rule is that a municipality is not liable under the doctrine of respondent superior for the acts of officers, agents, or employees that are governmental in nature but is liable for negligent acts of its agents in the performance of duties relating to proprietary or private corporate purposes of the city. Denver v. Madison, 142 Colo. 1, 351 P.2d 826 (1960). The construction, maintenance, and repair of drainage improvements have been regarded as proprietary or corporate functions. Denver v. Maurer, 47 Colo. 209, 106 P. 875 (1910). Although the governmental-proprietary distinction has been abolished by statute in Colorado, the distinction apparently still applies whenever the injury arises from the act, or failure to act, of a public employee who would be, "or heretofore has been personally immune from liability." 24-10-106 C.R.S. Thus, a municipality may be held liable for the acts of its officers, agents, or employees for injuries resulting from the design, construction or maintenance of drainage and flood control facilities when the claim is based on inverse condemnation for the taking of property rights without compensation.

Before an individual can recover damages from a public entity for injuries caused by the public entity or one of its employees, the CGIA requires written notice to the public entity involved within 180 days after the date of discovery of the injury. Otherwise, failure to notify is a complete defense to a personal injury action against a municipality. 24-10-109 C.R.S. Kristensen v. Jones, 575 F.2d 854 (1978).

2.3.2 Municipal Liability for Acts of Developers

Unless an ordinance or statute imposes a duty on a municipality to prevent or protect land from surface water drainage, a municipality will not incur liability for wrongfully issuing building permits, failing to enforce an ordinance, or approving defective subdivision plans. Breiner v. C & P Homebuilder's Inc., 536 F.2d 27 (3rd Cir. 1976), reversing the District Court. (In a suit by landowners in an adjacent township against a borough, its engineers, and subdivision developer for damages caused by increased flow of surface water from development where the borough approved a subdivision plan which did not provide drainage facilities and issued building permits, the borough was not liable because it owed no duty to landowners outside its boundaries. However, the developer was held liable.)

One state court, however, has held that a municipality is liable for damages where the municipality has furnished building permits to a contractor for development of an industrial complex which benefited the village financially but also diminished surface area available for drainage of water, causing flooding of neighboring servient estates. Myotte v. Village of Mayfield, 375 N.E.2d 816 (1977). In Myotte, the village's liability was based on the following reasoning:

> To require the developer to pick up the cost of flood prevention by requiring him to acquire land along stream margins for widening or deepening to accommodate accelerated flow, would subject him to possible overreaching by riparian owners. The developer has no power of eminent domain. Municipalities do have powers of condemnation. Accordingly, as an advantaged party with the power to protect itself from crisis pricing, it seems reasonable and just that the municipality should either enlarge the stream to accommodate water accelerated from permitted improvements that enrich it or pay the consequences. Myotte, supra at 820. (Day, J. concurring.). See also, Armstrong v. Francis Corporation, 20 N.J. 320, 120 A.2d 4 (1956); Sheffet v. County of Los Angeles, 3 Cal. App. 3d 720 (1970); Powers, et al., County of Clark and Clark County Flood Control District, District Court, State of Nevada (No. A 125197) (1978).

There is a trend toward imposing a greater burden or responsibility on municipalities for the drainage consequences of urban development. See Wood Brothers Homes, Inc. v. City of Colorado Springs, 568 P.2d 487 (1977) (where the city abused its discretion by not granting variance and by assessing the entire cost of a major drainage channel on the developer, where the area to be served by the major drainage channel already suffered from occasional flooding and needed an expanded drainage facility whether the property was developed or not).

2.4 Personal Liability of Municipal Officers, Agents, and Employees

An injured person always has a remedy against the original tort feasor even if no recovery may be had from the municipality for acts of its officers, agents, or employees in discharge of governmental functions. Denver v. Madison, 142 Colo. 1, 351 P.2d 826 (1960). Thus, public employees generally have been personally liable for injuries caused by their negligent actions within the scope of employment, even when the defense of sovereign immunity was available to their employers. Antonpoulos v. Town of Telluride, 187 Colo. 392, 532 P.2d 346 (1975); Liber v. Flor, 143 Colo. 205, 353 P.2d 590 (1960). Since an injured person's right to sue the negligent employee of an immune entity derives from the common law, the Colorado Supreme Court will not infer legislative abrogation of that right absent clear legislative intent. Thus, the CGIA is only directed toward liability of public entities. Kristensen v. Jones, 574 P.2d 854 (1978) (a bus driver for the regional transportation district was found personally liable for injuries sustained in a collision with the district's bus, and written notice was not a condition precedent to a suit against a public employee in his or her individual capacity).

The CGIA provides both for the defense of any governmental employee who is sued individually as a result of the employee's acts during the performance of his or her duties as well as the payment of any judgment or settlement. The act provides in part that a public entity shall be liable for the payment of all judgments and settlements of claims against any of its public employees where the claim against the public employee arises out of injuries sustained from an act or omission of such employee occurring during the performance of his or her duties and within the scope of employment, except where such act or omission is willful and wanton or where sovereign immunity bars the action against the public entity (24-10-110 (b)(l) C.R.S.).

Therefore, it is possible for an employee to be personally liable for a negligent act and the public entity to escape liability. Such a situation would arise when the claimant or employee fails to give proper notice to the public entity, thus providing that entity with the defense of lack of jurisdiction against it. However, the public employee would have no such defense.

3.0 Drainage Improvements by a Local Government

> In an era of increasing urbanization and suburbanization, drainage of surface water most often becomes a subordinate feature of the more general problem of proper land use—a problem acutely sensitive to social change. Pendergast v. Arkin, 236 S.E. 2d 787, 796 N. Carolina.

3.1 Constitutional Power

A municipality's inherent police powers enable it to enact ordinances that serve the public's health, safety, morals, or general welfare. Ordinances addressing drainage problems are clearly a proper exercise of a municipality's police powers. Wood Brother's Homes, Inc. v. City of Colorado Springs, 568 P.2d 487, 490 (1977). Hutchinson v. Valdosta, 227 U.S. 303, 308 (1913).

3.2 Statutory Power

3.2.1 Municipal Statues

Municipal Powers—Public Property and Improvements
31-15-701, 31-15-714 C.R.S. The statute grants municipalities the power to establish, improve, and regulate such improvements as streets and sidewalks, water and water works, sewers and sewer systems, and water pollution controls. In addition, a municipality may, among other powers, "deepen, widen, cover, wall, alter or change the channel of watercourses." 31-15-711 (1) (a) C.R.S.

Public Improvements—Special Improvement Districts in Municipalities
31-25-501, 31-25-540 C.R.S. The statute authorizes municipalities to construct local improvements and assess the cost of the improvements wholly or in part upon property specially benefited by such improvements. By ordinance, a municipality may order construction of district sewers for storm drainage in districts called storm sewer districts.

Public Improvements—Improvement Districts in Municipalities
31-25-601, 31-25-630 C.R.S. The statute authorizes municipalities to establish improvement districts as taxing units for the purpose of constructing or installing public improvements. The organization of districts is initiated by a petition filed by a majority of registered electors of the municipality who own real or personal property in the district.

Sewer and Water Systems—Municipalities
31-35-401, 31-35-417 C.R.S. The statute authorizes municipalities to operate, maintain, and finance water and sewage facilities for the benefit of users within and without their territorial boundaries. Sewerage facilities are defined as "any one or more of the various devices used in the collection, treatment, or disposition of sewage or industrial wastes of a liquid nature or storm, flood, or surface drainage waters...." 31-35-491(6) C.R.S.

3.2.2 County Statutes

Public Improvements—Sewer and Water Systems
30-20-401, 30-20-422 C.R.S. The statute authorizes county construction, maintenance, improvement and financing of water and sewerage facilities for the county's own use and for the use of the public and private consumers and users within and without the county's territorial limits.

County Public Improvement Districts
30-20-501, 30-20-531 C.R.S. The statute authorizes creation of public improvement districts within any county as taxing units for purposes of constructing, installing, or acquiring any public improvement. 30-20-513 C.R.S. lists special benefits for purposes of assessing improvements within a public improvement district, particularly with respect to storm sewer drainage and drainage improvements to carry off surface waters.

Public Improvements—Local Improvement Districts—Counties
30-20-601, 30-20-626 C.R.S. The statute authorizes a county by resolution to construct local improvements and assess costs thereof wholly or in part upon property specially benefited by such improvements.

Flood Control—Control of Stream Flow
30-30-101, 30-28-105 C.R.S. The statute authorizes the board of county commissioners of each county for flood control purposes only:

> ...to remove or cause to be removed any obstruction to the channel of any natural stream which causes a flood hazard, and for such purpose only the board of county commissioners shall have a right of access to any such natural stream, which access shall be accomplished through existing gates and lanes, if possible. Such authority includes the right to modify existing diversion or storage facilities at no expense to the diverter of a water right, but it shall in no way alter or diminish the quality or quantity of water entitled to be received under any vested water right. 30-30-102 (1) C.R.S.

Conservancy Law—Flood Control
37-1-101, 37-8-101 C.R.S. The statute authorizes the district court for any county to establish conservancy districts for any of the following purposes:

> Preventing floods; regulating stream channels by changing, widening, and deepening the same; regulating the flow of streams; diverting, controlling, or in whole or in part eliminating watercourses; protecting public and private property from inundation…

Drainage Districts
37-20-101, 37-33-109 C.R.S. The statute authorizes owners of agricultural lands susceptible to drainage by the same general system of works to petition the board of county commissioners for the organization of a drainage district.

3.2.3 State Statutes

Colorado Land Use Act
24-65-101, 24-65-105 C.R.S. The statute establishes a nine-member Colorado land use commission. Among other powers, the commission has authority to assist counties and municipalities in developing guidelines for developing land uses and construction controls within designated floodways.

Drainage of State Lands
37-30-101, 37-30-105 C.R.S. The statute authorizes the state board of land commissioners to make contracts with any person, corporation, association, or drainage district to provide drainage of state lands.

Water Conservation Board of Colorado
37-61-101, 37-60-123 C.R.S. The statute creates a 13-member state water conservation board for purposes of water conservation and flood prevention. An important duty of this board is to "designate and approve storm or floodwater runoff channels or basins, and to make such designations available to

legislative bodies of cities and incorporated towns, and counties of this state." 30-60-123 C.R.S.

State Canals and Reservoirs
37-88-101, 37-88-109 C.R.S. The statute authorizes the Department of Corrections to locate, acquire, and construct ditches, canals, reservoirs, and feeders for irrigating and domestic purposes for the use of the State of Colorado. The Board of County Commissioners have charge and control of any state reservoir in their county including the obligation to maintain and keep said reservoir in good condition at the county's expense. In addition, the county in which the state reservoir is located is liable for any damages resulting from breakage of the dams or water discharges there from.

Regulatory Impairment of Property Rights
29-20-201 C.R.S. This law became effective July 1, 1999. One of the legislative declarations of the act is that "The general assembly further finds and declares that an individual private property owner should not be required, under the guise of police power regulation of the use and development of property, to bear burdens for the public good that should more properly be borne by the public at large." The main thrust of the act is contained in 29-20-203 (1) C.R.S., which reads as follows:

> In imposing conditions upon the granting of land-use approvals, no local government shall require an owner of private property to dedicate real property to the public, or pay money to a public entity in an amount that is determined on an individual and discretionary basis, unless there is an essential nexus between the dedication or payment and a legitimate local government interest, and the dedication or payment is roughly proportional both in nature and extent to the impact of the proposed use or development of such property. This section shall not apply to any legislatively formulated assessment, fee, or charge that is imposed on a broad class of property owners by local government.

The act goes on to prescribe the remedies available to a private property owner who believes his or her rights have been violated under the act. However, unlike most litigation, it is the burden of the local government and not the plaintiff "to establish, based upon substantial evidence appearing in the record" that the dedication or payment required by the local government is roughly proportional to the impact of the proposed use of the subject property.

Therefore, the Colorado legislature has now established a standard that is consistent with the leading case law in this area to assist local governments with reaching a safe harbor when imposing conditions on development. The concepts are fairly simple. First, the conditions imposed have to have some causal relationship with the impact of the development and, second, those conditions must be "roughly proportional" to the impact of the development. However, it should be noted that these restrictions relate only to those instances where the local government is negotiating individually with a developer as to what conditions will be imposed by the local government. The act does provide that, if the local government is legislatively imposing conditions for development on a broad class of property owners, the "essential nexus" and "roughly proportional" requirements of the act do not apply to those legislatively imposed conditions.

Intergovernmental Relationships
29-1-201 C.R.S. In 1974, Section 2 of Article XI of the state constitution was amended to permit and encourage governments to make the most efficient and effective use of their powers and responsibilities by cooperating and contracting with other governments. 29-1-203 C.R.S. provides more detail in regard to how that cooperation is to be carried out. It reads in part as follows:

> Governments may cooperate or contract with one another to provide any function, service, or facility lawfully authorized to each of the cooperating or contracting units, including the sharing of costs, the imposition of taxes, or the incurring of debt, only if such cooperation or contracts are authorized by each party thereto with the approval of its legislative body or other authority having the power to so approve.

3.2.4 Urban Drainage and Flood Control Act

32-11-101 C.R.S., et. seq., established the Urban Drainage and Flood Control District (UDFCD), including all of the City and County of Denver and the urbanized and urbanizing portions of Adams, Arapahoe, Boulder, Broomfield, Douglas, and Jefferson Counties. A twenty-three member board of directors, comprised of twenty-one elected officials and two professional engineers, is given the power to (1) plan solutions to drainage and flood control problems (with an authorized mill levy of 0.1 mill); (2) construct drainage and flood control improvements (with an authorized mill levy of 0.4 mill); (3) maintain such improvements and other natural drainageways in UDFCD (with an authorized mill levy of 0.4 mill); and (4) construct drainage and flood control improvements in and adjacent to the South Platte River (with an authorized mill levy of 0.1 mill). The board also has the power to adopt and enforce a floodplain regulation.

3.2.5 Drainage Authority

29-1-204.2 C.R.S. et. seq. permits any combination of municipalities, special districts, or other political subdivisions of the State of Colorado to own and operate drainage facilities and, by contract with each other, to establish a drainage authority to be used by such contracting parties to effect development of drainage facilities in whole or in part for the benefit of the inhabitants of such contracting parties or others.

4.0 Financing Drainage Improvements

> The ability of one owner to develop land, install impervious surfaces, alter drainage paths, and accelerate runoff onto other properties involves more than issues of what rights and relief should be accorded neighboring property owners. Urbanization may double or triple the peak flows of 5- and 10-year floods. Lands far downstream may be severely affected by the cumulative impact of unplanned and unregulated changes in drainage patterns due to urban clearance, grading, and development. Increasingly, the costs of uncontrolled drainage modifications and stormwater management have fallen on the state and federal budgets. Westen, Gone With the Water—Drainage Rights and Storm Water Management in Pennsylvania, 22 Vill. L. Rev. 901, 902 (1976-77).

4.1 Capital Improvement

Resources from the current budget, usually derived from sales, property, and income taxes, can be used to finance drainage improvements. Since the cost is paid from the "general fund" or "capital improvement fund" and no specific property tax is levied, the financing is relatively simple.

4.2 Local Improvement

Financing for drainage improvements through local improvements or as part of a general bond issue requires that all property be assessed on a valuation basis. Since a majority of all taxpaying electors must approve the decision, the success of this method usually turns on how well the facts (needs) have been prepared and how well a plan has been developed.

4.3 Drainage / Stormwater Authority

Drainage authorities also known as stormwater authorities have been created by either single governmental entities or combinations thereof in order to raise funds and use those funds for the design, construction and maintenance of drainage and flood control facilities. Often these authorities fund these improvements by assessing a fee on real property based in part upon the impervious area of each property and whether it is a residence or a commercial property. For example, a significant number of utilities base fees on both total site area and total impervious area. Others utilize "intensity of development" factors. Finally, many others include sophisticated programs of credits and adjustments, depending on site-specific factors. The majority of these authorities have become highly successful since they do not rely on general funds from the forming governments but, instead generate their own source of revenue that does not impact the governmental entities taxing authority. In Colorado, as a result of Colorado statutory law, these drainage and stormwater authorities can be created and funded by the assessment of fees without a vote of the citizens within the boundaries of the authority.

4.3 Special Improvement

When drainage improvements are financed as special improvements, the property assessed must be specially benefited. In Colorado, benefits, for purposes of special assessments, are defined in several statutory sections. (See 30-20-513, 30-20-606, 31-25-507, and 37-23-101.5 C.R.S.). For example, 37-23-101.5 C.R.S. provides:

> Determination of special benefits—factors considered. (1) The term 'benefit,' for the purposes of assessing a particular property within a drainage system improvement district, includes, but is not limited to, the following: (a) any increase in the market value of the property; (b) the provision for accepting the burden from specific dominant

> property for discharging surface water onto servient property in a manner or quantity greater than would naturally flow because the dominant owner made some of his property impermeable; (c) any adaptability of property to a superior or more profitable use; (d) any alleviation of health and sanitation hazards accruing to particular property or accruing to public property in the improvement district, if the provision of health and sanitation is paid for wholly or partially out of funds derived from taxation of property owners of the improvement district; (e) any reduction in the maintenance costs of particular property or of public property in the improvement district, if the maintenance of the public property is paid for wholly or partially out of funds derived from taxation of property owners of the improvement district; (f) any increase in convenience or reduction in inconvenience accruing to particular property owners, including the facilitation of access to and travel over streets, roads, and highways; (g) recreational improvements accruing to particular property owners as a direct result of drainage improvement.

This statute was adopted by the Colorado legislature to define "benefits," a term previously defined only by courts. See Shoemaker, "What Constitutes 'Benefits' for Urban Drainage Projects," 51 *Denver L. Journal* 551 (1974).

A special assessment for a local improvement must specifically benefit or enhance the value of the premises assessed in an amount at least equal to the burden imposed. Bloom v. City of Fort Collins, 784 P.2d 304 (Colo. 1989). Although a benefit to the premises assessed must at least be equal to the burden imposed, the standard of apportionment of local improvement costs to benefits is not one of absolute equality, but one of reasonable approximation. Satter v. City of Littleton, 185 Colo. 90, 522 P.2d 95 (1974). A presumption of validity inheres in a city council's determination that benefits specifically accruing to properties equal or exceed assessments thereon. Satter, supra. Further, a determination of special benefits and assessments is left to the discretion of municipal authorities, and their determination is conclusive in the courts unless it is fraudulent or unreasonable. Orchard Court Development Co. v. City of Boulder, 182 Colo. 361, 513 P.2d 199 (1973). A determination of no benefit in an eminent domain proceeding does not preclude a subsequent special assessment providing a landowner's property benefited from construction of the improvement. City of Englewood v. Weist, 184 Colo. 325, 520 P.2d 120 (1974). See, also, Denver v. Greenspoon, 140 Colo. 402, 344 P.2d 679 (1959); Town of Fort Lupton v. Union Pacific R.R. Co., 156 Colo. 352, 399 P.2d 248 (1965); Houch v. Little River District, 239 U.S. 254 (1915); and Miller and Lux v. Sacramento Drainage District, 256 U.S. 129 (1921).

4.4 Service Charge

UDFCD can charge service fees for the use of its facilities or services and thereby finance its improvements. 32-11-217 (l)(e), 32-11-306 C.R.S. provides:

> Such service charges may be charged to and collected in advance or otherwise by UDFCD at any time or from time to time from any person owning real property within UDFCD or from any occupant of such property which directly or indirectly is, has been, or will be connected with the drainage and flood control system of UDFCD or from which or on which originates or has originated rainfall, other surface and subsurface drainage, and storm and flood waters (or any combination thereof) which have entered or may enter such system, and such owner or occupant of any such real property shall be liable for and shall pay such service charges to UDFCD at the time when and place where such service charges are due and payable.

Storm and flood control facilities fall within the definition of "sewerage facilities" defined in 31-35-401 (6) C.R.S; 31-35-402 (1) C.R.S. states:

> In addition to the powers which it may now have, any municipality, without any election of the taxpaying or qualified electors thereof, has power under this part for:
>
> (f) to prescribe, revise and collect in advance or otherwise, from any consumer or any owner or occupant of any real property connected therewith or receiving service therefrom rates, fees, tolls, and charges or any combination thereof for the services furnished by, or the direct or indirect connection with, or the use of, or any commodity from such water facilities or sewerage facilities or both...

A service charge is neither a tax nor a special assessment but is a fee for the sole purpose of defraying the cost of establishing and maintaining a storm drainage and flood control utility. Western Heights Land Corp. v. City of Fort Collins, 146 Colo. 464, 362 P.2d 155 (1961). See, also, City of Aurora v. Bogue, 176 Colo. 198, 4-9 P.2d 1295 (1971); Brownbriar Enterprises v. City and County of Denver, 177 Colo. 198, 493 P.2d 352 (1972); and City of Boulder v. Arnold, 978 P.2d 149 (Colo. App. 1976) which upheld the City of Boulder's flood control fee. Counties in Colorado have similar powers pursuant to 30-20-402 (1) C.R.S.

4.5 Developer's Cost

A county planning commission or the board of adjustment of any county may condition any portion of a zoning resolution, or any amendments or exceptions thereto, upon "the preservation, improvement, or construction of any storm or floodwater runoff channel designated and approved by the Colorado Water Conservation Board." 30-28-111 (2) C.R.S.

Every Colorado County is required to have a planning commission to develop, adopt and enforce subdivision regulations. Among the provisions that the board of county commissioners must include in the county's regulations are those requiring developers to submit:

1. A plat and other documentation showing the layout or plan of development, including, where applicable, the following information:

    i. Estimated construction cost and proposed method of financing of the streets and related facilities, water distribution system, sewage collection system, storm drainage facilities, and such other utilities as may be required of the developer by the county.

    ii. Maps and plans for facilities to prevent stormwater in excess of historic runoff caused by the proposed subdivision from entering, damaging, or being carried by conduits, water supply ditches and appurtenant structures, and other storm drainage facilities. 30-28-133 (3)(c) C.R.S. Although Colorado law does not require it, in certain instances the maps and plans for facilities are required to include storage, treatment, and conveyance facilities for the total runoff from the proposed subdivision.

In addition, subdivision regulations must include provisions governing standards and technical procedures applicable to storm drainage plans and related designs, in order to ensure proper drainage ways, which may require, in the opinion of the board of county commissioners, detention facilities which may be dedicated to the county or the public, as are deemed necessary to control, as nearly as possible, stormwaters generated exclusively within a subdivision from a one-hundred year storm which are in excess of the historic runoff volume of stormwater from the same land area in its undeveloped and unimproved condition. 30-28-133 (4)(b) C.R.S.

The United States Supreme Court in 1987 issued its opinion in the case of Nollan v. California Coastal Comm. 107 S.Ct. 3141 (1987). This was the first United States Supreme Court case to discuss exactions

imposed upon developers by local governments. The Court in Nollan held that the Coastal Commission's requirement that conditioning the granting of a rebuilding permit upon the landowner dedicating an easement that would allow the public to pass across the landowner's beach was an unconstitutional taking under the just compensation clause of the Fifth Amendment. The reasoning of the Court was that the requirement of the grant of the easement had no relationship to the request of the landowner for a rebuilding permit nor was it related to the impact of the issuance of that permit. The Court thus introduced the essential nexus test in regard to governmental exactions in exchange for building permits. In other words, the exaction by the government must have a relationship to the impact of the requested development. Although initially the Nollan case was thought to apply to both exactions of interest in land by government as well as the assessment of fees, subsequent cases have held that Nollan is only applicable to exactions and not fees.

In 1994, the United States Supreme Court in the case of Dolan v. City of Tigard 114 S.Ct. 2309 (1994) considered a case which involved drainage and exactions by the city in the form of dedication of property lying within the 100 year floodplain as well as an additional 15 feet as a pedestrian/bicycle pathway in order to obtain a permit to develop a site within the city. The U.S. Supreme Court added a second consideration to the one already contained in the Nollan case. The Court held that "we must first determine whether the 'essential nexus' exists between the legitimate state interests and the permit condition exacted by the city. If we find that a nexus exists, we must then decide the required degree of connection between the exactions and the projected impact of the proposed development." The Court went on to hold:

> We think a term such as "rough proportionality" best encapsulates what we hold to be the requirement of the Fifth Amendment. No precise mathematical calculation is required, but the city must make some sort of individualized determination that the required dedication is related both in nature and extent to the impact of the proposed development.

This case too was thought initially to apply to both exactions in land by government as well as the assessment of fees. Again, subsequent cases limited the application of the Dolan case to exactions and not fees.

Subsequent to these cases, the Colorado Legislature enacted a statute codifying the requirements of Nollan and Dolan. See Section 3.2.3 *Regulatory Impairment of Property Rights*.

The "Local Government Land Use Control Enabling Act" C.R.S. § 29-20-104.5 C.R.S. became law in 2001 and its focus was on impact fees charged by local governments. The most important portion of the statute is set forth below.

> (1) Pursuant to the authority granted in section 29-20-104 (1) (g) and as a condition of issuance of a development permit, a local government may impose an impact fee or other similar development charge to fund expenditures by such local government on capital facilities needed to serve new development. No impact fee or other similar development charge shall be imposed except pursuant to a schedule that is:
>
> (a) Legislatively adopted;
>
> (b) Generally applicable to a broad class of property; and
>
> (c) Intended to defray the projected impacts on capital facilities caused by proposed development.

(2) A local government shall quantify the reasonable impacts of proposed development on existing capital facilities and establish the impact fee or development charge at a level no greater than necessary to defray such impacts directly related to proposed development. No impact fee or other similar development charge shall be imposed to remedy any deficiency in capital facilities that exists without regard to the proposed development.

(3) Any schedule of impact fees or other similar development charges adopted by a local government pursuant to this section shall include provisions to ensure that no individual landowner is required to provide any site specific dedication or improvement to meet the same need for capital facilities for which the impact fee or other similar development charge is imposed.

(4) As used in this section, the term "capital facility" means any improvement or facility that:

(a) Is directly related to any service that a local government is authorized to provide;

(b) Has an estimated useful life of five years or longer; and

(c) Is required by the charter or general policy of a local government pursuant to a resolution or ordinance.

The "Local Government Land Use Control Enabling Act" restates many of the criteria for the imposition of fees by local governments, in regard to obtaining land-use approvals, which are discussed above. However, it also adds a number of other criteria that need to be met in order to not violate the statute, including the following:

1. The impact fee must be limited to impacts on capital facilities by the proposed development.
2. The local government must quantify the reasonable impacts that are directly related to the proposed development and charge a fee no greater than necessary to defray those impacts.
3. No impact fee shall be imposed to remedy any deficiency in capital facilities that exists without regard to the proposed development.
4. Both an impact fee and a site specific dedication may not be required to meet the same need for capital facilities.
5. A capital facility is defined as having a useful life of five years or longer.

The above is the general framework and legal authority that should be considered when attempting to comply with applicable statutory law and case law addressing the constitutional questions surrounding the imposition of a drainage basin fee.

Developers may be charged for general costs of drainage infrastructure required due to new development within and outside of the basin in which they are developing. However, in order to do so, it must be established that the impact fee is no greater than necessary to defray the cost of the impacts of that specific development. As long as an impact can be established outside of a drainage basin then an impact fee may include those impacts as well as those inside the drainage basin in which the development is located.

Developers may be charged the costs of drainage infrastructure associated with the runoff created by development if, again, those impact fees have been quantified by the local government and those fees directly relate to the impact of a specific development. The method of calculation of those fees only has to have a rational foundation and does not have to be the best, if there is a rational reason for the selection of the method of calculation.

Developers can also be charged for impact fees that contain a calculation for use of existing local government's stormwater systems to accommodate water originating from specific developments. Again, such impact fees must be no greater than necessary to defray the costs of the impacts of that specific development. In addition, the impact fee shall not be imposed to remedy any deficiency in capital facilities that exists without regard to the proposed development. The rationale for permitting an impact fee for use of existing facilities is that the increased runoff diminishes the capacity of the existing facilities which eventually will require additional improvements to address that diminished capacity.

The selection of whether the drainage fee will be uniform throughout the local government's boundary, by groups of basins with similar characteristics or by individual basins, is dictated by each of the requirements to meet the legal criteria set forth above as well as the ease in which the fee can be practically determined and implemented. The questions that need to be answered in the affirmative for one of these options to be selected are as follows:

1. Is there an essential nexus between the impact fee and the area grouping that the fee will apply to?
2. Is the impact fee roughly proportional to the needs of the grouping selected?
3. Does the fee defray impacts directly related to a proposed development?
4. Does the fee not remedy past deficiencies in capital facilities? and
5. Is there a rational foundation for the selection of the particular grouping?

In conclusion, based upon both case law from the U.S. Supreme Court and the Colorado courts as well as Colorado statutory law, there exists some protection for local governments in regard to drainage impact fees if such fees are legislatively enacted and there is no opportunity for local government to individually negotiate an extraction in exchange for a land-use approval.

In Wolf Ranch, LLC v. City of Colorado Springs, 220 P.3d 559 (Colo.2009) a drainage fee was imposed as a condition of land use approvals with a development. The fee was challenged and the Colorado Supreme Court held that because the Colorado General Assembly has authorized the fee, the fee was publicly promulgated on a per-acre basis and equally applied to all new development within the drainage basin; the fee was legally enforceable.

4.6 The Taxpayers Bill of Rights, Article X, Section 20, Colorado Constitution

On December 31, 1992 the Taxpayers Bill of Rights (TABOR) became effective. Its effect is to limit governmental spending generally so that "the maximum annual percentage change in each local district's fiscal year spending equals inflation in the prior calendar year plus annual local growth." In addition to a spending limitation, TABOR imposes a revenue limit that is similar to the spending limit. Finally, districts must have voter approval in advance for:

> ...any new tax, tax rate increase, mill levy above that for the prior year, valuation for assessment ratio increase for a property class, or extension of an expiring tax, or a tax policy change directly causing a net tax revenue gain to any district.

Prior to the passage of TABOR there were a number of cases that addressed whether a service charge was a tax. The first of note was Zelinger v. City and County of Denver, 724 P.2d 1356 (Colo. 1986) wherein a storm drainage service charge was attacked as an unconstitutional property tax and an unconstitutional denial of equal protection and due process guarantees to property owners. The storm drainage service charge applied to all owners of property in Denver and was used to pay for the operation, maintenance, improvement and replacement of the city's storm drainage facilities. The charge was based on the ratio of impervious to pervious land surface. The higher the ratio of impervious to pervious surface, the greater is the charge per square foot. The Colorado Supreme Court held that such a service charge was not a tax nor was it a violation of due process or equal protection. The court concluded with the following finding:

> ...although alternative cost allocation schemes may be equally well-suited or arguably better suited to serving the governmental interest in providing storm drainage facilities than the scheme actually adopted, the equal protection clauses do not authorize the invalidation of the scheme chosen unless it is without rational foundation.

The Zelinger case has continued as good law ever since 1986 and has been cited recently as the law of Colorado in regard to these matters. Thus, a storm drainage service charge similar to that adopted by Denver is not a tax and therefore is not subject to the limitations of TABOR.

In 1989 the Colorado Supreme Court revisited fees in the case of Bloom v. City of Fort Collins, 784 P.2d 304 (Colo. 1989). In that case the court considered a transportation utility fee and held that such a fee was not a property tax but rather a special fee imposed upon owners or occupants of developed lots fronting city streets and that such a fee is reasonably related to the expenses incurred by the city in carrying out its legitimate goal of maintaining an effective network of city streets. The court in reaching this conclusion considered any number of possibilities as to what this fee was and rejected the following as not applying: property tax, excise tax, and special assessment. It therefore found that the fee was a special fee that was a charge imposed on persons and property and reasonably designed to meet the overall cost of the service for which the fee is imposed.

Finally, in the case of City of Littleton v. State of Colorado, 855 P.2d 448 (Colo. 1993), the Colorado Supreme Court addressed another stormwater and flood management utility fee. The fee was enacted to prevent damage to property from accumulations and uncontrolled runoff of water. The ordinance declares that as the ultimate beneficiaries and users of the contemplated system, the owners of property within the city shall be required to pay a fee for the costs of constructing, operating, maintaining and replacing the system and its facilities. The state Community Colleges Board challenged the fee as a special assessment and thus something that could not be charged against the state. The court found that, despite the fact that the service fees did not specifically benefit the property owned by the state, it did create the capacity to remove excess water from property and prevent flooding, which benefited all property owners; thus, the fee is a permissible fee.

In conclusion, drainage fees, if properly structured, are not property taxes and can be implemented without TABOR implications. However, outside of Colorado, there have been five recent cases where each have held, for various reasons, that a "stormwater service charge," a "stormwater utility charge", and a "stormwater drainage service charge" are each a tax and not a fee. Those cases are Bolt v. City of Lansing, 561 N.W. 2d 423 (Mich. 1997); Fulton County Taxpayers Association v. City of Atlanta, Georgia, Superior Court of Fulton County, State of Georgia, Civil Action File Number: 1999 cv05897; City of Cincinnati v. United States, United States Court of Appeals for the Federal Circuit, 98-5039; Lewiston Independent School District et. al. v. City of Lewiston, Idaho Supreme Court, November 2011 (the stormwater fee is an unauthorized tax not reasonably related to a regulatory purpose) and Zweig v. Metropolitan St Louis Sewer District, Missouri Court of Appeals, March 2012 (stormwater charge is an unconstitutional tax).

4.7 Water Activities—Enterprise Statute 37-45.1-101 C.R.S.

This statute, which was adopted after the passage of TABOR, takes advantage of the exception in TABOR that the same does not apply to governmental enterprises by setting forth, in regard to water activities, what a governmental entity needs to do to become and remain an enterprise and thus not be subject to TABOR. Numerous Front Range cities have taken advantage of this statute to adopt enterprises without a vote of the people to address drainage and flooding issues in their municipalities.

The statute provides in regard to the establishment of a water activity enterprise that:

> Any district which under applicable provisions of law has its own bonding authority may establish or may continue to maintain water activity enterprises for the purpose of pursuing or continuing water activities including...water project or facility activities, including the construction, operation, repair, and replacement of water or wastewater facilities. Any water activity enterprise established or maintained pursuant to this article is excluded from the provision of Section 20 of Article X of the state constitution.

The statute defines "water project or facility" as including a dam, storage reservoir, compensatory or replacement reservoir, canal, conduit, pipeline, tunnel, power plant, water or wastewater treatment plant, and any and all works, facilities, improvements, and property necessary or convenient for the purpose of conducting a water activity. The statute also defines water activity as including stormwater services.

Two restrictions in regard to water activity enterprises are that they cannot receive more than 10 percent of their annual revenues from grants from state and local governmental entities and that an enterprise may not tax.

5.0 Floodplain Management

Floodplain management involves fuller use of non-structural techniques. See 24-65.1-202 (2)(a)(I) C.R.S. Such techniques include:

1. Floodplain zoning and building code ordinances to regulate flood area construction.

2. Flood insurance programs.

3. Flood warning systems, including notification to occupants of floodplains.

See Westen, *Gone With the Water—Drainage Rights and Storm Water Management in Pennsylvania*, 22 Vill. L. Rev., 901, 972 (1976-77).

5.1 Floodplain Regulations

5.1.1 Constitutional Considerations

The general principles of zoning were established in Village of Euclid v. Amber Realty Co., 272 U.S. 365 (1926), in which the U.S. Supreme Court stated:

> While the meaning of constitutional guarantees never varies, the scope of their application must expand or contract to meet new and different conditions that are constantly coming within the field of their operation.

The court in Colorado has determined that zoning is justified as a valid exercise of police power, and that this legal basis for zoning legislation must be reconciled with the legitimate use of private property, in harmony with constitutional guarantees. Westwood Meat Market, Inc. v. McLucas, 146 Colo. 435, 361 P.2d 776 (1961); People ex rel. Grommon v. Hedgcock, 106 Colo. 300, 104 P.2d 607 (1940).

The adoption by a municipality of floodplain ordinances to regulate flood-prone areas is a valid exercise of police power and is not a taking. Morrison v. City of Aurora, 745 P.2d 1042 (Colo. App. 1987).

5.1.2 Statutory Grants of Power

Specific legislative action has given local governments authority to proceed in floodplain regulation. In Colorado, cities, counties, and UDFCD all have plenary grants of power.

The governing body of each municipality has the following authority:

> To establish, regulate, restrict and limit such uses on or along any storm or floodwater runoff channel or basin, as such storm or floodwater runoff channel or basin has been designated and approved by the Colorado Water Conservation Board, in order to lessen or avoid the hazards to persons and damage to property resulting from the accumulation of storm or floodwaters. 31-23-301 (1) C.R.S.

Counties in Colorado are directly authorized by statute to adopt zoning plans concerned with regulating use in a floodplain area through the provisions of 30-28-111 (1) C.R.S.:

> ...the county planning commission may include in said zoning plan or plans provisions establishing, regulating, and limiting such uses upon or along any storm or water runoff channel or basin as such storm or runoff channel or basin has been designated *and* approved by the Colorado Water Conservation Board in order to lessen or avoid the hazards to persons and damage to property resulting from the accumulation of storm or flood waters.

Home rule counties and cities have the same powers as noted above. These powers may be expanded by charter as long as those powers do not violate the Colorado constitution dealing with home rule governmental entities.

UDFCD is authorized to:

> ...adopt, amend, repeal, enforce, and otherwise administer under the police power such reasonable floodplain zoning resolutions, rules, regulations, and orders pertaining to properties within the district of any public body or other person (other than the federal government) reasonably affecting the collection, channeling, impounding or disposition

> of rainfall, other surface and subsurface drainage, and storm and flood waters (or any combination thereof), including without limitation variances in the event of any practical difficulties or unnecessary hardship and exceptions in the event of appropriate factors, as the board may from time to time deem necessary or convenient. In the event of any conflict between any floodplain zoning regulation adopted under this section and any floodplain zoning regulation adopted by any other public body, the more restrictive regulation shall control. (emphasis added) 32-11-218 (1) (f) (I) C.R.S.

Because of the underlined language above, UDFCD has proceeded on the basis that if local governments within UDFCD fail to adopt floodplain regulations, then UDFCD would administer its regulation within that local jurisdiction. Further, since UDFCD's regulation prohibits residential development within the floodway (the most hazardous portion of the floodplain), any local government failing to prohibit residential development within the floodway would be governed by UDFCD's regulation inasmuch as UDFCD's regulation would be "more restrictive" and, thus, controlling under the statute.

5.1.3 Court Review of Floodplain Regulations

The leading Colorado case is Famularo v. Adams County, 180 Colo. 333, 505 P.2d 958 (1973), in which the Colorado Supreme Court upheld the District Court's findings that (1) the Adams County Commissioners had authority to regulate, by resolution, the uses of land in unincorporated areas for "trade, industry, residence, recreation, or other purposes, and for flood control"; and (2) the regulation in question did not so limit the uses of plaintiff's land so as to violate the Colorado Constitution, Article II, §25 or the U.S. Constitution, Amendment XIV.

In the case of Kolwicz v. City of Boulder, 538 P.2d 482 (Colo. App. 1975) the court was asked to determine if a city resident had standing to sue the city to require the city council and its administrator to implement floodplain regulations by adopting a map that delineated the floodway and the flood storage areas within the floodplain, for which the city had adopted a map four years prior to the lawsuit. The court denied the city resident's request on the basis that nothing in the record showed that the resident herself had been aggrieved, wronged, or had any of her rights impaired or threatened as a result of the city council's failure to implement its regulations.

In the case of Hermanson v. Board of County Commissioners of Fremont, 595 P.2d 694 (Colo. App. 1979), the court addressed an assertion by the plaintiff that his property had been taken from him because of a series of regulatory obstructions to its development that had been imposed by the county. The plaintiff alleged that his property had been taken by inverse condemnation, and the court found that such an action is justified when there has been a taking of private property for public use without payment of just compensation by some public body that has the power of eminent domain. However, the court did acknowledge that it is true that the use of property may be regulated by valid exercise of the police power, if the regulation does not go beyond protection of the public health, safety, morals, and welfare. Therefore, it found that, when regulations are designed to depress value with a view to future acquisition, this may form the basis of a cause of action for compensation on the theory of inverse condemnation against the public entity initiating the regulation.

Finally, in the case of Morrison v. City of Aurora, 745 P.2d 1042 (Colo. App. 1987), a property owner alleged that the city's adoption of floodway restrictions was a taking of his property. The court found for the city, since an adoption by a municipality of floodplain ordinances to regulate flood-prone areas is a valid exercise of police power and is not a taking.

In Colorado, the legislature has taken the lead in granting local governments power to regulate flood hazard areas. Usually, courts interpret such regulation that follows on a case-by-case basis, depending on what is "reasonable" under the circumstances. Some guidelines that have emerged in anticipating

"reasonableness" follow.

Restriction of Uses
The restriction of uses on property that would prevent a public harm, as opposed to the creation of a public *benefit*, removes the requirement of compensation to property owners who are restricted from the full use of their property. Dunham, *A Legal and Economic Basis for City Planning*, 58 Colum. L. Rev. 650 (1958).

The restrictions on the uses must not be so severe as to deny the owners a constitutional right to make "beneficial use" of their land because such restrictions would be confiscatory and void. Francis v. City and County of Denver, 160 Colo. 440, 418 P.2d 45 (1966). However, a zoning ordinance is not unconstitutional because it prohibits a landowner from using or developing his or her land in the most profitable manner. It is not required that a landowner be permitted to make the best, maximum or most profitable use of his or her property. Baum v. City & County of Denver, 363 P.2d 688 (Colo. 1961); and Sundheim v. Board of County Commissioners of Douglas County, 904 P.2d 1337 (Colo. App. 1995).

Health Regulations
The relationship of the zoning restrictions to the public's health, safety, morals, and general welfare must be considered. Whether the zoning provisions are reasonable and for the promotion of the public's welfare must be determined by the court from the facts, circumstances, and locality in a particular case. DiSalle v. Giggal, 128 Colo. 208, 261 P.2d 499 (1953).

A similar matter in zoning restrictions was determined by the U.S. Supreme Court in upholding the validity of the police power in a zoning ordinance that prohibited excavation below a certain water table, which in effect deprived the property of its most beneficial use, stated:

> The ordinance in question was passed as a safety measure, and the town is attempting to uphold it on that basis. To evaluate its reasonableness, we therefore need to know such things as to the nature of the menace against which it will protect the availability and effectiveness of other less drastic protective steps, and the loss which the appellants will suffer from the imposition of the ordinance. Goldblatt v. Town of Hempstead, (N.Y.) 369 U.S. 590 (1962).

This holding appears to coincide with the Colorado cases on the requirements for the determination by the court from facts, circumstances, and locality in a particular case, as to the reasonableness of the zoning ordinances in their promotion of the general welfare, and to prove that the restrictive use would bear a substantial relation to the public's health, safety, morals, or general welfare. DiSalle v. Giggal, supra; Westwood Meat Market, Inc. v. McLucas, supra.

Determination of Boundaries
The boundaries of the floodplain should be accurately determined and based on a reasonable standard. Mallett v. Mamaroneck, 1313 N.Y. 821, 125 N.E. 2d 875 (1955).

The setting of the boundaries of the floodplain zone to determine the hydraulic reach of a potential flood should be determined accurately. The accuracy of which will be affected by terrain, river course, and other factors that will necessarily cause some variation from the initially adopted boundary.

The Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers, Colorado Water Conservation Board (CWCB), UDFCD, and local governments have conducted extensive stream surveys throughout Colorado. There is extensive written guidance about the methodology to be used in conducting these surveys that are required to be completed using reasonable engineering / scientific standards and have often become an integral part of the floodplain zoning ordinances and resolutions

adopted by Colorado's cities and counties.

The CWCB has actively cooperated in the past to designate and approve such areas as delineated as a storm or "floodwater runoff channel or basin." Such approval or designation of a runoff channel or basin by the CWCB is required by statute prior to any action by a local government, including UDFCD, to set the boundaries on proposed floodplain zoning resolutions.

5.2 Flood Insurance

The National Flood Insurance Act of 1968, as amended in 1973, provides for a federally subsidized flood insurance program conditioned on active management and regulation of flood plan development by states and local governments. 42 U.S.C., §§4001 and 4128; 24 C.F.R., §1979.1-1925.14 (1975). Communities designated as flood prone by FEMA can obtain flood insurance eligibility for structures within the community upon meeting the qualifications of the act by developing a floodplain management system. Development of a floodplain management system requires the community to promulgate a land use and building permit system that restricts development in flood hazard areas. FEMA publishes a list, updated monthly, of the status of communities. Flood insurance is provided on a subsidized basis through all licensed insurance agents.

Federally regulated lending institutions (FDIC, ESLIC, NCUA) must require flood insurance for loans made on structures in FEMA-identified flood hazard areas in communities where flood insurance is available. The lender is required to give notice to the borrower 10 days in advance that the property securing the loan is located in a flood hazard area, and written acknowledgement of the borrower's knowledge of the flood hazard must be obtained. If flood insurance is not available in the community, the lender may still make the loan, but he or she must notify the borrower that federal disaster assistance may not be available in the event of a flood disaster. Federally insured loans (SBA, VA and FHA) have the same requirements, with the exception that they cannot be made on property located in a FEMA identified flood hazard area if flood insurance is not available in the community.

An area of great concern is whether flood hazard boundaries should be based on current development in the drainage watershed or on future development. FEMA uses current development as its criteria. UDFCD uses future development, which results in the regulation of a larger floodplain area in most instances. Although the watershed may take time to develop in accordance with the local government's Master Land Use Plan and land use requirements may call for on-site upstream detention, it is UDFCD's position that "future condition" criterion is preferable because existing floodplain users are put on notice of what the future may bring, and potential users of the floodplain are also put on notice of the potential hazard. The net result is a more restrictive regulation under 32-11-218 (l)(f) C.R.S. This section of the statute reads as follows: "To adopt, amend, repeal, enforce, and otherwise administer under the police power such reasonable floodplain zoning resolutions, rules, regulations, and orders pertaining to properties within the district of any public body or other person (other than the federal government) reasonably affecting the collection, channeling, impounding, or disposition of rainfall, other surface and subsurface drainage, and storm and flood waters (or any combination thereof), including without limitation variances in the event of any practical difficulties or unnecessary hardship and exceptions in the event of appropriate factors, as the board may from time to time deem necessary or convenient. In the event of any conflict between any floodplain zoning regulation adopted under this section and any floodplain zoning regulation adopted by any other public body, the more restrictive regulation shall control." With UDFCD being granted police powers it is granted discretion to adopt positions that have as their purpose the protection of life and property. Another example of UDFCD's exercise of its police powers is its position of privately owned detention facilities. UDFCD will not permit the recognition of those facilities unless there are written adequate assurances that the detention facility will not be modified in a way that it would reduce its flood control benefits.

5.3 Flood Warning Systems and Notification

UDFCD has adopted a procedure to notify known occupants of identified flood hazard areas (100-year floodplains). Although larger floods can and do occur, the local governments in Colorado are directed by the legislature to identify the areas that would be affected by 100-year storms. The CWCB has been directed by the legislature to coordinate this land use program.

UDFCD's "Flood Hazard Information Official Notice" also suggests actions that individuals can take to help themselves mitigate the hazard. This notice is mailed annually to the occupants of all residential units identified as being in the flood hazard area.

With the use of radar and a communications network, UDFCD has put in place a system to help inform all residents of UDFCD of potential flooding.

There is no legal requirement that UDFCD utilize any of these notification procedures. However, 32-11-220 (1)(c) C.R.S. provides that UDFCD has the power: "To carry on technical and other investigations of all kinds, make measurements, collect data, and make analyses, studies, and inspections pertaining to the facilities and any project, both within and without the district . . . . " Therefore, given the power to determine the location of 100-year floodplains and to gather information in regard to potential flooding; it follows that such information should be disseminated to the public.

As noted earlier, UDFCD, by reason of it taking on these tasks, does not assume any liability since it is protected under the Colorado Governmental Immunity Act.

6.0 Special Matters

6.1 Irrigation Ditches

In situations in which an irrigation ditch intersects a drainage basin, the irrigation ditch does not have to take underground waters diverted by a tile drain. However, the surface drainage must be accepted if the irrigation ditch is constructed in such a way that surface water would naturally flow into it. Clark v. Beauprez, 151 Colo. 119, 377 P.2d 105 (1962) (between private parties, the owner of an irrigation ditch can prevent an upstream landowner from diverting waters from their natural course into the irrigation ditch); City of Boulder v. Boulder and White Rock Ditch & Reservoir Company, 73 Colo. 426, 216 P. 553 (1923) (where an irrigation ditch was constructed in a natural drainageway into which surface water would naturally flow, the ditch owners could not complain merely on the ground that the city, in building storm sewers, collected the surface water and accelerated its flow and precipitated or discharged it at some particular point in the line of the ditch instead of spreading it out at different places of entrance).

In urbanizing areas, the conflict between the natural flow of surface water and irrigation ditches which bisect many drainage basins continues to be a difficult condition to resolve, taking into consideration the rights and liabilities of upstream property owners and irrigation ditch owners. Innumerable natural drainageways have been blocked by irrigation ditches, although they were constructed long before the basin became urbanized. This special area of urban drainage points to the need for good land use requirements, as well as identification of potential problem areas.

7-42-108 C.R.S. provides in part that:

> Every ditch corporation organized under the provisions of law shall be required to keep its ditch in good condition so that the water shall not be allowed to escape from the same to the injury of any mining claim, road, ditch, or other property.

This provision of Colorado law was interpreted in the case of Oliver v. Amity Mut. Irrigation Co., 994 P.2d 495 (Colo. App. 1999). In this case, the ditch company was being sued for damages to property resulting from a break in the bank of the ditch company's ditch. The court held that the statute imposed a duty of ordinary care, such as a person of average prudence and intelligence would use, under like circumstances to protect his or her own property. The court went on to state that, in order for the ditch company to fulfill its statutory duty, it had to prevent erosion of the ditch bank, keep the ditch free of sediment and debris, and control the amount of water flowing through its ditch, among other things, keeping the spillway at the intersection of its ditch and another free of obstructions. Finally, the court concluded that, although a ditch company is not liable for damages caused solely by an act of God, the company may not escape liability if its negligence contributed to or cooperated with an act of God to cause the damage.

In conclusion, those that own ditches owe a duty to those property owners, whose property their ditches pass to maintain their ditches, using ordinary care so as to prevent damage to the adjoining real property.

6.2 Dams and Detention Facilities

Subdivision regulations adopted by the board of county commissioners must include provisions requiring subdivisions to submit:

> Maps and plans for facilities to prevent stormwaters in excess of historic runoff, caused by the proposed subdivision, from entering, damaging, or being carried by conduits, water supply ditches and appurtenant structures, and other storm drainage facilities. 30-28-133 (3)(c)(VIII) C.R.S.

In addition, the regulations must include provisions governing:

> Standards and technical procedures applicable to storm drainage plans and related designs, in order to ensure proper drainageways, which may require, in the opinion of the board of county commissioners, detention facilities which may be dedicated to the county or the public, as are deemed necessary to control as nearly as possible, stormwaters generated exclusively within a subdivision from a one-hundred year storm which are in excess of the historic runoff volume of stormwater from the same land area in its undeveloped and unimproved condition. 30-28-133 (4)(b) C.R.S. See Shoptaugh v. Board of County Commissioners, 543 P.2d 524 (Colo. App. 1975).

The law in regard to liability for damages caused by failure of a dam or detention facility has changed. In the case of Kane v. Town of Estes Park, 786 P.2d 412 (Colo. 1990), the Colorado Supreme Court considered the issue of whether the Town of Estes Park was negligent for the failure of its dam and reservoir, which was the result of the failure of an upstream dam. The court held that "To impose a burden on a downstream builder to construct facilities adequate to hold or bypass the entire capacity of an upstream reservoir has the potential for foreclosing construction of beneficial downstream storage facilities because of prohibitive costs." The court then concluded as follows:

> In summary, we hold that public entities that own dams or reservoirs are not subject to strict liability for damages caused by water escaping from their dams or reservoirs.

> Furthermore, we hold that Estes Park had no duty to ensure that waters released from an upstream reservoir because of a dam failure of this magnitude would be contained by its facilities or would bypass those facilities without augmentation.

The Colorado legislature, in response to the 1982 flood that then resulted in the above-referenced lawsuit, amended the statute in regard to storage reservoirs to clarify the law. The applicable sections of 37-87-104 C.R.S. read as follows:

1. Any provision of law to the contrary notwithstanding, no entity or person who owns, controls, or operates a water storage reservoir shall be liable for any personal injury or property damage resulting from water escaping from that reservoir by overflow or as a result of the failure or partial failure of the structure or structures forming that reservoir unless such failure or partial failure has been proximately caused by the negligence of that entity or person. No entity or person shall be required to pay punitive or exemplary damages for such negligence in excess of that provided by law. Any previous rule or law imposing absolute or strict liability on such an entity or person is hereby repealed. See also East Meadows Company, LLC v. Greeley Irrigation Company, 99 P.3d 214 (Colo. App. 2003).

2. No such entity or person shall be liable for allowing the inflow to such reservoir to pass through it into the natural stream below such reservoir.

The law therefore is relatively clear now in regard to the ownership of dams and reservoirs and the owner's liability for them. No longer are dam owners subject to strict liability for damages caused by those dams. Meaning, that now in order to hold a dam owner responsible for damage caused by the dam, it must be established that the dam owner was negligent in maintenance or operation of the dam. However, this test of negligence is further limited by the law's permission to dam owners to pass all inflows through the dam.

The court, in the case of Barr v. Game, Fish and Parks Commission, 497 P.2d 340 (Colo. App. 1972), held that the criteria for the construction of a dam is to safely pass the probable maximum precipitation (PMP). In Barr, the Colorado Court of Appeals found that, since modern meteorological techniques provide a method of predicting the probable maximum storm and flood, liability should be imposed for injuries resulting from a failure to determine the probable maximum flood and to design and construct a dam with a spillway having the capacity to handle that storm. The court stated:

> The maximum probable storm, by definition, is both maximum and probable. It can and may occur…Thus being both predictable and foreseeable to the defendant in the design and construction of the dam, the defense of act of God is not available to them.

However, the Colorado State Engineer, pursuant to 37-87-105 (1) and (3) C.R.S. must approve plans and specifications for the alteration, modification, repair, or enlargement of a jurisdictional reservoir or dam and, pursuant to regulation, may impose less stringent requirements than those dictated by consideration of the PMP. In fact, the Colorado State Engineer has issued *Rules and Regulations for Dam Safety and Dam Construction*, 2 CCR 402-1 (September 1988) wherein at Rule 4 dams are classified based upon an evaluation of the consequences of the failure of the dam absent of flooding conditions. Based upon that classification, Rule 5 sets forth the inflow design flood to be used in determining the spillway capacity of that dam.

A question arises, however, regarding the proper criteria to use in determining the size of the floodplain or channel below the dam: the 100-year flood, before the dam was constructed or after construction? This special area has not been resolved by either the legislature or the courts in Colorado. However, since some dams and reservoirs are required by law to safely pass the PMP (storms greater than the 100-year

storm) it might be argued that the watercourse below the dam should be constructed to at least carry the same water as before construction of the dam. Assuming the dam safely passes a 500-year flood, for example, the 100-year floodplain would obviously be inadequate. But with no dam in place, the same floodplain would also be inadequate.

30-28-133 (4)(b) C.R.S. provides: "Standards and technical procedures applicable to storm drainage plans and related designs, in order to ensure proper drainage ways, which may require, in the opinion of the board of county commissioners, detention facilities which may be dedicated to the county or the public, as are deemed necessary to control, as nearly as possible, stormwaters generated exclusively within a subdivision from a one hundred year storm which are in excess of the historic runoff volume of stormwater from the same land area in its undeveloped and unimproved condition …." Therefore, based upon this statute as well as accepted engineering design standards, if it is possible to design a facility based upon a 100-year storm frequency and to limit development in a 100-year floodplain, that should occur.

Preserving the 100-year floodplain before the dam was constructed, where possible, is prudent and will lessen damage below the newly constructed dam in the larger than 100-year storm, although not for the PMP.

6.3 Stormwater Management and Water Law

> Stormwater runoff is a major non-point source of water pollution. In urbanizing areas, where land-disturbing activities are numerous, stormwater washes soil and sediment into surface waters causing increased levels of turbidity and eutrophication, threatening fish and wildlife, and blocking drainage. In developed areas, runoff carries with it the pollutants from surfaces over which it runs, including, oil, litter, chemicals, nutrients and biological wastes, together with soils eroded from downstream channels of the flow. U.S. Environmental Protection Agency, Legal and Institutional Approaches to Water Quality Management Planning and Implementation. VI-I (1977).

It is reasoned that water quality control should be an integral part of any drainage or stormwater management program, since stormwater management techniques are often consistent with water quality objectives. However, this special area, as related to urban drainage, has not been researched adequately enough so as to provide the facts upon which a cost-effective approach could integrate water quality objectives with plans for surface drainage improvements. See City of Boulder v. Boulder and White Rock Ditch & Reservoir Company, 73 Colo. 426, 216 P. 553, 555 (1923).

Currently, counties and municipalities are under regulation through the U.S. Environmental Protection Agency and the State of Colorado to address water quality issues. Volume 3 of the USDCM deals in detail with those requirements.

Water quality has become an integral part of each and every drainage and flood control facility that is being constructed in the United States. Some of the emerging issues in regard to water quality are numeric effluent limits, TMDLs (total maximum daily loads) and LID (low impact development). Although it is not the purpose of this section of the USDCM to address these issues from an engineering standpoint (See Volume 3), it is important to note their existance and, in some cases, their unintended consequences.

In the case of the EPA's regulation of numeric effluent limits, as a result of litigation, the EPA has agreed to withdraw the numeric turbidity effluent limitation and monitoring requirements and to add a definition of "infeasible" recognizing that there can be a site-specific constraint that makes it technically infeasible

to implement the effluent limits, or that implementing the requirement would be cost-prohibitive.

In regard to TMDLs, the EPA has identified the total pollutant loading that a waterbody can receive and still meet water quality standards, and specifies a pollutant allocation to specific point and nonpoint sources. The difficulty in meeting the TMDL standards is designing a system that addresses those standards without impacting the water rights of others.

LID practices include BMPs that divert and consume rain water (e.g., bioretention facilities, rain gardens, green roofs, and rain barrels). The problem with each of these, especially in the arid West, is that in some cases they may impact on a water right owned by others. If such an issue is raised by either the state or a water rights owner, the impact could cause the use of certain BMPs to become uneconomical. In addition, consideration should be given to the design of certain BMPs when located close to other structures so as to avoid a claim of damage to those adjacent structures by reason of the detained water.

Colorado laws are so strict that even when a pilot program was approved by the Colorado General Assembly (37-60-115 C.R.S.) permitting the collection of precipitation from rooftops and impermeable surfaces for nonpotable uses, the participants were required to replace the water that was captured by those means.

On May 11, 2011 the Colorado Department of Natural Resources Division of Water Resources issued a Memorandum in regard to stormwater management. It required that all detention and/or infiltration facilities that are used for managing stormwater quality and volume of discharge must release all of the water detained from the site within 72 hours of the end of the precipitation event. In regard to green roofs, those may only intercept precipitation that falls directly onto the landscaping and the green roof may not intercept and consume concentrated flow and may not store water below the root zone. This memorandum only applied to individual sites and did not provide legal protection. In 2014, UDFCD requested the same administrative allowance for regional installations and was denied. UDFCD, with support from communities within the region, sought legislation to provide legal protection for both individual and regional water quality and flood control facilities.

In May 2015, Senate Bill 15-212 was signed into law by Governor Hickenlooper and became effective August 5, 2015 as Colorado Revised Statute (CRS) 37-92-602 (8). The statue provides legal protection for any regional or individual site stormwater detention and infiltration facility in Colorado except those in the Fountain Creek watershed that are not required by or operated in compliance with an MS4 permit, provided meets the following criteria:

1. It is owned or operated by governmental entity are subject to oversight by a governmental entity (e.g., required under an MS4 permit);
2. It continuously releases or infiltrates at least 97 percent of all the runoff from a rainfall event that is less than or equal to 85 year storm within 72 hours after the end of the event;
3. It continuously releases or infiltrates as quickly as practicable, but it all cases releases or infiltrates at least 99 percent of the runoff within 120 hours after the end of events greater than a five year storm; and
4. It operates passively and is not subject this storm water runoff to any active treatment process(e.g., coagulation, flocculation, disinfection, etc.).

6.4 Professional Responsibility

The Colorado Rules of Professional Conduct of the State Board of Registration for Professional Engineers and Professional Land Surveyors provides in the *Basis and Purpose* section the following:

> In order to safeguard life, health and property, to promote the public welfare, and to establish and maintain a high standard of integrity and practice, the following Rules of Professional Conduct shall be binding on every person holding a certificate of registration and on all partnerships or corporations or other legal entities authorized to offer or perform engineering or land surveying services in Colorado.

These Rules were authorized by Colorado statute and in 12-25-108 (1) C.R.S.

> The board has the power to deny, suspend, revoke, or refuse to renew the license and certificate of registration of, limit the scope of practice of, or place on probation, any professional engineer or engineer-intern who is found guilty of:..(e) Violating, or aiding or abetting in the violation of,...any rule or regulation adopted by the board in conformance with the provisions of this part 1,...Rule I—Registrants shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.
>
> 2. Rule I shall include, but not be limited to, the following:
>
> A. Registrants shall at all times recognize that their primary obligation is to protect the safety, health, property and welfare of the public. If their professional judgment is overruled under circumstances where the safety, health, property or welfare of the public are endangered, they shall notify their employer or client and/or such other authority as may be appropriate.

Based upon the law and rule set forth above, a professional engineer is required not only to serve the interests of his or her employer/client but is also required as a primary obligation to protect the safety, health, property, and welfare of the public. Therefore, this obligation of protection is superior to the obligation to an employer/client and therefore must be considered in all professional decisions made by a professional engineer. Therefore, an engineer is required even if there is no law or regulation being violated to act to protect the safety, health, property, and welfare of the public in regard to any portion of a project in which the engineer is involved. In addition, a goal of an engineer should also be to report to an appropriate authority any condition on a project that jeopardizes the safety, health, property, or welfare of the public even if that condition is not his or her responsibility.

6.5 Professional Liability

For those practicing a profession requiring specialized knowledge or skill, reasonable care requires the actor to possess "a standard minimum of special knowledge and ability" and to exercise reasonable care "in a manner consistent with the knowledge and ability possessed by members of the profession in good standing." Rian v. Imperial Municipal Services Group, Inc., 768 P.2d 1260 (Colo.App.1989). This statement of the law applies to engineers in the State of Colorado.

Specific suggestions for design engineers to reduce their liability in regard to drainage-related work include the following:

- Check projected peak flows for reasonableness using multiple methods.
- Check for evidence of historic flooding.
- Make sure to coordinate design work with all applicable local governments and potentially other affected parties, such as railroads, highway departments, adjoining public and private property owners, and others.

- Be very sure of what local, state and federal regulations apply, and bring all of them to the attention of the project applicant.
- Assure that there is an adequate drainage outfall for runoff from the development.
- Be careful about changing the historic drainage status quo—carefully examine upstream and downstream implications.
- Bring in special assistance when merited.
- Stay abreast of new laws, regulations, policies, news events, etc., in the areas in which one is practicing.[2]

6.6 Miscellaneous Issues

1. Reliance on others' work in performing engineering services including relying on FIRM maps prepared by FEMA. An engineer is not required to re-perform another's work upon which the engineer relies. However, an engineer should critically review the work to determine if there are any obvious errors.

2. Reliance on local governments in regard to the National Flood Insurance Program. The NFIP is a Federal program created by Congress to mitigate future flood losses nationwide through sound, community-enforced building and zoning ordinances and to provide access to affordable, federally backed flood insurance protection for property owners. In support of the NFIP, FEMA identifies flood hazard areas throughout the United States and its territories. Most areas of flood hazard are commonly identified on Flood Insurance Rate Maps (FIRMs). An engineer should always check the FEMA National Flood Insurance Program Community Status Book to determine whether the community that the engineer is working in has been put on probation, suspended for failure to enforce or withdrawn from the NFIP. If so, caution should be exercised in regard to reliance on the community to enforce the FIRMs applicable to that community.

3. The Urban Drainage and Flood Control District Board is given broad powers in regard to the adoption of master plans. "To adopt, amend, repeal, enforce, and otherwise administer under the police power such reasonable floodplain zoning resolutions, rules, regulations, and orders pertaining to properties within the district of any public body or other person (other than the federal government) reasonably affecting the collection, channeling, impounding, or disposition of rainfall, other surface and subsurface drainage, and storm and flood waters (or any combination thereof), including without limitation variances in the event of any practical difficulties or unnecessary hardship and exceptions in the event of appropriate factors, as the board may from time to time deem necessary or convenient. In the event of any conflict between any floodplain zoning regulation adopted under this section and any floodplain zoning regulation adopted by any other public body, the more restrictive regulation shall control." 32-11-218 (1)(f)(I) C.R.S. As noted in the last sentence of the statute, the more restrictive floodplain boundary will always apply in these matters. In addition, as long as master plans whether adopted by UDFCD or any other governmental entity

[2] Jonathan E. Jones, P.E., D.WRE

are adopted during a legislative process with public notice, the challenge to those master plans will most likely be unsuccessful due to Colorado law (29-20-203 C.R.S.)

4. If a developer constructs onsite detention but the same is not recognized by UDFCD or another governmental entity, is the developer afforded legal protection from downstream property owners? Whether UDFCD or another governmental entity recognizes a private onsite detention facility, has no bearing on a developer's potential legal liability to downstream property owners. The test, in this case, is whether the discharge from the development is in a manner or quantity to do more harm than formerly downstream. If it is, the developer would be liable for that damage. If it is not, the developer would not be liable to downstream property owners. Hankins v. Borland, 431 P.2d 1007 (Colo. 1967).

5. Engineers should be aware that just following the USDCM or similar manual adopted by a governmental entity in their design efforts might not be enough to meet all of the governmental regulations applicable to the design. For example, zoning ordinances and subdivision regulations, or similar documents may be applicable to the design being prepared. Checking with the governmental department in the community where the structure is to be built usually will provide the engineer with information in regard to all standards that need to be complied with in regard to the design.

6. Changing historic drainage capacity must be carefully analyzed in regard to the impact on both upstream and downstream property owners. If the capacity of a culvert is being increased, before that increase takes place, adequate sizing increases of facilities downstream must take place to accommodate those increased flows otherwise liability to downstream property owners damaged by that increase may occur. Scott v. City of Greeley, 931 P.2d 525 (Colo.App. 1996).

7. Drainage and flood control structures once constructed should be maintained so as to function over the years as designed. Understanding the importance of maintaining UDFCD constructed infrastructure, the Colorado General Assembly added the ability for UDFCD to levy up to one-half mill for these expenses. This ability was added to the UDFCD statute and covers operation and maintenance expenses. The failure to maintain drainage and flood control structures can lead to damage to property and injury or death of individuals. An example of this would be the failure of pipe under a highway while automobiles are travelling on the highway. Not only may the highway be damaged, but the traveling public may be injured due to collapse of the highway.

8. Prior to Colorado law changing in regard to liability of governmental entities for drainage and flood control facilities that they construct, operate and maintain (See Section 1.2 2. of this chapter), governmental entities were found legally responsible for injuries and deaths that occurred in those facilities. In the case of City of Longmont v. Henry-Hobbs, 50 P.3d 906 (Colo. 2002) the Colorado Supreme Court found that a city is liable for a death that occurred in an artificial irrigation ditch of which the city is a shareholder and which is an integral part of the city's storm drainage system. The spillway in which a child drowned was constructed for and adopted by the city as part of the use of the ditch and the alleged negligence related to the design of this spillway. The Court held that thus, his death may have resulted from the operation and maintenance of a sanitation facility.

   In a companion case, the Colorado Supreme in the case of City of Colorado Springs v. Powell, 49 P.3d 561 (Colo. 2002) held the city may have been negligent in failing to post warning signs that would have alerted a passersby to the danger of the ditch. Further, the Court held the city may have been negligent in constructing the ditch with steep concrete sides that make it difficult to escape.

> Although, governmental entities may be immune from liability in regard to drainage and flood control facilities, this immunity does not extend to privately owned drainage and flood control facilities.

7.0 Conclusion

The force of gravity, which causes all waters flowing on the earth to seek the lowest level, creates natural drainage and provides for the distribution of all water, whether surface or otherwise. This natural drainage is necessary to render the land fit for the use of man.

> The streams are the great natural sewers through which the surface water escapes to the sea, and the depressions in the land are the drains leading to the streams. These natural drains are ordained by nature to be used and, so long as they are used without exceeding their natural capacity, the owner of land through which they run cannot complain that the water is made to flow in them faster than it does in a state of nature. 2 Farnham, Water and Water Rights, p. 968.

Drainage is both simple and complicated. If the facts are ascertained and a plan is developed before initiating a proposed improvement, the likelihood of an injury to a landowner is remote, and the municipality or developer should be able to undertake such improvements relatively assured of no legal complications and be able to use several different means of financing the improvement.

An engineer designing drainage improvements should consider the following:

1. Walking the site or watershed under study.
2. Whether there are existing problems and what causes them (obstructions, topography, development, present or future).
3. Whether proposed improvements will make the situation better.
4. Whether the proposed improvements require or result in changes to the natural drainage patterns.
5. Whether there is potential liability for doing something versus doing nothing.
6. Who will benefit from the proposed improvements?
7. If what is proposed is “reasonable,” using the criteria set forth in paragraph 2.1.3.

Chapter 3
Planning

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1.0 Importance of Drainage Planning

Planning the urban storm runoff system is fundamental for protection of public health, safety, welfare and the environment. The urban storm drainage system is a subsystem of the total urban infrastructure system and should be integrated with other subsystems including transportation, parks, open space, and utilities. When properly planned in concert with other subsystems, the storm drainage system can provide multiple benefits to urban communities. Effective planning requires an understanding of both urban and drainage planning, as well as the many social, technical, and environmental issues specific to each watershed.

Photograph 3-1. Bible Park with fully integrated drainage, flood control, recreation, and open space functions represents a partnership among engineers, landscape architects, planners, and parks and recreation professionals.

Drainage engineers should be included in urban planning from the beginning. Conducting drainage planning after decisions are already made regarding the layout of a new subdivision, commercial area or the transportation network often leads to costly and difficult drainage solutions and urban space allocation problems. When included early in the planning process, drainage engineers are able to work with the planning team to maximize benefits from drainage systems, including amenities such as recreation and open space. Consideration of multiple uses and benefits in drainage planning and engineering can reduce drainage costs and increase benefits to urban communities.

Urban Drainage and Flood Control District (UDFCD) has been engaged in drainage master planning for watersheds and streams in the metropolitan Denver area since the early 1970s. During the planning process, planners and engineers evaluate hydrology and identify important constraints, areas of open space preservation, needs for easements, opportunities for recreation and other multi-use opportunities, and means of accommodating utility conflicts. The team will develop design alternatives for locations and types of structures and facilities while also evaluating the suitability, type, and location of detention basins and water quality facilities. This is also a good time to identify opportunities and criteria to decrease the effective imperviousness of the built watershed through minimizing directly connected impervious areas. The planning process includes active participation by sponsoring municipalities, UDFCD and other regulatory stakeholders and includes public meetings and outreach to obtain community stakeholder input. Through public input and technical analysis, alternatives are vetted to make decisions and arrive at a conceptual plan for the system that is technically and politically feasible.

1.1 Planning Philosophy

Urban drainage planning should proceed on a well-organized basis with a defined set of drainage policies supported by local ordinances. The policies, objectives and criteria presented in this manual provide a foundation on which additional local policies can be built. Many local ordinances and municipal stormwater permits incorporate the criteria in the Urban Storm Drainage Criteria Manual (USDCM) by reference.

A Resource in Place

The urban stormwater planning process should attempt to make drainage, which is often a "resource out of place," a "resource in place" that contributes to the community's general wellbeing.

Drainage must be integrated early into the fabric of the urban layout, rather than be superimposed onto a development after it is laid out. The planning and design team should think in terms of natural drainage easements and street drainage patterns and should coordinate efforts with the drainage engineers to follow the policies and achieve the objectives presented in the USDCM.

Urban drainage planning should address three key components:

1. Minor (Initial) Drainage System: As defined in the *Policy* chapter, the minor (or initial) drainage system includes conveyances such as grass swales, streets and gutters, storm drains, and roadside ditches. It may also include conveyance and storage-based water quality facilities. If the initial drainage system is properly planned and designed, complaints from the community related to localized flooding and drainage nuisance conditions will be reduced. A well-planned initial drainage system provides for convenient drainage, reduces costs of streets, and minimizes disruptions to the function of urban areas during runoff events.

2. Major Drainage System: A well-planned major system protects the urban area from extensive property damage, injury, and loss of life from flooding. The major system exists in a community whether or not it has been planned and designed and regardless of whether development is situated wisely with respect to it. General principles that UDFCD has recognized in planning for the major drainage system include:

    - Water will obey the law of gravity and flow downhill regardless of whether buildings, roads and people are in its way.

    - Targeted stabilization (e.g., grade control, toe protection and other measures) before a stream begins to degrade is generally far more cost effective and environmentally beneficial than a reactive approach addressing channel stability/restoration after significant degradation has occurred.

    - The practice of straightening, narrowing, and filling natural watercourses comes at a high environmental cost. This practice also increases velocities and typically results in high maintenance costs.

Importance of Drainage Planning

Storm runoff will occur when rain falls or snow melts, no matter how well or how poorly drainage planning is done. Drainage and flood control measures are costly when not properly planned. Good planning results in lower-cost drainage facilities for the developer and the community and more functional community infrastructure.—D. Earl Jones, 1967

3. Floodplain Management: Floodplain management is closely tied to major drainage systems. Nature's prescriptive floodplain easements along streams and rivers should be maintained using tools including floodplain/floodway delineation, floodplain regulation, open space preservation and zoning. Small waterways and gulches lend themselves to floodplain regulations in the same manner as larger creeks.

For all three of these components, drainage system planning that best serves the community follows natural drainage patterns.

1.2 Elements of Early Drainage Planning

The drainage engineer, planner, and the entire planning team should work in close cooperation, recognizing that good urban drainage planning is a complex process. Early drainage planning should include these elements and guiding principles:

1. Address fundamental drainage features and objectives, including the major drainage system, initial drainage system, stormwater water quality management, multi-use objectives, and the environment.

2. Street conveyance is an important part of the minor (initial) drainage system. For new subdivision planning, evaluate various conceptual drainage alternatives before decisions are made regarding street location and layout.

Benefits of a Well Planned Drainage System

An urban area with well-planned drainage facilities is usually an area that experiences orderly growth and realizes benefits such as:

1. Fewer downstream constrictions and increased conveyance capacity for upstream property owners.
2. Better managed runoff, less pollution entering stormwater, and more stable waterways.
3. Improved water quality.
4. Protection and enhancement of environmentally sensitive areas.
5. Reduced street maintenance costs.
6. Reduced street construction costs.
7. Improved traffic movement.
8. Improved public health and environment.
9. Lower-cost park and open space areas and more recreational opportunities.

3. Consider the level of flood hazard in the planning area. Protect public safety and avoid unnecessary complications with local planning boards and governments.

4. Don't compromise on drainage in a new development to increase short-term profits. Long-term community interests will suffer as a result. Both governmental and private planners are encouraged to confer and work with drainage engineers.

5. Address federal, state and local regulatory requirements early in the planning process. Drainage projects will frequently trigger the need for environmental permits required under federal, state and/or local water quality regulations (e.g., disruption of wetlands, riparian setback ordinances). For some

Nature's Floodplain Easement

On any floodplain, nature possesses, by prescription, an easement for intermittent occupancy by runoff waters. Man can deny this easement only with difficulty. Encroachments upon or unwise land modifications within this easement can adversely affect upstream and downstream flooding occurrences during the inevitable periods of nature's easement occupancy.—Gilbert White, 1967

permits and approvals (e.g., CLOMRs, individual 404 permits, threatened and endangered [T&E] species), the review period can be lengthy. A solid understanding of applicable regulatory permits and requirements is imperative because these requirements can significantly affect the design, construction and long-term maintenance of channels, ponds, wetlands, and other facilities.

2.0 Minor (Initial) Drainage System Planning

For the area served by UDFCD, the minor (initial) storm is defined to have a return frequency of once every 2- to 10-years. The minor drainage system is needed to convey flows from the initial design storm to reduce inconvenience, frequently recurring damages, and street maintenance costs, and to help create an orderly urban system with a multi-functional drainage system. The initial system may include a variety of features such as swales, curbs and gutters, storm drain pipes, on-site detention, runoff reduction (e.g., minimized directly connected impervious areas) practices, and water quality BMPs. Generally, the initial drainage system drains a tributary no larger than 130 acres, as the runoff from this area would be in excess of the typical capacity of these features within a street section. The initial system exists with or without storm drains. Storm drains are needed when the other parts of the initial system no longer have capacity for additional runoff. A good major drainage system coupled with wise layout of streets can often significantly reduce the need for storm drains. The *Policy* chapter and the *Streets, Inlets and Storm Drains* chapter of this manual provide policies, criteria and procedures for designing the initial drainage system, including criteria related to streets as part of the initial drainage system. The discussion in the remainder of this section is limited to planning-level considerations.

Photograph 3-2. UDFCD drainage criteria are aimed at respecting the needs of safe, unimpeded traffic movement. This intersection represents a long-standing drainage problem needing a solution.

The preliminary layout of a storm drainage system should consider urban drainage objectives, hydrology, and hydraulics. The preliminary layout of the system has more effect on the success and cost of the storm drains than the final hydraulic design, preparation of the specifications, and choice of materials. For this reason, preliminary work on the layout of the storm drains should occur prior to finalizing street layout in a new development. Once the street layout is set, options to provide a more cost-effective system are greatly reduced. Various layout concepts should be developed and reviewed, and critical analyses should be done to arrive at the best layouts. For example, the longer that street flow can be kept from concentrating in one street, the further gutters or swales can be used for conveyance. This will reduce the length of pipe required. In storm drain design, it is important to remember that small-diameter laterals represent a large part of the total construction cost. A key planning objective should be the design of a balanced system in which all portions will be used to their full capacity without adversely affecting the drainage of areas served by the system. See the *Streets, Inlets, and Storm Drains* chapter for limitations of street flow.

Another fundamental planning consideration for the initial system is the runoff or rainfall return period for designing a storm drain system required by local governments. Whenever the system crosses jurisdictional boundaries, differences in sizing policies for the initial system must be coordinated so that a consistent design is achieved for the entire system. Once the overall design return period has been

established, the system should be reviewed for points where deviation is justified or necessary. A drainage area must be reviewed on the basis of both the initial and the major storm occurrence. When analysis implies that increasing the storm drain capacity is necessary to help convey the major storm, the basic system layout of the major drainage should be analyzed and changed, as necessary. For example, in a sump area that has no other method of drainage, it may be necessary to plan for a storm drain to receive more than the initial runoff.

3.0 Drainage Master Planning Process

3.1 General

Drainage master plans provide guidance for drainage and flood control related improvements for all or part of an evolving watershed, often crossing jurisdictional boundaries and incorporating public participation. Drainage master plans are most effective when sound hydrologic and hydraulic engineering analysis is coordinated with planning for open space, recreation, transportation, water quality, urban wildlife, and other considerations. Master plans are important tools to help identify capital projects for construction by local governments. Master plans also help guide new land development projects to be consistent with regional drainage and stormwater quality needs and help to identify and acquire land and rights-of-way for future capital improvements, drainageway maintenance, and floodplain preservation. Master plan recommendations can be remedial (correcting existing problems) and/or preventive. The drainage master planning process is based on a two-pronged approach:

1. Preserve: Where development has not yet occurred, preservation of existing drainage features and associated floodplains in a manner that preserves natural flow paths, ecological benefits and natural floodplains is preferred.

2. Mitigate: Both historic and future development may require mitigation of the impacts of urbanization through improvements that stabilize or restore stream channels, detain increased runoff volumes, and improve conveyance.

An effective drainage master planning process typically begins with research and data collection, and

UDFCD's Master Planning Program

The Master Planning Program produces drainage master plans based on the following four key policy decisions which guide the program implementation:

1. Each master planning effort must be requested by the local governments and should have a multi-jurisdictional aspect;

2. Master plans are completed by consultants acceptable to all local project sponsors and UDFCD;

3. UDFCD will pay up to 50% of the study costs, with the local sponsors sharing the remainder of the costs; and

4. The master plan must be acceptable to all the affected local governments.

Master plan recommendations can be remedial or preventive and are important for identifying projects for construction. The master plans also provide valuable input to UDFCD's Five-Year Capital Improvement Program. They help new land development projects to be consistent with regional drainage and stormwater quality needs and help to identify and acquire land and rights-of-way for future capital improvements, for stream management, and for floodplain preservation.

ends with a solid conceptual design plan for future improvements that addresses multiple stakeholders' needs and can be used as a reference document for the future. The process includes technical analysis, engineering calculations, agency and public coordination, attention to the environment, and the use of sound judgment and common sense. The planning process generally includes the following tasks:

- Collection and evaluation of available reports and studies on existing drainage facilities, zoning and land ownership plans, current and future land use plans, soils information and other drainage related information.
- Coordination and meetings with the project sponsors and stakeholders.
- Performance of a site investigation to identify major drainage structures, existing problem locations and hydrologic and hydraulic parameters.
- Development of hydrology for the existing and proposed future watershed conditions, including runoff volumes and flow rates for various return periods of flooding along streams.
- Estimation of the flooding potential to properties throughout the watershed.
- Evaluation of the hydraulic capacity of the existing drainage system and facilities.
- Development of stormwater infrastructure alternatives that address stakeholders' future needs.
- Evaluation of alternatives based on criteria, estimated construction costs, potential flooding, planning constraints and/or other related issues.
- Providing a recommended plan to the project stakeholders and the affected communities.
- Determining a final selected plan for future improvements based on feedback from the stakeholders and communities.
- Preparation of the Major Drainageway Plan or Outfall System Plan and development of conceptual design documents.

Shelf Life

Drainage master plans typically have a shelf life of 20 to 30 years, gradually becoming outdated due to changes in philosophy, policy, and/or planning. They lay the foundation for development while allowing some flexibility for the design phase of developments within a watershed. Urban land development in general accordance with the master plan does not give cause to update the master plan.

3.2 Types of Drainage Plans

UDFCD works with local project sponsors to implement two types of drainage plans: Major Drainageway Planning Studies and Outfall Systems Planning Studies, as described below.

3.2.1 Major Drainageway Planning Studies

Major Drainageway Planning Studies (MDPs) are based on hydrologic analyses from CUHP and SWMM and on hydraulic analyses from HEC-RAS. These studies generally focus on the main stem of the stream, identifying a floodplain and making recommendations to mitigate the flood hazard, as well as to improve the safety and function of the stream. These studies are often completed in conjunction with a Flood Hazard Area Delineation (FHAD) studies. Improvements evaluated may include:

- Channel enlargement and/or stabilization of channel banks and bottom.
- Longitudinal grade control of channel invert.
- Crossing structure improvements.
- Floodplain preservation.
- Detention for flood mitigation.
- Acquisition of flood prone properties.
- Water quality protection strategies and treatment facilities.
- Restoration of a natural stream system.
- Maintenance access.

A benefit-cost analysis is performed for reaches where structures are identified in the 100-year floodplain to assist in the alternative selection process. The benefit is primarily measured in reduced flood damages to existing structures as a result of recommended improvements, though it is important to also identify other intangible (or at least difficult to valuate) benefits like improved water quality, reduction/elimination of street flooding, public safety, aesthetics, and recreation (either active recreation such as organized sports and individual exercise, or passive recreation which may simply entail being in the open space). Time spent in an urban open space for recreation offers the healthful benefit of an aesthetic and psychological reprieve from the urban environment.

3.2.2 Outfall Systems Planning Studies

Outfall Systems Planning Studies (OSPs) are also based on hydrology from CUHP and SWMM but utilize only limited hydraulic analyses (no HEC-RAS). These studies only rarely identify a regulatory floodplain. OSPs typically focus on a watershed tributary to a large waterway that may have its own MDP. Typical types of analyses and proposed improvements may include:

- Detention for flood mitigation.
- Water quality protection strategies and treatment facilities.

- Storm drain system improvements.
- Crossing improvements.
- Channel enlargement and/or stabilization.
- Floodplain preservation.
- Maintenance access.

3.3 Phases of Planning

UDFCD's planning process proceeds in a standardized, orderly sequence, which includes three phases: 1) Baseline Hydrology, 2) Alternatives Analysis and 3) Conceptual Design. UDFCD provides standardized checklists (see www.udfcd.org) for completion of each phase of the planning process, along with specific guidelines for electronic deliverables and mapping. Each of these phases is discussed below.

3.3.1 Baseline Hydrology

Baseline hydrology defines the storm runoff volumes and peak flow rates for the 2-, 5-, 10-, 25-, 50-, and 100-year storm events under existing and proposed future build-out conditions. These runoff volumes and peak flow rates are used to evaluate the sufficiency of existing drainage facilities, identify potential drainage problems, and evaluate alternative drainage improvements. Two computer models are typically used to estimate baseline hydrology:

1. The Colorado Urban Hydrograph Procedure (CUHP): This model is used to calculate runoff for each catchment in a watershed for the 2-, 5-, 10-, 25-, 50-, and 100-year storm events. CUHP considers physical characteristics of each sub-watershed including shape, slope, impervious area, and soil conditions. See the *Runoff* chapter for a full description of CUHP.

2. The EPA Stormwater Management Model (SWMM): SWMM is used to route runoff from sub-catchments through the drainage system. Hydrograph routing considers the characteristics of conveyance elements, certain flood detention facilities, flow diversion conditions where existing storm drains cause flows to diverge from overland flow paths, and other factors.

Other models or techniques can be used to develop the baseline hydrology for MDPs and OSPs, but the CUHP and SWMM models are often preferred due to the size and complexity of study areas, degree of spatial variation in development and land-use within watersheds, and compatibility with UDFCD standards. Existing conditions used in these models are typically documented by a combination of field visits and Geographic Information System (GIS) analysis of data provided by local governments, such as imperviousness, land use, transportation infrastructure, soil types, slopes, and other features. Future conditions hydrologic analysis is completed based on future land use data from local governments, typically in the form of adopted zoning or comprehensive plans.

When developing existing and future hydrology, only detention facilities that are municipally-owned and operated and/or those with assurances for perpetual operation and maintenance are recognized in the modeling (i.e., most privately owned on-site detention and inadvertent detention are not considered in the modeling). This results in a model that conservatively bases runoff volumes and flow rates on only those flood control facilities that have a high probability of proper future maintenance and function.

Within the UDFCD planning area, master plans are often updated to reflect changes in development conditions, implementation of regional detention facilities and other factors. In these cases, a first step in

hydrologic modeling is to compare results from the previous models being used to the hydrology from the study that is being updated. This is a critical step that is necessary due to changes in algorithms in CUHP and SWMM over time, as models have evolved. It is also a useful step for detecting and correcting input errors from earlier models where numeric input file formats made it more difficult to find input problems than current graphical user interfaces and GIS-based methods.[1] When there are differences in baseline hydrology results simply due to changes in model algorithms, the baseline hydrology is "calibrated" back to original model conditions.[2] Once the baseline hydrology model has been corrected and "calibrated" to the previous study, model inputs are adjusted based on current and future-projected changes in physical conditions such as revised imperviousness, regional detention, channel modifications, etc.

3.3.2 Alternatives Analysis

After completion of baseline hydrology, the alternatives analysis process is initiated based on stream reaches, sub-catchments, or other planning zones. These planning areas are typically defined based on geopolitical boundaries, changes in stream characteristics, roadway crossings and other major land features. The goal of the alternative development process is to identify problem areas within each planning reach and develop a range of alternatives that mitigate the problem. For purposes of evaluating improvements, UDFCD design criteria and guidance for improvements such as open channels, culverts, storm drains, grade control structures, stabilization measures, and detention basins (as well as the hydrologic methodologies used to size the facilities) are followed. Alternatives are then evaluated based on considerations such as right-of-way acquisition, cost, constructability, long-term maintenance issues, environmental impacts (and benefits), multiuse functionality, and public acceptance.

Although each watershed is unique and there is no standard formula that can be used for each planning study, alternatives considered typically include options such as these:

- "Status Quo" – the "do nothing" alternative that maintains the existing configuration. This alternative provides a baseline for comparison of other alternatives. There are costs associated with a "do nothing" alternative related to ongoing flooding issues, existing and future channel stability, maintenance and other factors.
- Floodplain preservation.
- Conveyance improvements including new channels and restoration/improvement of existing channels.
- Road crossings, including culverts and bridges.
- Channel stabilization – grade control structures to prevent vertical degradation and bank stabilization measures to prevent lateral migration.

[1] This process is analogous to the Duplicate Effective and Corrected Effective modeling process that is used for FEMA floodplain modeling with HEC-RAS.

[2] This calibration exercise involves engineering judgment and familiarity with sensitivity of CUHP and SWMM to input parameters. The goal of the calibration is to obtain reasonable agreement between the previous and current studies in the context of overall hydrologic model uncertainty. Drainage engineers should exercise caution when adjusting inputs for calibration to be sure that parameters are physically realistic and within published ranges.

- Detention and/or water quality planned at the regional level. Detention and water quality are frequently planned conjunctively.
- Acquisition of flood-prone properties and other non-structural measures (e.g., easements).

Alternatives are evaluated based on many factors, including:

- The balance of detention and conveyance needed for flood mitigation.
- How the alternative fits into the existing area based on right-of-way acquisition and easements, transportation, general consistency in long-term floodplain and stormwater management along the corridor.
- Environmental considerations.
- Property rights considerations (e.g., detention is generally not proposed on private lands due to difficulty in future implementation without invoking the power of eminent domain).
- Benefit-cost analysis.
- Regulatory/permitting constraints.
- Public safety.
- Aesthetics.
- Public acceptance.
- Operation and maintenance requirements.
- Other feasibility issues.

Estimation of costs to implement improvements is a key component of the alternatives analysis. Costs for each alternative are developed based on approximate unit costs for each improvement. To assist with development of cost estimates, the UD-MP Cost workbook available at www.udfcd.org can be utilized. Typical costs considered include capital costs, land costs (e.g., ROW, permanent or temporary easement), engineering/legal/administrative costs, construction costs, maintenance costs and a contingency factor.

Regulatory constraints are also considered during the alternatives analysis phase. Implementation of drainage plans is affected by a variety of federal, state and local permit requirements. When developing drainage master plans, it is important to be aware of how these requirements can affect the feasibility of planned improvements. In particular, Section 404 permits and threatened and endangered (T&E) species issues can have significant effects on planned drainage improvements and should be considered during the planning process, not just prior to construction.

Because of the high quality wetland and riparian ecosystems associated with waterways, many species of wildlife spend part of their life cycle in these corridors. The U.S. Fish and Wildlife Service (USFWS) regulates T&E species, and if a T&E species, or habitat for a T&E species, is present in a project area, federal permitting will likely be required. Two of the most commonly encountered T&E species within the riparian areas of the Colorado Front Range are the Preble's Meadow Jumping Mouse and the Ute Ladies'-tresses Orchid.

Section 404 Permits

Section 404 of the federal Clean Water Act regulates the discharge of dredged and fill material into waters of the United States, including wetlands. The USACE administers individual and general permit decisions, jurisdictional determinations and enforces Section 404 provisions. Prior to discharging dredged or fill material into the waters of the United States, a Section 404 permit must be obtained from the USACE. Waters of the United States include essentially all surface waters such as all navigable waters and their tributaries, all interstate waters and their tributaries, all wetlands adjacent to these waters, and all impoundments of these waters. Typical activities requiring Section 404 permits include:

1. Site-development fill for residential, commercial, or recreational construction.
2. Construction of revetments, groins, breakwaters, levees, dams, dikes, and weirs.
3. Placement of riprap.
4. Construction of roads.
5. Construction of dams.
6. Any grading work affecting Waters of the United States.

Any person, firm, or agency (including federal, state, and local government agencies) planning to work, dump, or place dredged or fill material in waters of the United States, must first obtain a permit from the USACE. Other permits, licenses, or authorizations may also be required by other federal, state, and local agencies, and the issuance of a 404 permit does not relieve the proponent from obtaining such permits, approvals, licenses, etc.

Other water quality permit-related requirements also apply with regard to erosion and sediment control practices during construction, as discussed further in Volume 3 of this manual.

3.3.3 Conceptual Design

Based on the Selected Plan that emerges from the alternatives analysis, the conceptual design is intended to provide guidance to the project sponsors for future planning and capital improvement projects along streams within the study area. The conceptual design typically provides reach-by-reach recommendations for improvements in terms of the problems being addressed, specific recommended actions, and expected costs (capital and long-term operation and maintenance). The conceptual design Plan includes plan and profile drawings for each reach, as well as details for typical channel sections, ditch crossings, drop structures, detention ponds, and other features. The conceptual design serves as the "roadmap" for future improvements to streams.

Major components of the conceptual design include:

- Plan Development Overview: Describes how the master plan will prevent or mitigate drainage problems and damages and documents the rationale for changes from the Selected Alternative (if any).
- Master Plan Description: Describes the Master Plan on a reach-by-reach basis, along with costs, mapping and profiles.

- Prioritization and Phasing: Discusses priority of improvements, specifically how they are interrelated to other improvements, which are independent, which need to be implemented first and which need to be implemented as a system to avoid transferring damage potential to other reaches. MS4 requirements should also be considered with phasing improvements.

- Water Quality Impacts: Describes how the plan addresses stormwater quality or mitigates stormwater quality impacts on the receiving system.

- Operations and Maintenance: Describes operations and maintenance aspects and costs of master plan.

- Environmental and Safety Assessment: Describes how the recommended alternative will affect the environmental character and public safety of each reach and how it will fit into the community being served.

3.4 Alternative Plan Components

Drainage plans typically address conveyance, channel stabilization, acquisition of flood-prone property or structures, stream crossings, detention (storage), and water quality. Each of these components is discussed further below. Although these components are discussed separately below, they are interrelated. For example, there are often tradeoffs between detention and conveyance (increasing detention storage can reduce conveyance needs and vice versa).

3.4.1 Conveyance

Conveyance alternatives consider channel improvements needed to convey large flood events (typically the 100-year flood, although lesser events may be considered to improve undersized systems). Conveyance-based alternatives can be cost effective and provide benefits to the community, especially when there is space available for integration with trails and open space. Depending on how the conveyance improvements are implemented, there can be potential for a loss or significant alteration of natural ecological resources, especially in areas with greater space constraints. As a result, the aesthetic and environmental concerns of conveyance alternatives must be carefully evaluated. Conveyance objectives can often be achieved by using stabilized, naturalized channels with improvements such as bridges or culverts at road crossings. In areas of existing development with flooding problems and undersized drainage systems, lined, engineered channels and/or closed systems that maximize conveyance within a limited right-of-way may be needed.

Photograph 3-4. An engineered wetland channel can serve as a filter for low flows and carry the major flood event without damage. Wetlands and vegetated overbank areas aid in providing transient storage that is beneficial for attenuating runoff.

For the major drainage system, using open channels rather than closed conduits has significant advantages in regard to costs, capacity, multi-use potential, aesthetic purposes, environmental protection/enhancement, and potential for detention storage. A constraint for open channels relative to closed conduits is the greater right-of-way requirement (e.g., the inability for a roadway to be built atop the stream) for an open channel system. Careful planning and design are needed to minimize disadvantages and maximize benefits. See the *Open Channels* chapter for design principles.

Benefits of Open Conveyance

- Public Awareness – Visibility serves as a reminder to the community that stormwater quality is important and that potential for flooding exists, whereas a piped system diminishes the value of stormwater and streams and also hides the function of conveyance.
- Safety – Open channels offer eggress to escape flow when a person or animal unintentionally enters the water.
- Excess Capacity – The freeboard provided in an open channel will provide protection for a storm event higher than the design storm.
- Overbank Storage – Overbanks offer significant inadvertant detention that provides an extra level of protection that is not available when flows are conveyed underground.
- Water Quality – The natural bottom of a channel provides contact between the water and both soil and vegetation. This provides water quality benefit not available in a piped system.
- Habitat – Open channels provide opportunities for riparian vegetation and wildlife habitat.
- Education – A naturalized open channel can provide an outdoor classroom experience in an urban setting, bringing the public closer to nature.

3.4.2 Stabilization

Channel stabilization is typically needed in developing areas to mitigate the erosive impacts of urbanization. Grade control structures prevent downward incision of streams. When strategically positioned to reduce the longitudinal slope of channels, they help stabilize streams, thus protecting existing riparian zones, private and public property and urban infrastructure (DeGroot and Urbonas, 2000). The protection and/or establishment of wetland and riparian vegetation upstream of these structures is an added habitat benefit. Grade control structures also reduce silt deposits in downstream aquatic-habitat areas (Urbonas and Doerfer 2003).

Two categories of grade-control structures are typically considered in MDPs: drop structures and check structures. Drop structures are mitigation measures to raise the degraded bottom of a stream to return its elevation close to what was there before degradation occurred. Check structures are preventive and are installed as hard-points across the stream before degradation occurs. Planning for such structures is an

important element in any master-planning project for urbanizing watersheds (Urbonas and Doerfer 2003).

Increasingly, other forms of channel restoration involving bioengineering methods, which go beyond traditional stabilization practices, are also being considered. See the *Open Channels* chapter for additional discussion of stream restoration techniques.

3.4.3 Acquisition of Flood-prone Properties or Structures

Acquisition of flood-prone properties and structures can be a very effective way to preserve floodplains and reduce flood hazards. Many municipalities have parks and open space programs that have acquired and continue to acquire land for this purpose, including large tracts of floodplains. When landowners develop along drainage corridors, the area within the floodplain is often dedicated to the municipality as an open space or park tract. The open space provides multiple benefits to the community including trails, recreation, wildlife and, most importantly, keeps development out of a hazardous location. Floodplain acquisition is also a major factor to consider in planning locations of detention and water quality facilities within or adjacent to the floodplain.

Acquisition is also an alternative considered in areas with frequent flooding due to undersized drainage systems, often in older neighborhoods developed before modern floodplain regulations. Although it is typically far more expensive to acquire developed lots in urban areas than undeveloped floodplain land, acquisition of flood-prone properties and structures may be necessary to upgrade undersized systems and reduce flood hazards in developed areas that have undersized drainage systems. Often the cost of infrastructure required to remove the flood hazard from one of these properties far outweighs the cost of acquiring the property when it is put up for sale.

3.4.4 Crossing Structures

Crossing structures often include transportation features that cross or run parallel to major channels and streams, along with major utilities and pedestrian bridges. Many existing flood problems are due to inadequate waterway openings (bottlenecks) under transportation facilities. These inadequate openings have resulted from lack of appropriate basic criteria or changes in criteria, lack of good planning, lack of proper hydraulic engineering, and lack of coordination between the various agencies. Many storm drainage problems can be avoided by cooperation and coordination between the various public agencies and public and private stakeholders in the very early stages of planning for storm drainage infrastructure associated with transportation features. This coordination is essential to providing proper drainage at a reasonable cost.

Transportation agencies often focus on drainage improvements needed for their specific projects; however, such planning should be integrated with drainage planning for the adjacent urban area. For example, in some cases, transportation-related drainage facilities may also need to be designed to intercept and convey storm runoff from a significant urban watershed. In design and construction of sound barriers along freeways, which can act as dams impeding conveyance, highway designers must account for the major drainage needs of the uphill land and provide a way for the water to pass under or around the sound barriers without backing up. A similar situation develops with the construction of crossings – roadway embankments or median barriers that impede flow. These can create costs that should be avoided. In such cases, cooperation between the transportation agency and the local government is particularly advantageous so that joint planning, design, and construction can result in a better urban environment.

See the *Culverts and Bridges* and the *Stream Access and Recreational Channels* chapters of this manual for specific guidance related to channel crossings that should be considered during the master planning process.

3.4.5 Detention (Storage)

Detention and retention storage for flood control are key components of drainage planning, as described in the *Policy* and *Storage* chapters of this manual. Although on-site, subregional and regional flood detention facilities all play a role in drainage and floodplain planning, only detention and retention facilities with assurances for construction and perpetual operation and maintenance are considered in master plans. For planning purposes, UDFCD adheres to the following policies when developing hydrology for the delineation and regulation of the 100-year flood hazard zones:

1. Hydrology must be based on fully developed watershed condition as estimated to occur, at a minimum, over the next 50 years.
2. No detention basin will be recognized in the development of hydrology unless:
   a) It serves a watershed that is larger than 130-acres or otherwise significantly reduces the downstream flow rate, and
   b) It provides a regional function, and
   c) It is owned and maintained by a public agency, and
   d) The public agency has committed itself to maintain the detention facility so that it continues to operate in perpetuity as designed and built.

Photograph 3-5. Urban stormwater detention basins can create neighborhood amenities that at the same time serve their flood control function.

Importance of Implementing Master Plan Recommendations

The success of any master plan depends upon whether or not it is implemented. The master plan provides a "roadmap" for the future and provides the basis for incorporating the facilities and practices it recommends as lands develop or when funds become available to design and build new facilities. It also provides coherence of function so that each stormwater management facility, whether a channel, culvert, storm sewer, or detention basin provides the needed function to make the entire system work. Site drainage cannot function in a vacuum; it is affected by what happens upstream and, in return, affects what happens downstream.

When implementing a master plan a certain amount of flexibility is warranted, however, the spirit of the plan and its major features must not be compromised if the community desires to have the system function as intended in the plan. Nevertheless, some modifications of the plan are expected over time. Any major omission of a critical plan element, such as a regional flood-detention basin, will render the plan ineffectual and create a potential for damage to public health, safety, and welfare.

Any master plan is a living document. It cannot remain static for too long without outliving its usefulness. Thus, as areas urbanize and facilities are installed, it becomes evident over time that the assumptions made when the plan was developed may have changed, or the community needs are not the same anymore. As a result, most master plans have to be updated over time.

(Urbonas and Doerfer, 2003)

Storage areas for detention and water quality can have significant multipurpose uses and benefits related to recreation, water quality, aesthetics, and wildlife. In order to maximize these benefits, early coordination among the engineer, planner, parks and open space staff, and others is needed.

As a part of local ordinances across the UDFCD region, flood detention is required for new development and redevelopment. In some areas, regional facilities provide detention while in others sub-regional and on-site facilities are common. Under certain circumstances flood detention facilities may not be needed, although volumetric water quality may still be required. This is typically only the case for onsite facilities that have all of the following characteristics:

- The area has a direct outfall to a major waterway and is a small fraction of the overall watershed area with a time of concentration that is much shorter than the watershed time of concentration. Theoretically, for a uniformly spatially-distributed design storm, the runoff peak from a small, undetained property under this condition would enter the major drainage system and flow downstream long before the peak from the overall watershed occurs. This theory it is often referred to as "beat the peak."

- There are no benefits to be realized from detention in terms of sizing conveyance infrastructure from the property to the point of outfall.

- Undetained flows will not cause adverse impacts in terms of flooding, erosion and water quality to other structures or property, on the property or between the property and the point of outfall.

The decision on whether to grant a waiver from detention requirements typically rests with the local floodplain administrator.

3.4.6 Water Quality

Drainage planning for quantity (rate and volume) should proceed hand-in-hand with planning for water quality management. Generally, in urban areas, water quantity and water quality are inseparable. Volume 3 of the USDCM provides design criteria for best management practices (BMPs) recommended to mitigate the adverse effects of increased runoff rates and volumes and pollution, both during and post-construction. Another essential aspect of water quality protection is stream stability. Unstable streams can experience significant degradation and aggradation, both of which can be detrimental to aquatic life. Consequently, channel stability must be addressed during the planning process.

Photograph 3-6. A wide, open waterway carries floodwater at modest depths while maintaining low velocities to inhibit erosion.

4.0 Floodplain Management

Urbanization modifies the natural hydrologic and water quality response of the watershed. Because urbanization usually proceeds in accordance with land use rules and land development regulations and with the review and approval of detailed development plans, the local government in effect becomes a party to the inevitable hydrologic modifications. It follows that a community cannot disclaim liability from the consequences of such development, either upon the developed area itself or downstream therefrom. Government has a responsibility to protect the public's health and safety;

therefore, it is implicit that government is at the risk of incurring liability if it permits unwise occupancy or use of the natural floodplain easement. Floodplain regulation is the government's response to limit its liability and is an exercise of its health and safety protective function. The concept of the existence of a natural easement for the storage and passage of floodwaters is fundamental to the assumption of regulatory powers in a definable flood zone. Floodplain regulation must define the natural easement's boundaries and must delineate easement occupancy consistent with total public interests.

Key components of floodplain planning include reduction of the exposure to floods, use of development policies, disaster preparedness, flood risk management (see the *Flood Risk Management* chapter). The administrative tools created to undertake and implement a floodplain management program require a commitment of personnel, financing, and other resources. Flood control planning should consider the following management measures:

- Appropriate measures to limit development of land that is exposed to flood damage including:
  - Enacting floodplain management or other restrictive ordinances (i.e., building, subdivision, housing and health codes).
  - Preempting development of vacant flood fringe areas by public acquisition of land where appropriate for good drainage and community planning.
  - Adhering to Colorado Water Conservation Board (CWCB) and/or Federal Emergency Management Agency (FEMA) higher regulatory standards (critical facilities, freeboard, minimum floor elevations, etc.).
- Appropriate measures to guide proposed development away from locations exposed to flood damage include:
  - Developing floodplain regulations.
  - Limiting access to flood-prone areas.
  - Requiring setbacks from channel banks.
  - Restricting the reconstruction without mitigation of properties damaged by floods.
  - Withholding public financing from development projects in the floodplain.
  - Withholding utilities (electricity, water, sewers, etc.) from flood-prone area development.
  - Examining equivalent or similar alternative sites.
  - Maintaining low property value assessment for tax purposes allowing flood-prone land to economically remain idle.
  - Providing incentives for floodplain dedication to the public such as density credits.
- Appropriate measures to assist in reducing individual losses by flooding in areas developed before flood damage exposure was identified include:

- Structural flood abatement devices.
- Flood-proofing buildings.
- Early warning systems.
- Emergency preparedness plans (e.g., sandbagging, evacuation, etc.).
- Ongoing maintenance of the minor and major drainage systems.
- Disaster relief (funds and services).
- Tax subsidies (i.e., ameliorating assessments).
- Floodplain acquisition.

Furthermore, good urban drainage planning practices and management procedures should make it possible to initiate:

- Land use planning that recognizes flood hazards and damage that values the riparian environment along streams.
- A plan for expansion of public facilities that recognizes the implications of flood hazards for sewer and water extensions, open space acquisition, and transportation.
- Implementation of measures that demonstrate an existing or proposed floodplain management program such as:
  - Building codes, zoning ordinances, subdivision regulations, floodplain regulations, and map regulations with flooding encroachment lines. These should be consistent with land use recommendations discussed earlier.
  - Participation in regional land-use planning.
  - Participation in available floodplain management services, including flood warning systems.
  - Cooperation in flood damage data collection programs.
- Use of major public programs that are available (e.g., urban renewal, public health, open space, code enforcement, highway programs and demonstration programs).

Finally, the planner and engineers should understand the underlying principles of floodplain regulation, the requirements of the National Flood Insurance Act of 1968 (as amended), and state and local floodplain regulations to effectively plan for flood risk management.

5.0 Multi-use Opportunities

Regional detention facilities, preserved floodplains, and naturalized streams with hydraulically connected floodplains provide a wealth of natural and beneficial functions (NBFs), as discussed in the UDFCD's "Good Neighbor Policy." The land along natural streams and gulches has already been chosen by nature as a storm runoff easement for intermittent occupancy. Nature will always exact some price for use of its floodplains, so use of this land for open space is a good choice.

Zoning land for floodplains and limiting the potential uses of such land provides for open space and greenbelts that enable preservation of riparian zones. Floodplain land acquisition costs should be lower because of the limited potential for development without costly improvements and permitting.

The design team should develop park and greenbelt objectives in conjunction with the master planning and floodplain zoning. Without this early coordination, opportunities for multipurpose benefits may be lost. Additionally, working across local government departments presents opportunities to leverage funding and achieve multi-use objectives associated with open space and regional trail master plans.

Good Neighbor Policy

In 2011, the UDFCD Board adopted a "Good Neighbor Policy," which recognized a variety of opportunities that arise from drainage planning and programs. Among these, the UDFCD Board recognized the Natural and Beneficial Functions (NBF) of floodplains; including trail corridors, parks, recreation, wildlife habitat, flood storage, and groundwater recharge, can serve as amenities to adjacent neighborhoods and entire communities. The Good Neighbor Policy states:

- The Master Planning Program will, during the preparation of storm drainage criteria, major drainage plans, outfall systems plans, and other master planning studies, identify and incorporate NBF and other opportunities.
- The Floodplain Management Program will continue to map the 1% and 0.2% floodplains in undeveloped areas in order to identify areas that are hazardous to develop, and areas of significant NBF; and to work with local governments in the management of future development in or near these hazardous areas to minimize future flood risks and maximize preservation of the NBF.
- The Design, Construction, and Maintenance (DCM) Program will, when feasible, include amenities in flood management projects that enhance neighborhoods and preserve NBF. As a result of including these amenities, the public will be drawn to the flood management projects; therefore, public safety is of paramount importance and will be included in all planning, design, construction, operation, and maintenance of these facilities.
- The DCM Program will participate with local government partners and others such as Great Outdoors Colorado and the Trust for Public Land to acquire and preserve areas of significant NBF and/or flood hazards.
- The Information Services and Flood Warning Program will continue adapting state-of-the-art information technologies to keep decision-makers, partners and other stakeholders informed concerning past, present and future flood threats; and will provide local governments, consultants, affiliates, and the general public with easy access to educational material, publications and other helpful information associated with UDFCD programs and activities.

Utah Park: A Multi-Use Success Story

Utah Park, located at the northeast corner of Peoria Street and Jewell Avenue in Aurora, is a recreational area heavily used by the surrounding community that also serves on rare occasions as a regional flood detention facility. Utah Park provides recreational amenities including tennis courts, ball fields, trails and open space. This park is the upper-most flood detention facility on the main stem of Westerly Creek. In 2006, Utah Park storage capacity was expanded from 135 acre-feet (roughly the volume of the 50-year flood) to 160 acre-feet, the estimated volume of the 100-year flood.

During the September 2013 flood, Utah Park exceeded its 100-year capacity, with water reaching a peak depth of over 2 feet above the 100-year level during the afternoon of September 12. Floodwaters exceeded the capacity of the overflow spillway and overtopped the western bank onto Peoria Street as designed. Despite the fact that conditions significantly exceeded the design storm (100-year event), spillway overflows caused only limited damage. In the absence of this facility, widespread catastrophic damage would have occurred from flooding.

Aerial view of Utah Park a few days after record rainfall in 2013. (Photo: David Mallory).

Utah Park providing critical flood detention during the September 2013 flood.

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Flood Risk Management

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1.0 Introduction

This chapter addresses programs and policies adopted by the Urban Drainage and Flood Control District (UDFCD) to manage flood risks and reduce potential losses from flood events. This chapter also provides guidance for specific physical measures that can be implemented to help protect individual structures from flood damage.

Flood risk management includes all of the activities that the public and private sector can employ to reduce risk to individuals, structures, and communities from flooding. It includes master planning; floodplain management; design, construction and maintenance of flood management facilities; acquisition and relocation of structures at risk; floodplain preservation (including natural and beneficial functions); flood insurance; floodproofing; public information and awareness; flood warnings and preparedness; self-help; best management practices (BMPs); and green infrastructure. UDFCD pursues all of these activities to varying degrees. The theme of flood risk management is integrated throughout the Urban Storm Drainage Criteria Manual (USDCM), from key principles and policies in the *Drainage Policy* Chapter to guidance on master planning in the *Planning Chapter*, to criteria for designs in the *Open Channel* Chapter and others. The purpose of this chapter is to provide guidance on flood risk management topics not addressed in other portions of the USDCM. This chapter should be used in conjunction with the flood risk management policies, guidance and criteria in other portions of the USDCM.

UDFCD's Approach to Floodplain Management

Historically, development has encroached into floodplains, constricted floodways, impacted ecological integrity, and removed the natural character of riparian corridors. In recent years, enlightened developers have recognized the value of preserving floodplain, wetland, and riparian areas in general. This offers the opportunity to establish the character of the new development and offer amenities that are components of livable communities and healthy economies. UDFCD therefore advocates the following approach:

- Preserve floodplain and riparian systems to the greatest extent possible,
- Mitigate the effects of watershed urbanization with stream stability techniques, and
- Restore degraded and damaged stream systems.

A key component of flood risk management is the National Flood Insurance Program (NFIP), which was created in 1968 when Congress passed the National Flood Insurance Act. The NFIP is administered at the federal level by the Federal Emergency Management Agency (FEMA). UDFCD works closely with FEMA through its Cooperating Technical Partners (CTP) program.

Local, state, and federal governments and private insurance companies all have important roles related to the goals and objectives of the NFIP. The role of participating communities is especially important and is given special attention in this chapter. Communities (i.e., city, county, or other local governments) are eligible for federally-backed flood insurance if they have the statutory authority to adopt and enforce floodplain regulations and participate in the NFIP, and if they adopt the NFIP's minimum requirements, which include regulating development in mapped floodplains. Only when a community carries out its floodplain ordinance responsibilities can residents and property owners obtain flood insurance. UDFCD encourages all communities to participate in the NFIP and, currently, all of the communities within the UDFCD boundary that have mapped floodplains are participants.

This chapter provides a general overview of both preventive and corrective measures for mitigating flood risks. Topics addressed include:

- Floodplain management fundamentals, including definitions, key policies, and key strategies,
- Flood Hazard Area Delineation (FHAD) studies by UDFCD,
- Flood Insurance Rate Maps (FIRMs) and revision methods, such as Conditional Letters of Map Revision (CLOMRs), Letters of Map Revision (LOMRs), and others,
- The relationship between FHADs and FIRMs,
- Flood insurance,
- Floodplain regulations, and
- Floodproofing guidance.

A glossary of flood risk management terms is provided at the end of the chapter.

Ribbons of Green

Stream corridors and adjacent riparian zones are not geographically large; however, their environmental importance is immense. "Riparian areas comprise less than one percent of the land area in most western states, yet up to 80 percent of all wildlife species in this region of the country are dependent upon riparian areas for at least part of their life cycles." (Congressional Testimony of Robert Wayland, EPA, June 26, 1997). Riparian areas are often called "ribbons of green", reflecting the contrast with the otherwise dry landscape of the arid west. Agricultural and land development activities have resulted in loss or significant degradation of 75 to 95 percent of this invaluable habitat. Development projects have the opportunity to preserve, protect, and utilize stream corridors and adjacent riparian areas. In fact, increased urban runoff often results in sustained base flows in streams that were ephemeral in the pre-development condition.

Natural and Beneficial Functions of Floodplains

The low banks adjacent to streams are infrequently occupied by floodwaters. During a flood event, these overbank areas serve an important function in moderating peak discharges and velocities, and filtering out sediment and debris. The natural and beneficial functions of floodplains can be summarized as follows:

Flow conveyance - Floodplains have the capacity to store and convey floodwaters, thus diminishing floodwater velocities and reducing flood damages and erosion.

Soil fertility - Soil fertility is increased as periodic floodplain inundation replenishes nutrients in the surrounding soils.

Biodiversity - Floodplains enhance biodiversity, providing breeding and feeding grounds for fish and a wide variety of wildlife including endangered species.

Water quality - Floodplains improve water quality and quantity by providing areas of groundwater recharge, while also filtering impurities and nutrients.

2.0 Floodplain Management Fundamentals

2.1 Basic Definitions

In order to understand floodplain management, some of the key terms defined by and used throughout the NFIP are provided below. Additional terms are defined in a glossary at the end of this chapter. Much of the information provided here can also be found on the websites for FEMA (http://www.fema.gov) and the United States Army Corps of Engineers' (USACE) National Flood Risk Management Program (http://www.nfrmp.us/).

2.1.1 Floodplain

A floodplain is any land area susceptible to being inundated by flood waters from any sources. Most floods fall into one of three

categories: 1) riverine flooding, 2) shallow flooding, and 3) coastal flooding (not relevant within UDFCD). Riverine flooding is the most common along the Front Range of Colorado, and includes flash floods, which can occur in urban areas where impervious surfaces, gutters and storm sewers generate and convey runoff at a rate that exceeds the capacity of the receiving stream. Floodplain boundaries (i.e., the area inundated during a flood) typically are determined based on the peak runoff rate generated during a specific, design-storm event (see below).

2.1.2 100-year Flood/Base Flood

The 100-year flood has a 1 percent chance of occurring in any given year (Annual Exceedance Probability [AEP] = 0.01) and is referred to as the base flood by FEMA. The base flood is used by the NFIP for the purpose of requiring the purchase of flood insurance and regulating development. It should also be noted that the 100-year floodplain is an estimation of flood limits produced from a model that includes a large number of variables. At the same time, there are also variables that are not typically considered in this determination such as debris and mud flow, changes in vegetation, potential embankment failures (where present), and other "what if" scenarios. Determining the limits of flooding during this event draws a line which can be regulated. Those within "the line" and who don't own their home are required to buy flood insurance. Those who do own their home or who may be just beyond "the line" are not required to buy flood insurance. In reality, limits of flooding associated with this event frequently include homes beyond the mapped floodplain which means that structures close to a stream, even those outside the mapped area of flooding are still at risk. UDFCD recommends providing 18 inches or more of freeboard for new development projects to account for debris flow, aggradation, and changes in vegetation, as these cannot be considered when determining the regulatory floodplain.

Photograph 4-1. Colorado flooding in September of 2013 forced hundreds, many of them outside of mapped floodplains, out of their homes.

Properties Outside of the Mapped Floodplain are still at Risk

"More than 17 percent of homes destroyed or damaged in four of the counties hardest-hit by the September Floods in Colorado–Weld, Larimer, Boulder, and Logan, were NOT in the floodplain" (Brown and Crummy). Flood insurance outside of the floodplain can be purchased at a relatively low cost.

2.1.3 Base Flood Elevation

The base flood is used by the NFIP as the basis for mapping, insurance rating, and regulating new construction. The base flood elevation (BFE) is the computed elevation of the water surface during the base flood. BFEs are published in Flood Insurance Studies (FISs) and on FIRMs for Special Flood Hazard Areas (SFHAs) that have been identified as high-risk flooding zones and have consequently been studied in detail. BFEs are used by governmental agencies, insurance agencies, engineers, and others to manage development and determine property owners' risk to flooding.

2.1.4 Special Flood Hazard Area and Floodplain Zones

The base floodplain (1 percent chance of flood) is referred to as the SFHA on NFIP maps, otherwise known as FIRMs. The SFHA can have any of several designations (e.g., Zone A, AE, A1-30, AO, AH, V, VE or V1-30), depending on the flood data available, the severity of the flood hazard, and/or the age of the flood map (see Table 4-1 for definitions of different flood zones). In addition to the SFHA, Shaded Zone X areas also exist, which are generally areas that are outside of the 100-year floodplain, areas inundated with less than one foot of water during the 100-year flood, or areas that are within the 500-year floodplain. Unshaded Zone X areas are typically areas outside of the 500-year floodplain. The SFHA is the area, at a minimum, where NFIP floodplain regulations must be enforced by a community if it is a participant in the NFIP. The SFHA is also the area where mandatory flood insurance purchase requirements apply. Detailed definitions for flood zones can also be found on FEMA's website.

Table 4-1. FEMA Flood Zone Definitions

MODERATE TO LOW RISK AREAS	
Zone	**Description**
B and X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. Are also used to designate base floodplains of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than 1 foot or drainage areas less than 1 square mile.
C and X (unshaded)	Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level.
HIGH RISK AREAS	
Zone	**Description**
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas, no depths or base flood elevations are shown within these zones.
AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.
A1-30	These are known as numbered A Zones (e.g., A7 or A14). This is the base floodplain where the FIRM shows a BFE (old format).
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.
A99	Areas with a 1% annual chance of flooding that will be protected by a federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.
UNDETERMINED RISK AREAS	
Zone	**Description**
D	Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted. Flood insurance rates are commensurate with the uncertainty of the flood risk.

Notes: Definitions for high risk coastal zones are not provided here because they are not relevant to areas within the UDFCD boundary.

Flood Insurance Rate Maps relevant to areas within the UDFCD boundary have all been updated with the new flood zone nomenclature, so Zones A1-30 no longer exist on these FIRMs.

2.1.5 Floodway and Flood Fringe

Where a detailed study has been conducted, the floodplain includes two main components: 1) the regulatory floodway and 2) the flood fringe. In most waterways, the floodway is where the water flow is deepest and most rapid; within Colorado, it is the area that must be reserved (kept free of obstructions) in order to discharge the base flood without increasing 100-year water surface elevations more than 0.5-foot. In addition to the 0.5-foot surcharge, provide a minimum of one foot of freeboard above 100-year water surface elevations as shown on Figure 4-1.

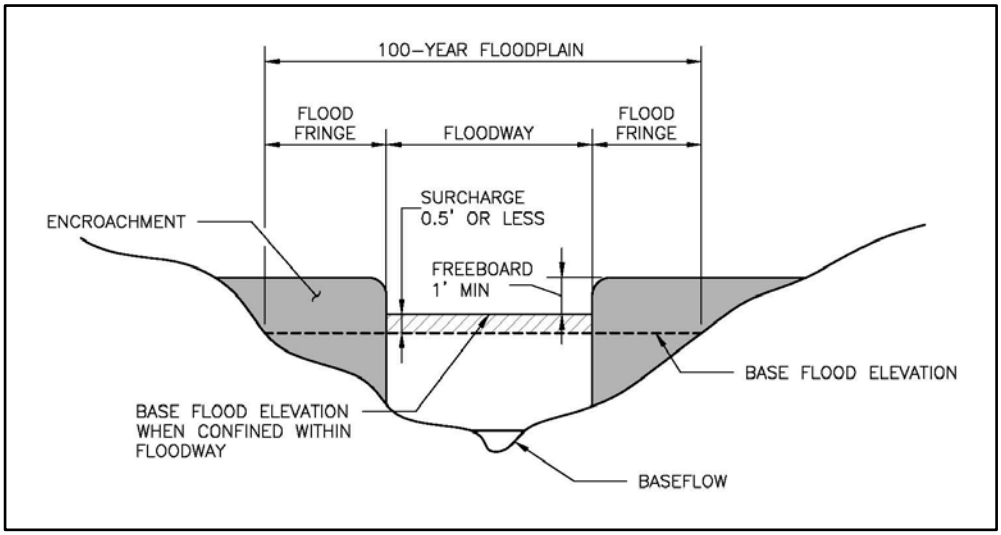

Figure 4-1. Floodway and flood fringe

Floodway boundaries are determined through the use of computer modeling. The flood fringe is the area located outside of the designated floodway but within the floodplain boundary. In contrast to the floodway, where no development is allowed, minimum NFIP regulations allow development within the flood fringe, though some communities adopt stricter regulations and restrict development within the flood fringe. The local floodplain administrator within a particular community can provide details about specific regulations pertaining to whether any development is allowed within the 100-year flood fringe.

2.1.6 Community Rating System (CRS)

The CRS program provides reductions in flood insurance premium rates based on a community's floodplain management activities. Communities that implement activities above and beyond the minimum requirements of the NFIP are eligible to receive reductions of up to 45 percent for flood insurance premiums. The reduction in rates is a reflection of reduced flood risks within the community. The voluntary program helps to reduce flood risks to insurable properties, strengthens insurance aspects of the NFIP, and encourages a comprehensive approach to floodplain management. UDFCD encourages communities to participate in the CRS program, and by doing so, citizens have an opportunity to benefit from the perspectives of both reduced flood risk and economics. Credits are provided for a variety of community flood protection activities.

2.1.7 CRS Credits

As a community accrues more points for implementing floodplain management activities, its CRS Class rating improves, corresponding to increasingly higher insurance discounts for its citizens. Points are awarded for engaging in any of 18 creditable activities, which fall under one of the following categories: 1) Public information; 2) Mapping and regulations; 3) Flood damage reduction; and, 4) Flood preparation.

In addition to lower flood insurance rates, there are several benefits of the CRS program:

- Increased opportunities for citizens and owners to learn about flood risk relative to their properties and businesses and how to better protect themselves,
- Enhanced public safety,
- Reduced damage to property,
- Decreased economic loss,
- Technical floodplain management activities are made available to community officials at no charge in some cases, and
- Incentives to maintain flood programs.

2.1.8 CRS Application Process

For a community to apply for CRS participation, their first step is to inform FEMA of their interest in applying. A CRS application must then be submitted, with documentation showing the activities the community is seeking credit for. The application, along with the floodplain activities for which the community is seeking credit, will be reviewed and verified. Once verified, the community, the State, insurance companies, and others will be notified by FEMA of the new credit to be granted.

To learn more about the CRS program, visit http://www.fema.gov/nfip/crs.shtm or contact UDFCD.

2.1.9 Flood Insurance Study (FIS)

The FIS is a report published by FEMA by county and issued along with the county FIRM. A FIS is a compilation and presentation of flood risk data for specific watercourses, lakes and coastal flood hazard areas within a community. The FIS contains background information such as the base flood discharges and water surface elevations used to develop the FIRM. The FIS and FIRM together serve as the basis for flood insurance ratings and regulating floodplain development.

2.2 Floodplain Management Strategies

In 1972 UDFCD adopted a two-pronged approach consisting of a comprehensive floodplain management program to prevent new problems from being created by new development, while "fixing" existing problems. UDFCD dedicates many resources to the planning, design, construction, and maintenance of projects aimed to fix past mistakes of development and works with FEMA, the Colorado Water Conservation Board (CWCB), and local governments to utilize and enforce floodplain regulations effectively. The two–pronged approach can be described as follows:

- **Floodplain Preservation.** Identify areas of significant natural and beneficial functions relevant to floodplains and manage future development in these areas in a way that preserves these floodplains. Natural and beneficial functions of floodplains include the following:

    1. Floodplains diminish floodwater velocities and reduce flood damages and erosion through their natural characteristics of conveyance and storage.

2. Soil fertility is increased as floodplains naturally replenish nutrients during times of flood inundation.

3. Floodplains improve water quality and quantity by filtering impurities and recharging groundwater.

4. Floodplains provide breeding and feeding grounds for fish and wildlife.

- **Mitigation of Effects of Urbanization.** Work with local governments and developers to manage future development in or near hazardous areas to minimize future flood risks and identify areas potentially subject to flood hazards by mapping the 1% (100-year) floodplain and 0.2% (500-year) floodplain in undeveloped areas. UDFCD encourages the implementation of stream stability and improvement techniques to mitigate the effects of urbanization, such as increases in flood flows, velocities, shear forces and other hydraulic parameters, which can cause erosion and stream decay.

FEMA also identifies key floodplain management strategies for reducing economic losses and reducing losses of beneficial floodplain resources as a result of flooding. Figure 4-2 illustrates how these strategies are applied to reduce flood risk through federal, state, local, and individual efforts. FEMA's four strategies are:

- **Strategy 1**. **Modify human susceptibility to flood damage:** Replace disruption by avoiding hazardous, uneconomic or unwise use of floodplains. This strategy includes policies such as using zoning codes to direct development out of the floodplain; acquiring land in floodplains to preserve open space; and restoring and preserving the natural resources and functions of floodplains.

- **Strategy 2. Modify the impact of flooding:** Assist individuals and communities to prepare for, respond to, and recover from a flood. Actions to implement this strategy include providing information and education to assist communities with flood protection following flood emergency measures during a flood; reducing financial impacts through disaster assistance, flood insurance, and taxes; and preparing recovery plans and programs to help people rebuild.

Advantages of Sustainable Floodplain Management for Communities

There are tremendous advantages to communities that encourage a thoughtful approach to development adjacent to natural streams:

- UDFCD assistance in meeting NFIP maintenance responsibilities.
- CRS credits for floodplain preservation.
- Linear recreation corridors.
- Community identification and sense of community that encourages volunteerism.

Advantages of Sustainable Floodplain Management for Developers

UDFCD recognizes that development is essential to community building. Good environmental stewardship cannot exist in the absence of a good business process. When the approach to stream corridors turns from overcoming a problem to embracing a resource, the following positive outcomes emerge:

- Lower capital costs,
- Lower operation and maintenance costs,
- Open space credits,
- Multi-use opportunities, including parks and recreation,
- Increased marketing potential,
- Lot premiums adjacent to stream corridors,
- Community character and identification, and
- Neighborhood ownership of the stream corridor.

- **Strategy 3**. **Modify flooding itself:** Develop projects that control floodwater. Projects include dams and reservoirs that store excess runoff from developed areas upstream; creating dikes, levees, and floodwalls around developed areas; altering channels to increase flow capacity; diverting high flows around development; increasing pervious ground covers in developed areas; and developing on-site detention.

- **Strategy 4**. **Preserve and restore natural resources:** Renew the purpose of floodplains by reestablishing and maintaining floodplain environments in their natural state. Policies to implement this strategy include developing land use regulations such as zoning; acquiring land for open space; permanently relocating buildings; restoring floodplains, wetlands, and habitats; educating people on the importance of floodplains as natural resources and how to protect them; and providing financial initiatives for preserving and/or restoring land.

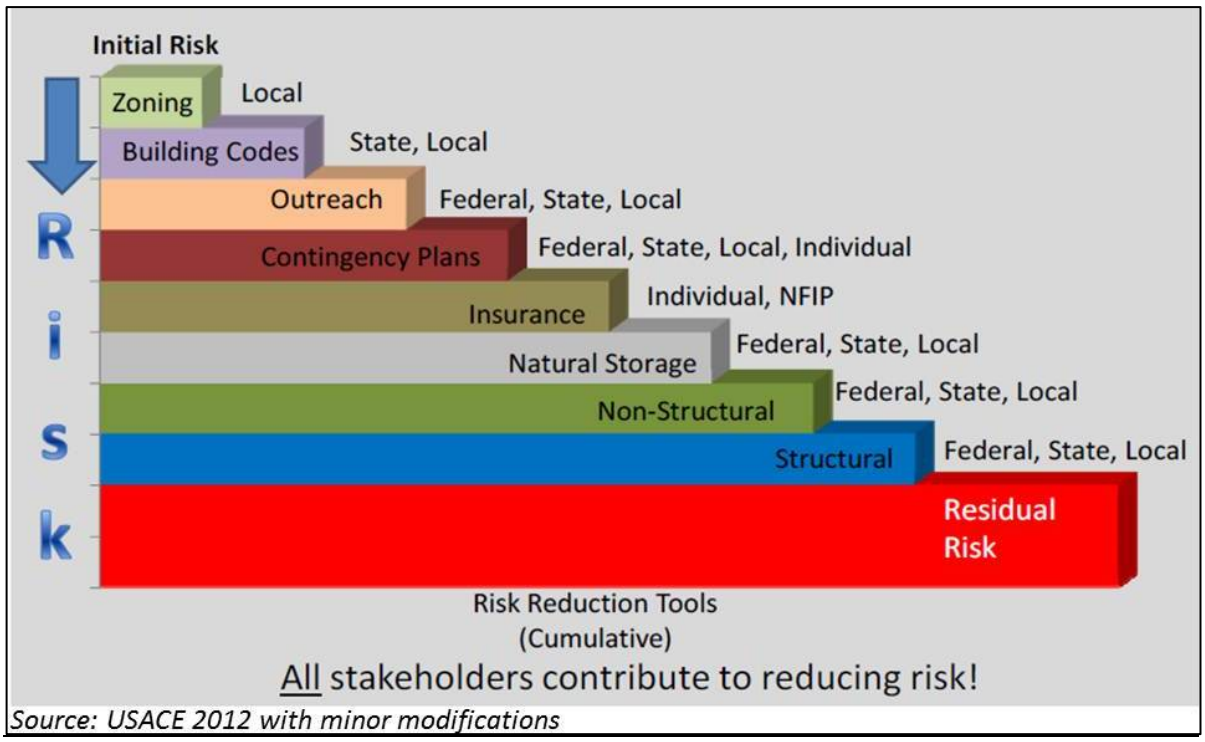

Figure 4-2. Shared strategies to "buy down" flood risk

3.0 Floodplain Mapping Changes and Administration

3.1 Background Information

FHADs and FIRMs are important tools that allow communities to manage floodplains and help to reduce flood risk by regulating development within mapped floodplains. FHADs delineate floodplain areas inundated by the 100-year flood and publish flood profiles for the 100-year flood and other flood frequencies. Hydrologic and hydraulic studies are performed to evaluate changes in watersheds and flood hazard areas. These changes are evaluated, including Master Planning changes which have been implemented, to predict the potential extent of flooding in flood-prone areas. UDFCD offers FHADs to communities within the UDFCD boundary as a tool to help preserve floodplains and reduce the risks of flooding to existing and future development. UDFCD currently does not regulate floodplains based on

FHAD studies, but instead relies on local governments to utilize FHAD mapping in conjunction with other resources to manage and administer floodplain regulations. FHADs often serve as the basis for FEMA FIRMs.

FIRMs show information such as the locations of properties relative to the 100-year floodplain, the type of SFHA zone for a property, the relative 100-year water surface elevations (BFEs), the vertical datum used for the BFEs and more. FIRMs are also used for flood insurance ratings and for making reasonable determinations of required flood insurance. By contrast, FHADs are typically based on contour intervals of two-foot or less (i.e., more precise resolution). For this reason, FHADs should be referenced when conducting localized planning and design.

FHADs are available through the Electronic Data Management (EDM) Map available at www.udfcd.org. The EDM is a user-friendly database that provides access to many resources including FHADs, as-built drawings, design reports, major drainageway planning studies, monument information, outfall systems planning studies, and other special reports. Flood hazard information included on the EDM is based on the best available data although floodplain maps included with the actual FHAD report will provide the most detail with regard to the delineation. While information on the EDM may be more current, it may differ from the official, effective Federal flood hazard information used in the NFIP. The official Federal flood hazard information for a given location needs to be obtained from FEMA. FEMA has a National Flood Hazard Layer (NFHL) that shows all digital flood hazard information for a given location. FEMA updates the NFHL with all approved PMRs and LOMRs.

Effective FIRMs may need to be updated or corrected by FEMA, communities, UDFCD, or individuals. Reasons for revising a floodplain map include:

- Non-flood-related map features (e.g., corporate boundaries) need correction.
- Current, more accurate topography is available and needs to be incorporated.
- Existing flood data, such as base flood elevations or new hydrology, need to be incorporated.
- A flood control project needs to be reflected in the mapping.

It is important to note that many small projects, such as clearing of overgrown vegetation along channels, minor bank stabilization work, and small-scale maintenance activities and projects do not have a measurable effect on the base flood and do not warrant a map change. Requests for map changes should be prepared by an engineer familiar with the FEMA guidelines.

Cooperating Technical Partner

The UDFCD Floodplain Management Program is a Cooperating Technical Partner (CTP) with FEMA and was the first CTP in the country. The Floodplain Management Program reviews Letter of Map Change (LOMC) submittals within UDFCD's service area in addition to completing flood insurance map modernization and maintenance projects.

When new map information becomes available to a community, the community is obligated by its agreement with FEMA to submit it as soon as practicable, but not later than six months after the date that the information became available (NFIP Section 65.3). Within the UDFCD boundary, CLOMRs and LOMRs, described in Section 3.3, are currently reviewed by UDFCD, which is a CTP with FEMA.

3.2 Types of Regulatory Floodplain Map Changes

Four types of map changes exist related to regulatory floodplains, including:

1. Restudies,
2. Physical Map Revisions (PMRs),
3. Revisions, and
4. Amendments.

Of the four types of map changes, UDFCD typically only administers the third category, map revisions (i.e., CLOMRs and LOMRs), for communities within their boundary. Brief descriptions of the different types of map changes include the following:

National Flood Hazard Layer (NFHL)

The NFHL is a computer database that contains the flood hazard map information from Digital Flood Insurance Rate Map (DFIRM) databases and LOMRs. The NFHL provides DFIRM and LOMR data as one integrated dataset. Letters of Map Amendment (LOMAs) and Letters of Map Revision Based on Fill (LOMR-Fs), which are based on property descriptions, are notated with a case number but not shown graphically. An NFHL dataset includes all the digital flood hazard data that are effective and available as of the dataset release date.

NFHL coverage is available in the UDFCD region. The NFHL is available on FEMA's website and can be used with GIS, as well as Google Earth.

Restudy: A restudy is a new Flood Insurance Study for a part or all of a community. A restudy may occur in cases where the hydrology (peak flow rates) has changed, perhaps due to increased development, new information, or changed topography. Another example of a restudy is when a community is interested in establishing BFEs along a watercourse located in an approximate or unnumbered Zone A (where BFEs have not previously been defined). UDFCD typically does not conduct restudies unless provided a grant to do so.

PMR: A PMR is an action whereby one or more map panels are physically revised and republished. A PMR is used to change flood risk zones, floodplain and/or floodway delineations, flood elevations, and/or planimetric features. A PMR requires the same detailed analysis as a LOMR but typically covers a greater area.

Revision: A map revision may be necessary for the following cases:

- A scientifically-based challenge to a published BFE has been confirmed.
- New flood data is available because of a flood control project.
- A physical change has occurred in the floodplain or floodway boundaries.
- New flood data are available.
- Fill has been placed in the floodplain that would change the effective floodplain.

Amendment: A map amendment is used to remove a specific property that was inadvertently or incorrectly mapped in the SFHA from the requirement to purchase flood insurance. For example, this can occur because of high ground that is not reflected on the map which delineates the SFHA. Map amendments do not change the SFHA on the FIRM.

3.3 Requests for Letter of Map Change

In order to officially revise a FIRM (or DFIRM), a LOMC must be issued by FEMA. A LOMC is a letter which reflects an official revision to an effective NFIP map. There are several types of requests for LOMC that can be submitted to FEMA, two of which are submitted to and reviewed by UDFCD. These are described below:

CLOMR: A CLOMR is FEMA's comment on a proposed project that would affect the hydrologic and/or hydraulic characteristics of a flooding source and, consequently, result in the modification of the existing regulatory floodway or effective BFEs. A CLOMR does not revise an effective NFIP map, but rather it indicates whether the project, if built as proposed, would or would not be removed from the SFHA by FEMA if later submitted as a request for a LOMR. A CLOMR becomes effective on the date sent and there is no appeal period. UDFCD reviews CLOMR applications for all areas within its boundary.

CLOMR-F: A Conditional Letter of Map Revision Based on Fill (CLOMR-F) is FEMA's comment on whether a proposed project involving the placement of fill would result in an area being removed from the SFHA on the NFIP map. This letter does not revise an effective NFIP map, but indicates whether the project, if built as proposed, would or would not be removed from the SFHA by FEMA if later submitted as a request for a Letter of Map Revision Based on Fill (LOMR-F). The CLOMR-F becomes effective on the date sent. CLOMR-F applications are not reviewed by UDFCD. For a project within the UDFCD boundary, a CLOMR-F application can be sent directly to FEMA for review.

LOMA: A LOMA is an official amendment, by letter, to an effective NFIP map. A LOMA establishes a property's location in relation to the SFHA. LOMAs typically remove areas that are inadvertently mapped in the 100-year floodplain. While a LOMA can be used to establish that a specific structure or parcel is not included in the SFHA, LOMAs do not change the delineation of the SFHA on the FIRM. UDFCD does not review LOMA requests; such requests must be submitted directly to FEMA. The map amendment becomes effective on the date of the approval letter sent by FEMA.

LOMR: A LOMR is an official revision, by letter, to an effective NFIP map. A LOMR may change flood insurance risk zones, floodplain and/or floodway boundary delineations, planimetric features, and/or BFEs. The letter becomes effective after a 90-day appeal period in addition to the time required to advertise the appeal. UDFCD reviews LOMR applications for all areas within its boundary.

LOMR-F: A LOMR-F is an official revision, by letter, to an effective NFIP map. A LOMR-F provides FEMA's determination concerning whether a structure or parcel has been elevated on fill above the BFE and excluded from the SFHA. LOMR-F applications are not reviewed by UDFCD; they must be submitted directly to FEMA. The map amendment becomes effective on the date of the approval letter sent by FEMA. A LOMR-F does not change the SFHA on the FIRM, and is therefore discouraged by UDFCD.

If physical changes to the floodplain have changed the flood hazard information shown on the effective FIRM, a revision must be requested. As soon as practicable, but not later than six months after the date such information becomes available, a community must notify FEMA of the changes by submitting technical or scientific data in accordance with Code of Federal Regulation 44 CFR 65.3. The request must be accompanied by the appropriate portions of the MT-2 application forms package, titled *Revisions to National Flood Insurance Program Maps* (FEMA Form 81-89 Series), along with the required supporting information. Within the UDFCD boundary, UDFCD will review the request on FEMA's behalf. See FEMA's website for all map change forms.

4.0 Flood Insurance

The Flood Disaster Protection Act of 1973 added a key requirement to the NFIP. If a community participates in the NFIP, flood insurance is a prerequisite for receiving grants or loans for the purchase of buildings located in a designated floodplain, if the grant or loan is from a federal agency or through a federally-related loan program.

The mandatory flood insurance requirement applies to all forms of federal or federally-related financial assistance for buildings located in SFHAs. The requirement applies to secured mortgage loans from all financial institutions such as lenders, savings and loan institutions, banks, etc., as well as all mortgage loans purchased by Fannie Mae or Freddie Mac.

Population Growth and Floodplain Management

Since 1969 the population living within the boundaries of the UDFCD has tripled; however, UDFCD estimates that there are 5,000 fewer structures in mapped 100-year floodplains than there were in 1969. This is due to UDFCD's two-pronged approach to floodplain management of preserving floodplains in areas that have not yet developed and implementing remedial measures where there are existing flood hazards.

4.1 Purchasing Flood Insurance

NFIP coverage is available to all owners of eligible property (a building and/or its contents) located in a community participating in the NFIP. Either property owners or renters may insure their property against flood loss. As long as a property is located in a community that participates in the NFIP, it is eligible to have flood insurance, even if the property is not located in a designated floodplain, provided that the building has two or more outside rigid walls, a fully secured roof affixed to a permanent site, and the building is not: 1) located entirely over water, or 2) located principally below ground. Owners of buildings under construction, condominium associations, and owners of residential condominium units in participating communities all may purchase flood insurance. Condominium associations may purchase insurance coverage on a residential building, including all units, and the building's commonly owned contents under the Residential Condominium Building Association Policy (RCBAP). The unit owner may separately insure personal contents as well as obtain additional building coverage under the Dwelling Form as long as the unit owner's share of the RCBAP and the added coverage do not exceed the statutory limits for a single-family dwelling. The owner of any condominium unit in a non-residential condominium building may purchase only contents coverage for that unit.

5.0 UDFCD, Local, and State Floodplain Management Programs

As noted in Section 1, a primary component of flood risk management is the NFIP, which is administered at the federal level by FEMA (within the UDFCD boundaries, UDFCD acts as an agent of FEMA). At the state level, floodplain rules and regulations are promulgated by the CWCB, and at the local level, the requirements of the NFIP, at a minimum, are adopted and enforced by communities that participate in the NFIP. Pertinent regulations at the different levels of government are summarized in the following sections.

5.1 UDFCD Programs

UDFCD operates four programs, all of which play a role in flood risk management. These programs include:

- The Master Planning Program identifies areas of existing problems, areas that will require

improvements as development occurs in the future and addresses the preparation of conceptual plans for drainage and flood control infrastructure.

- The Floodplain Management Program serves to keep new land development out of floodplains, while emphasizing their natural and beneficial functions.
- The Design, Construction and Maintenance Program corrects existing problems, emphasizing multiple-use opportunities, and maintains structural and non-structural solutions.
- The Information Services and Flood Warning Program provides valuable support to the preceding programs.

This approach to floodplain management has been effective, with the Floodplain Management Program leading preventive efforts and the Design, Construction, and Maintenance Program focusing on remedial efforts. Both of these are supported by the Master Planning and Information Services and Flood Warning Programs.

Descriptions of these programs as they pertain to floodplain management are provided below:

5.1.1 Master Planning Program

The Master Planning Program partners with communities within the UDFCD boundary in the development of master plans–Major Drainageway Plans and Outlet System Plans. Master plans are an important tool to help identify remedial flood risk management projects for construction and to guide new land development projects to be consistent with regional drainage and flood control needs. Master plans also provide valuable input to UDFCD's Five Year Capital Improvement Program, and help with the identification and acquisition of rights-of-way for future capital improvements and areas for preservation. The master planning program at UDFCD also promulgates design criteria for use by consultants working on UDFCD projects and those working for a developer.

5.1.2 Floodplain Management Program

One of the primary functions of the Floodplain Management Program is to prevent new flood damage potential from being introduced into the 100-year floodplains. This program assists local governments to assure they remain in the NFIP and keep flood insurance available for their citizens. UDFCD also works with FEMA and, since 2001 has received annual grants from FEMA to review requests for Letters of Map Change to FIRMs at the local level. UDFCD also has received several grants from FEMA for map modernization and maintenance.

"Good Neighbor Policy"

The UDFCD "Good Neighbor Policy" was passed by the UDFCD Board of Directors in 2011 in recognition of the importance of natural and beneficial functions of streams and floodplains, including trail corridors, parks, recreation, wildlife habitat, flood storage and groundwater recharge. The policy states UDFCD's commitment to preserving and enhancing natural and beneficial functions in all UDFCD programs. The policy includes partnering with local governments and others such as Great Outdoors Colorado and the Trust for Public Land to acquire and preserve areas of significant natural beneficial functions and/or flood hazards. The "Good Neighbor Policy" formalizes approaches that have been developed for many years by UDFCD to sustainably manage streams and floodplains.

In lieu of using its authority to regulate floodplains, UDFCD provides an incentive program, called the Maintenance Eligibility Program (see inset), and works with local governments to implement their own regulations.

The Floodplain Management Program reviews and comments on proposed developments in or near floodplains at the request of local governments. Through this process, developers and local governments are strongly encouraged to follow or implement the appropriate portions of UDFCD master plans. This also provides an opportunity for UDFCD to guide development away from the floodplains and to encourage communities to utilize the natural and beneficial functions of the floodplains as assets to their developments and their communities.

UDFCD Maintenance Eligibility Programs

In 1980, UDFCD adopted a Maintenance Eligibility Policy, which states: "Facilities constructed by, or approved for construction by, a local public body as of March 1, 1980, must be approved by the UDFCD in order for these facilities to be eligible for UDFCD maintenance assistance." The Maintenance Eligibility Program is run by the Floodplain Management Program and provides a mechanism for UDFCD to ensure that facilities are built to criteria that both allow for maintenance and provide multi-use benefits and preservation of beneficial natural functions.

With a preference for preservation over channelization or fill, the determination of maintenance eligibility rests with the Floodplain Management Program. The less disruption of the floodplain, the easier it is for the project to be eligible. In many cases, grade control and a maintenance access trail are all that is required to be eligible for maintenance.

5.1.3 Design, Construction, and Maintenance Program

The design and construction of master-planned projects are carried out through the Five Year Capital Improvement Plan (CIP). Each year the UDFCD Board adopts a Five Year Capital Improvement Plan which lists projects and UDFCD participation for the next five years. This plan forms the basis for UDFCD participation in design and construction projects. The emphasis of the Design, Construction and Maintenance Program is to provide flood management projects that serve multiple purposes, and to the extent possible, preserve, enhance, or recreate the natural and beneficial functions of the floodplain.

The Design, Construction, and Maintenance Program also provides long term maintenance for projects built by UDFCD, as well as those approved as part of the Maintenance Eligibility Program. This maintenance includes routine efforts such as debris removal and management of the vegetation, as well as long term structural repairs as needed for drainage facilities.

5.1.4 Information Services and Flood Warning Program

The Information Services and Flood Warning Program was established to enhance flood warning capabilities within the UDFCD region and consolidate and make available pertinent information. The Flood Warning Program assists local governments in developing flood warning plans and installing and maintaining automated flood detection networks. In addition, UDFCD contracts with a meteorological service to provide local governments with early predictions of flood potential and to warn them as flood threats become more imminent. Daily forecasts and real-time data are available from UDFCD's website. This UDFCD Program includes a number of vital multi-program support functions such as: developing, operating and maintaining UDFCD's Geographic Information System (GIS). GIS is used extensively for DFIRM production and maintenance, tracking projects for maintenance eligibility, design and

construction projects, routine and restorative maintenance projects, flood threat recognition and warning decision support, data sharing, regional mapping initiatives, and other applications.

5.2 Local Floodplain Regulations

For the purposes of the NFIP, a community is a political entity that has the authority to adopt and enforce a floodplain ordinance for the area under its jurisdiction. The participating communities in the NFIP carry out floodplain administration at the local level. Communities can benefit from both FEMA programs and UDFCD programs, as described below.

5.2.1 FEMA Programs for Participating Communities

There are two key FEMA programs for participating communities:

Community Rating System (CRS): The CRS is a voluntary program established by the NFIP to assist communities that want to reduce flood insurance premium rates based on a community's floodplain management activities. Communities that implement activities above and beyond the minimum requirements of the NFIP are eligible to receive reductions in rates of up to 45 percent for flood insurance premiums for properties within the community. Credits are provided for a variety of community flood protection activities (ASFPM 2009).

Community Assistance Program (CAP): (FEMA 480) CAP is a FEMA program that funds state activities which help communities that participate in the NFIP. States participating in the NFIP are eligible for CAP federal funding assistance. CAP is intended to help states identify, prevent and resolve floodplain management issues in participating communities prior to a flood occurring (ASFPM 2009).

5.3 State Floodplain Rules and Regulations

Rules and regulations for regulatory floodplains in the State of Colorado are designated and approved by the CWCB, which is part of the Department of Natural Resources (DNR). In general, the purpose of the Colorado rules are to provide uniform standards for regulatory floodplains in Colorado and to provide standards for activities that may impact regulatory floodplains.

The Colorado rules also assist the CWCB and communities with the development of floodplain management practices that are sound and that facilitate implementation of the NFIP. The Colorado rules apply throughout the state, regardless of whether a community participates in the NFIP. The rules also apply to activities conducted by state agencies and to federal activities that are fully or partially financed

Useful Links for Federal Floodplain Regulations

Code of Federal Regulations
44 CFR, Parts 59, 60, 65 and 70 http://ecfr.gpoaccess.gov

NFIP
Information and links on multiple aspects of the NFIP http://www.fema.gov/business/nfip

FEMA Map Service Center
Flood Insurance Rate Map information http://www.fema.gov/national-flood-insurance-program/map-service-center

by state funds, or for projects or studies for which the CWCB has made a loan or grant (DNR 2010).

The most recent version of the rules and regulations for Colorado was adopted on November 17, 2010 and became effective on January 1, 2011. The revised Colorado floodplain rules and regulations include 20 rules. Obtaining the complete version of these rules from CWCB website (http://cwcb.state.co.us/legal/Pages/Rules.aspx) is recommended. A few key aspects of these rules include the following:

Critical Facilities: The revised Colorado rules have special requirements for Critical Facilities regarding development in floodplains (see inset).

Standards for Regulatory Floodways: In cases where floodways are to be delineated through physical map revisions involving local government participation, communities shall delineate floodways for the revised reaches based on a 0.5-foot rise criterion. (Note: This is a change from the previous rules, which based floodways on a 1-foot rise criterion. For the definition of "floodway," see the Glossary at the end of this chapter.)

Criteria for Determining the Effects of Flood Control Structures on Regulatory Floodplains: If a publicly operated and maintained structure is specifically designed and operated either in whole or in part for flood control purposes, its effects shall be taken into consideration when delineating the floodplain below such structure. If a structure is not specifically designed and operated for flood control purposes (e.g., such as a roadway embankment), then its effects shall not be taken into account, even if it provides inadvertent flood routing capabilities that reduce the 100-year flood downstream. In addition, the CWCB recommends that irrigation facilities (including, but not limited to, ditches and canals) not be used as stormwater or flood conveyance facilities, unless specifically approved and designated by local governing jurisdictions and approved by the irrigation facility owners.

Critical Facilities – Floodplain Regulation

Critical Facilities in Colorado are subject to special requirements regarding their location within regulatory floodplains. Critical Facilities generally consist of the following categories (refer to the state regulations for detailed descriptions):

Essential Services: These include police and fire stations, hospitals, emergency shelters, communication hubs (e.g., telephone, broadcasting, etc.), public utility plants, and air transportation lifelines (airports, helicopter pads, air traffic control centers). Wastewater treatment plants, water treatment plants and hydroelectric facilities are specifically exempt from this category.

Hazardous Materials: Facilities that produce or store highly volatile, flammable, explosive, toxic and/or water-reactive materials are in this category. Examples include chemical plants, pharmaceutical manufacturing facilities, certain laboratories, refineries, hazardous waste and disposal sites, and above-ground gasoline storage or sales centers.

At-Risk Populations: Examples of facilities with at-risk populations include nursing homes, day care and assisted living for 12 or more individuals, pre-schools, and K-12 schools.

Vital to Restoring Normal Service: Facilities in this category include government operation (such as courts, jails, building permitting, and maintenance facilities) and essential structures for public colleges and universities (dormitories, office and classrooms).

The local jurisdiction having land use authority has the responsibility of identifying Critical Facilities in a community. Key components of the Critical Facility regulations include: 1) communities are encouraged to limit development of Critical Facilities within the 500-year floodplain, where possible, 2) all new and substantially changed critical facilities located within the 100-year floodplain shall have 2 feet of freeboard (instead of 1 foot), and 3) ingress and egress for new critical facilities shall have continuous non-inundated access for evacuation and emergency services.

Criteria for Determining the Effects of Levees on Regulatory Floodplains: Both UDFCD and CWCB discourage the use of levees for property protection, flood control, and flood hazard mitigation, unless other mitigation alternatives are not viable. Levees should not be constructed for the primary purpose of removing undeveloped lands from mapped floodplain areas for the purposes of developing those lands because of the potential impairment of the health, safety, welfare and property of the people. Design and construction of levees identified for this purpose are not eligible for UDFCD maintenance or for CWCB grants or loans. The Rule also provides requirements for mapping areas protected by levees, levee maintenance, ownership, freeboard, interior drainage, human intervention and operation, and analysis.

Recommended Activities for Regulatory Floodplains: The CWCB lists numerous floodplain management activities and actions to increase a community's overall level of flood protection. These suggestions include, but are not limited to, the following practices:

- Adopting local standards above and beyond the FEMA and CWCB minimum requirements,
- Enrolling in the NFIP and the Community Rating System programs,
- Developing early warning flood detection systems,
- Educating real estate and lending professionals about state and federal requirements,
- Advising the public that floods greater than the 100- and 500-year events do occur, and
- Prohibiting the construction of new levees that are intended to remove land from a regulatory floodplain for the purpose of allowing new development to occur.

6.0 Floodproofing

6.1 Definition of Floodproofing

Floodproofing is any combination of structural or nonstructural changes or adjustments incorporated in the design, construction, or alteration of individual buildings or properties that will reduce damage from flooding.

6.2 Scope of Floodproofing Guidance Provided

The primary focus of this section is on floodproofing commercial, institutional and critical facilities (public works projects). This section is not intended to address residential floodproofing.

For general guidance on residential floodproofing measures, FEMA has prepared the "Homeowner's Guide to Retrofitting," available online at: http://www.fema.gov/library/viewRecord.do?id=1420. Avoidance of development in floodplains is the preferred approach for flood risk management for residential development.

6.3 Typical Causes of Flooding

Flooding in the UDFCD region typically results from heavy rains during the spring and summer months. Intense rainfall can lead to flooding and, in general terms, is exacerbated by increased impervious cover associated with urban development. Typical causes of flooding are described in the following sections.

6.3.1 Inadequate Street Conveyance

As discussed in the *Street, Inlets, and Storm Drains* chapter, the minor drainage system should be designed to convey flows generated by storms ranging between the 2-year and 10-year event. Over time, the street conveyance capacity can be diminished by pavement overlays that reduce the gutter depth and alter the design slopes. As a result, even during minor storms, water can pond or exceed the gutter capacity and result in localized flooding.

6.3.2 Inadequate Storm Drain Conveyance

Older sections of the metropolitan area have storm drain systems that were constructed prior to the development of current drainage criteria. In many cases, capacity is limited to the 2-year, or more frequent, design storm. A less frequent storm event, such as the 5-year event, has larger flows and could cause surcharging in the storm drains and the occurrence of localized flooding.

6.3.3 Inadequate Channel Conveyance

Prior to the development of current floodplain and drainage criteria, development often encroached on natural streams which resulted in reduced conveyance capacity. Overbank flooding is the most dangerous type because of the combination of velocity and depth of floodwaters. Adherence to a community's floodplain requirements is important. The goals of these requirements include limiting development within the floodplain and restricting development within the floodway.

6.3.4 Sewage Backup

Flooding can inundate and overload sanitary sewer systems. As a result, water can flow backward through sewer lines and out through toilets or floor drains. Protection against sewage backup is typically addressed with the installation of a backflow valve in the sanitary service line running from the house.

6.4 Factors That Affect Flooding Damage

Damage to structures from flooding is primarily determined by a combination of the following six factors:

- Depth/elevation,
- Velocity of flow,
- Frequency of occurrence,
- Rates of rise and fall,
- Duration, and
- Debris impact.

Each of these factors is described further below.

6.4.1 Depth/Elevation of Flooding

The depth and elevation of flooding are closely related and are viewed as a single characteristic for the purpose of this discussion. Flood depth is the height of the floodwater above the surface of the ground or other feature at a specific point. Flood elevation is the height of the floodwater above an established reference datum. The standard datums used by most federal agencies and many state and local agencies are the National Geodetic Vertical Datum (NGVD) and the North American Vertical Datum (NAVD), though other datums are also used.

Whereas ground elevations are established by surveys, flood elevations may be calculated or surveyed from watermarks left by floods. Elevations of the ground, floodwaters, and other features cannot be meaningfully compared with one another unless they are based on the same datum. The flood depth at any point is equal to the flood elevation minus the elevation of the reference point (such as the ground or the lowest floor of the building), assuming that all elevations are based on the same datum. Figure 4-3 illustrates this relationship.

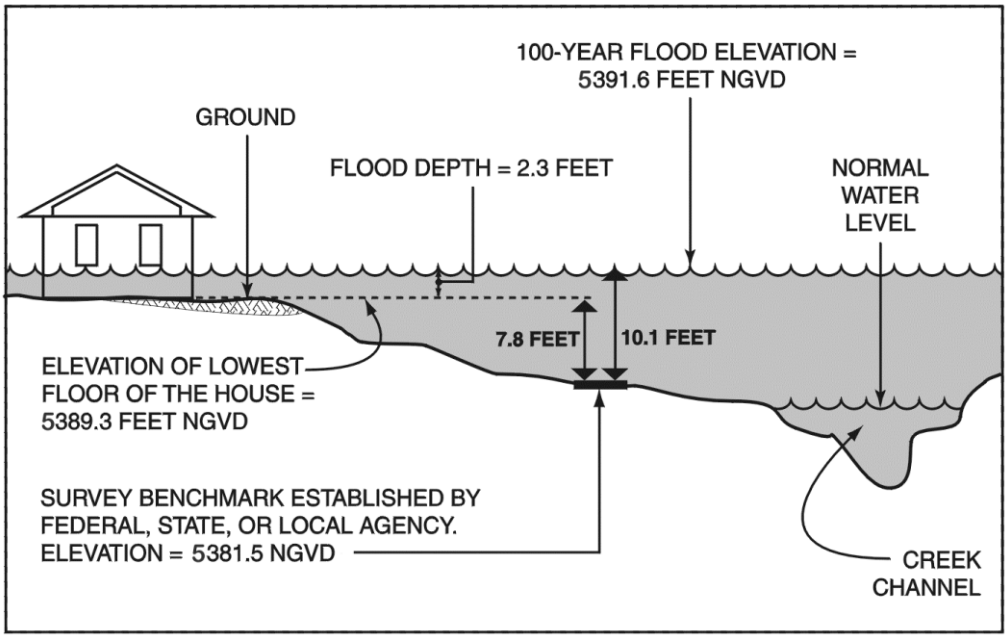

Figure 4-3. Schematic representation of flood depth and flood elevation

The depth of water during a flood directly affects the forces exerted on the building, including buoyant forces and hydrostatics pressure, as illustrated below.

Buoyant Force: Water surrounding and underneath a building, such as situations where soils are saturated around a basement or crawl space, creates a buoyant force upward on the floor slab, as shown in Figure 4-4. The buoyant force is directly related to the depth of water above the elevation of the floor slab.

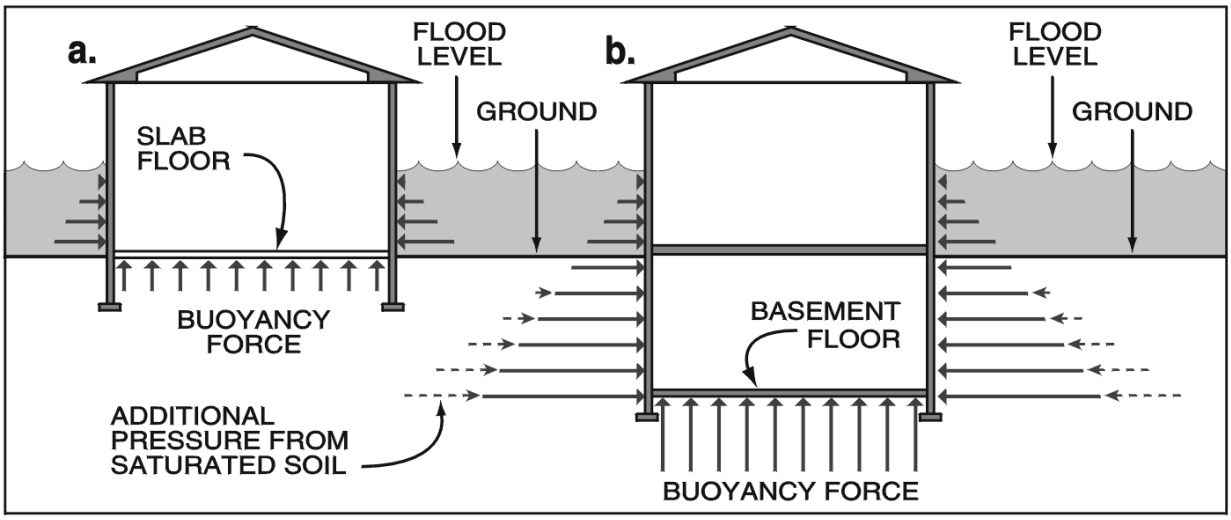

Figure 4-4. Buoyant force and hydrostatic pressure diagram

Hydrostatic Pressure: Hydrostatic pressure is applied horizontally to walls that are submerged below the water surface, as shown in Figure 4-4. The amount of hydrostatic pressure increases with the water depth, and therefore the pressure on basement walls is greater than the pressure on the walls of the upper

floor, as represented by the arrows in the figure. The horizontal pressure on basement walls is made even greater by the weight of the saturated soil that surrounds the basement. Extensive structural damage can occur, and possible collapse of the building, if the horizontal pressure exceeds the strength of the walls.

Note that in Figure 4-4, no water is shown inside the building. If water is allowed to enter, as shown in Figure 4-5, the hydrostatic pressures on both sides of the walls and floor are equalized, and the walls are much less likely to collapse and fail.

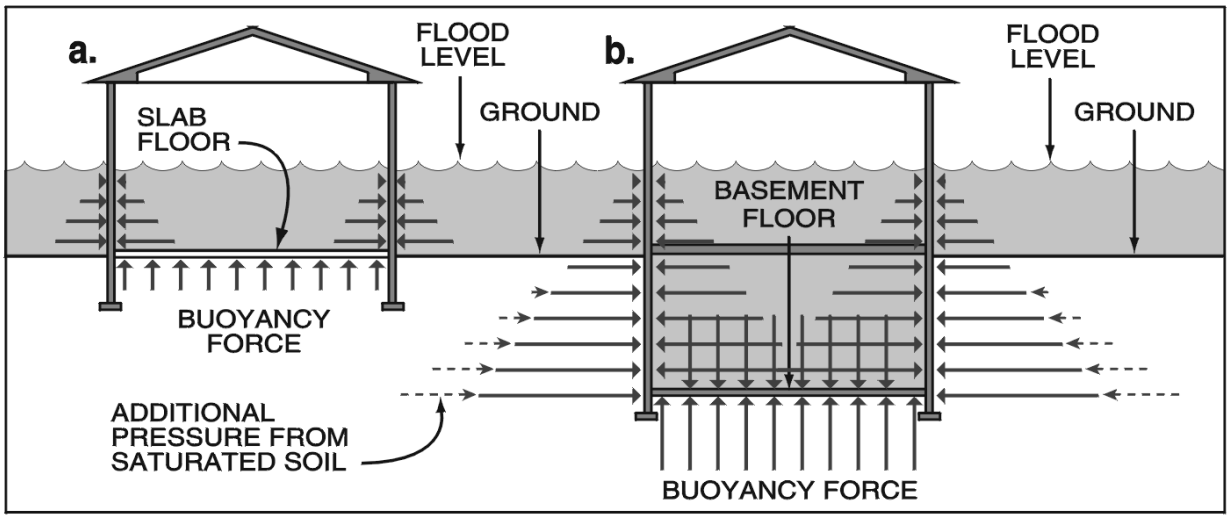

Figure 4-5. Hydrostatic pressure with wet floodproofing
(allowing flood waters to enter building)

6.4.2 Flow Velocity

Flow velocities during riverine floods can reach 5 to 10 feet per second (ft/sec), and may be greater in some situations. For reference, 10 ft/sec is roughly equivalent to 7 miles per hour.

The velocity of riverine floodwaters depends primarily on two factors: 1) the longitudinal slope of the channel/floodplain, and 2) the roughness of the channel/floodplain. As expected, flow rates are more rapid in steep floodplains and in floodplains that are relatively smooth (e.g., over parking lots) rather than rough (i.e., covered with large rocks, trees, dense vegetation, or other obstacles). Also, flow velocities in the floodplain are typically higher near the center of the main channel than at the outermost fringes, where velocities are slower.

If a structure is located where floodwaters are moving, the flow velocity influences the potential amount of structural damage incurred, particularly if the velocity exceeds approximately 5 ft/sec. The force exerted by flowing water, referred to as hydrodynamic pressure, is added to the hydrostatic pressure from the floodwater against the walls of the building. In addition to the hydrodynamic and hydrostatic forces, flow along the sides of a building creates friction that can damage wall coverings, such as siding. On the downstream side of the building, away from the flow, the water creates a suction force that pulls on walls (see Figure 4-6). In some situations, the combination of these forces can destroy one or more walls and cause the building to shift on its foundation or even be swept away.

Flowing water can also cause erosion and scour around objects that obstruct flow, such as foundation walls. Both erosion and scour can weaken the structure by removing supporting soil and undermining the foundation. In general, the greater the flow velocity and larger the building, the greater the extent and depth of erosion and scour. Also, any objects carried by floodwaters will be moving at roughly the same speed as the water.

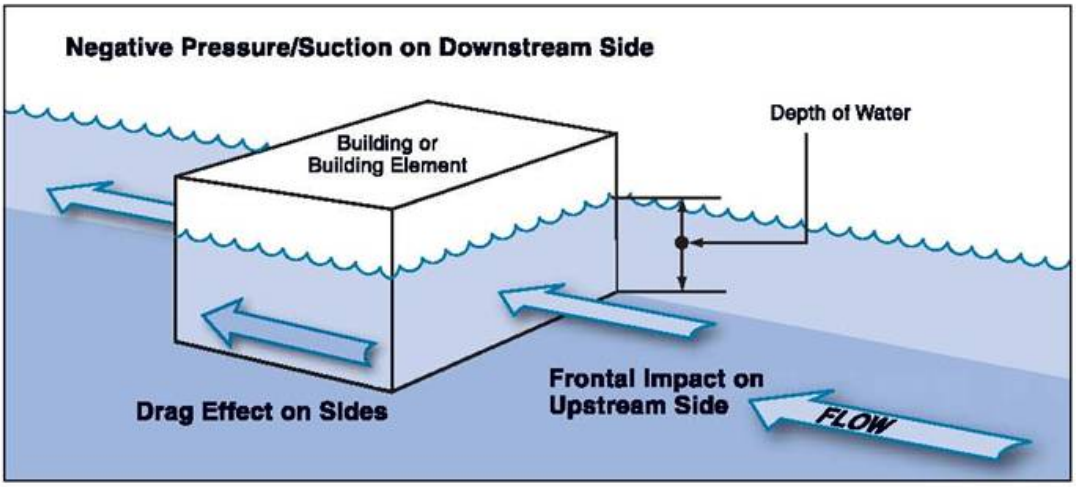

Figure 4-6. Effects of moving water on a structure

6.4.3 Flood Frequency

Flood frequencies are usually determined through statistical analyses performed by engineers, floodplain management agencies and other organizations as a basis for engineering designs and flood insurance rates. Those analyses define the probability, expressed as a percentage, that a flood of a specific magnitude will be equaled or exceeded in any year.

As previously noted, the 100-year flood is particularly important because it serves as the basis of the NFIP flood insurance rates and regulatory floodplain management. The 100-year flood is also referred to as the 1% annual exceedance probability flood (i.e., it has a 1% chance of being exceeded in a single year).

6.4.4 Rates of Rise and Fall

The rates of rise and fall refer to how rapidly the depth of floodwaters increase and decrease during a flood. Floodwaters with high flow velocities, such as those associated with steep terrain or caused by the failure of a dam or levee, usually rise and fall more rapidly than slower-moving floodwaters, as in gently sloping floodplains. The rate of rise is important because it affects the amount of warning prior to an impending flood. In floodplains of streams with high rates of rise, homeowners may have little notice of a coming flood, perhaps only hours, or none at all in some cases. If the flood protection method for a property involves contingent measures that a property owner must implement prior to the floodwaters arriving, the amount of warning time is especially important.

The rate of rise and rate of fall are also important because of their effect on hydrostatic pressure. As discussed previously, hydrostatic pressure is greatest when the water level outside the building is significantly different than the water level inside the building and, hence, the internal and external pressures are not equalized. When floodwaters rise rapidly, water may not flow into a building quickly enough for the level inside the building to rise at the same rate as the level outside. Conversely, when floodwaters fall rapidly, water that has filled a building may not flow out quickly enough, resulting in higher pressure inside the building than outside. In either situation, the unequal hydrostatic pressures can cause structural damage.

6.4.5 Duration

Duration is related to the rates of rise and fall. Relative to a flood, duration is the amount of time it takes for the source of the flood (i.e., river, creek) to return to its normal level. Generally, water that rises rapidly will recede more rapidly, and water that rises slowly will recede more slowly. Duration is important because it determines how long the structural members (e.g., foundation, floor joists, wall studs), interior finishes (e.g., drywall and paneling), service equipment (e.g., furnaces and hot water heaters), and building contents will be affected by floodwaters. Long periods of inundation are more likely to cause damage than short periods. In addition, long-duration flooding can saturate soils as shown on Figure 4-4, resulting in increased pressure on the foundation. Duration also affects how long a building remains uninhabitable.

6.4.6 Impact of Debris and Contaminants in Floodwaters

Floodwaters can carry debris of all types, including trees, automobiles, boats, storage tanks, mobile homes, and even entire buildings. All of these add to the dangers of flooding. Even when flow velocity is relatively low, large objects carried by floodwaters can easily damage windows, doors, walls, and, more importantly, critical structural components of a building. As velocity increases, so does the danger of greater damage from debris.

Contaminants in floodwaters, in addition to sediment, frequently include substances such as oil, gasoline, sewage, and various chemicals. If floodwaters carrying large amounts of dirt or hazardous substances enter a building, cleanup costs are likely to be higher and cleanup time greater.

6.5 Classes of Floodproofing Techniques

Floodproofing techniques are classified based on the type of protection provided:

- **Permanent measures:** Always in place and require no action if flooding occurs.
- **Contingent measures:** Require installation prior to the occurrence of a flood.
- **Emergency measures:** Improvised at the site when flooding occurs.

In the Denver metropolitan area, floodproofing efforts should focus on permanent measures because most of the stream systems respond rapidly to intense rainfall events. Contingent measures are more effective when combined with an early flood warning system or in areas not immediately adjacent to a stream channel.

Most floodproofing methods are more appropriate only where floodwaters are less than 3 feet deep. At depths greater than 3 feet, walls and floors are more likely to collapse because of the higher water pressure.

6.6 Floodproofing Methods

For new development, the first option for flood risk management should always be to construct outside of the floodplain. If building outside the floodplain is impractical for a site, then the structure should be constructed in compliance with local floodplain regulations. The remaining floodproofing methods discussed in this chapter are primarily for retrofitting existing structures.

6.6.1 Overview of FEMA Methods

Most regulations for floodproofing are based on the minimum NFIP standards for constructing, modifying, or repairing buildings located in the floodplain. FEMA has published numerous references on the subject of floodproofing methods (FEMA 1984, 1986a, 1986b, 1991, 1993a, 1993b, 1993c, 1993d, 1993e, 1994, 1995, 1996, 1998, 2000, 2001, 2008, 2009), several of which list six specific methods. Three of the methods can be used to meet NFIP residential floodproofing requirements. The other three do not meet the minimum NFIP requirements, but can be used to minimize damages, as listed below:

Methods that <u>can</u> be used to meet NFIP residential floodproofing requirements:

Elevation: Raise the structure so the lowest floor is above the flood level.

Relocation: Move the structure out of the floodplain to higher ground where it will not be exposed to flooding.

Demolition: Tear down the damaged structure and either: a) properly rebuild the structure on the same property, or b) buy or build a structure outside the floodplain.

Methods that <u>cannot</u> be used to meet NFIP residential floodproofing requirements:

Dry floodproofing: Seal the structure to prevent floodwaters from entering.

Levees and floodwalls: Build a physical barrier around the structure to hold back floodwater.[1]

Wet floodproofing: Make uninhabited portions of the structure resistant to flood damage and allow water to enter during flooding (cannot be used to meet NFIP requirements for residential floodproofing).

Sections 6.6.2 through 6.6.7 provide descriptions of each of the six floodproofing methods identified by FEMA, their respective advantages and disadvantages, and where they are appropriate to apply.

6.6.2 Elevation

Elevating a building to prevent floodwaters from reaching living areas is an effective retrofitting method. The goal of the elevation process is to raise the lowest floor to a level at or above the flood protection elevation (FPE). This can be achieved by elevating the entire building, including the floor, or by leaving the building in its existing position and constructing a new, elevated floor within the building. See figure 4-7. The method used depends largely on the construction type, foundation type, and flooding conditions.

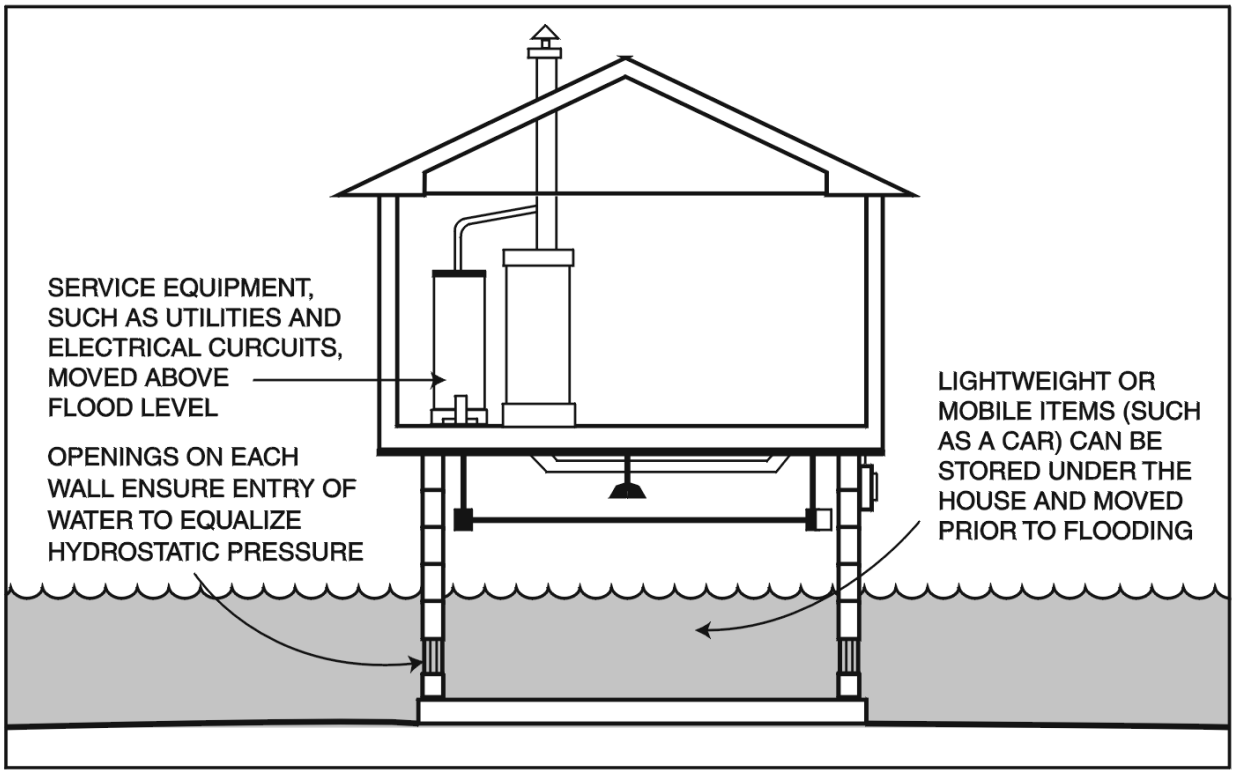

Figure 4-7. Example of a structure elevated on continuous foundation walls

[1] In February 2007, the UDFCD Board of Directors adopted a levee policy which discourages local governments from authorizing or permitting levees for new development and states that such levees would not be eligible for UDFCD maintenance assistance. The policy will allow the use of levees as a last resort to protect existing structures.

During the elevation process, most buildings are separated from their foundations, raised on hydraulic jacks, and held by temporary supports while a new or extended foundation is constructed below. This method works well for buildings originally built on basements, crawl spaces, or open foundations. The new or extended foundation can consist of continuous walls or separate piers, posts, columns, or pilings.

A variation of this method is used for buildings with slab-on-grade foundations, where the slab forms both the foundation and the floor of the building. Elevating that type of structure is easier if the building is left attached to the slab foundation and both are lifted together. After the building and slab are lifted, a new foundation is constructed below the slab.

In cases where the building is on an open foundation, it can be elevated with piers, columns, or piles. Piers should be properly anchored to footings. Columns are typically braced members but also need to be properly anchored.

Alternative techniques are available for masonry buildings on slab-on-grade foundations. These techniques do not require the lifting of the building. Instead, they involve raising the floor within the building or moving the living space to an upper story.

Although elevating a building can help protect it from floodwaters, other factors need to be considered before choosing this method. For example, the walls and roof of an elevated building may be more susceptible to wind forces because they are higher and more exposed. In addition, continuous wall foundations and open foundations both can fail as a result of damage caused by erosion and the impact of debris carried by floodwaters. If portions of the original foundation, such as the footings, are used to support new walls or other foundation members or a new second story, they must be capable of safely carrying the additional loads imposed by the new construction as well as any additional loads generated by wind or flood waters.

Advantages and disadvantages of the elevation method of floodproofing are summarized in Table 4-2.

Table 4-2. Advantages and disadvantages of the elevation method

Advantages	Disadvantages
Raising the floor elevation to or above the FPE allows a substantially damaged or substantially improved building to be brought into compliance with the community's floodplain management ordinance or law[1]. The elevation method does not require the additional land that may be needed for construction of floodwalls or levees. Except where a lower floor is used for storage, the elevation method eliminates the need to move vulnerable contents to areas above the water level during flooding. The elevation method often reduces flood insurance premiums. Elevation techniques are well known, and qualified contractors are often readily available.	Cost may be prohibitive. The appearance of the building may be adversely affected. Access to the building may be adversely affected. The building must not be occupied during a flood. Unless special measures are taken, elevation is not appropriate in areas with high-velocity flows, waves, fast-moving ice or debris flow, or erosion. Additional costs are likely if the building must be brought into compliance with current code requirements for plumbing, electrical, and energy systems. Potential wind and earthquake loads must be considered.

1 Verify all requirements when applying for the floodplain permit.

6.6.3 Wet Floodproofing

Wet floodproofing a building is accomplished by modifying the uninhabited portions of the structure (such as the crawl space or unfinished basement) to enable floodwaters to enter without causing significant damage to either the building or its contents. The purpose of allowing water to enter portions of the building is to equalize the interior and exterior hydrostatic pressures, thereby reducing the likelihood of wall failures and structural damage (see Figure 4-8). Wet floodproofing is practical in only a limited number of situations and is typically used when all other retrofitting methods are either too costly or are not feasible.

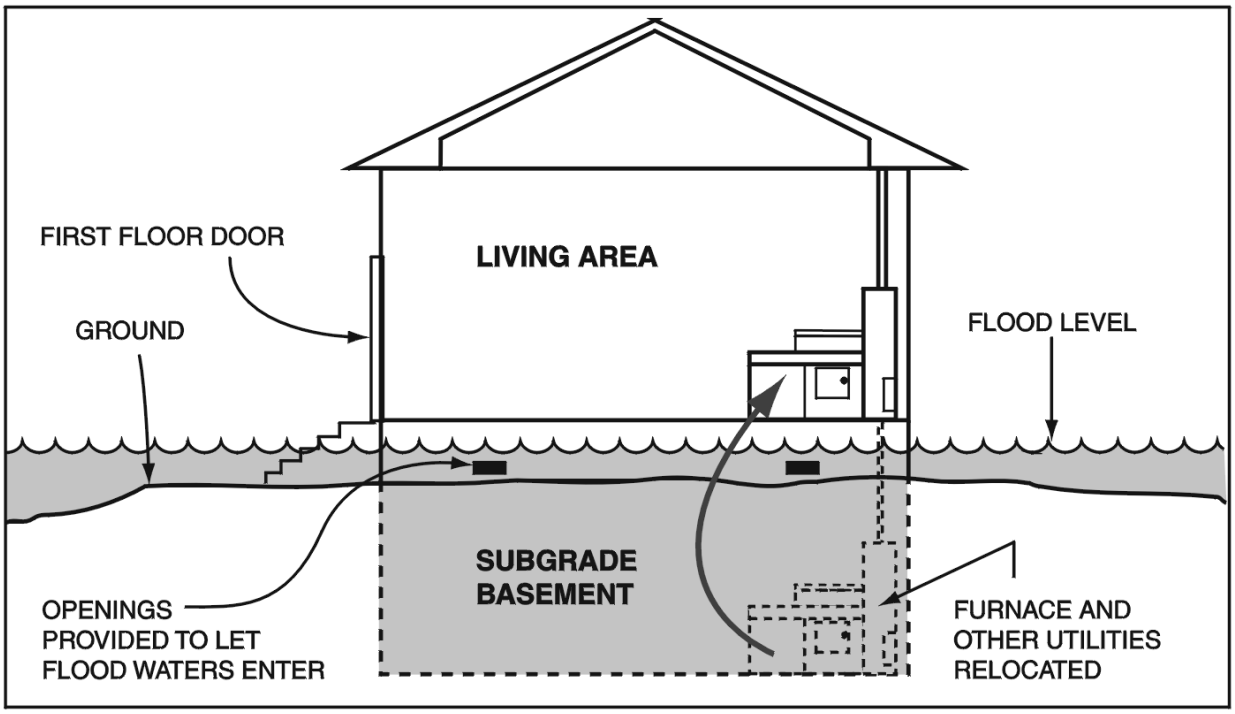

Figure 4-8. Example of building with wet floodproofed subgrade basement

Because wet floodproofing allows floodwaters to enter the building, all construction and finishing materials below the FPE must be resistant to flood damage. For this reason, wet floodproofing is practical only for portions of a building that are not used for living space, such as a basement as defined by the NFIP regulations, a walkout-on-grade basement, crawl space, or attached garage. It would not be practical for most slab-on-grade buildings, in which the living space is at or very near the ground level. Whether or not wet floodproofing is appropriate for a building will depend on the flood conditions, the FPE selected, the design and construction of a building, and whether the building has been substantially damaged or is being substantially improved.

Advantages and disadvantages of wet floodproofing are summarized inTable 4-3.

Table 4-3. Advantages and disadvantages of wet floodproofing

Advantages	Disadvantages
Wet floodproofing can, in many instances, reduce structural damage to a building. Because wet floodproofing allows internal and external hydrostatic pressures to equalize, the loads on walls and floors will be less than in a dry floodproofed building. Flood insurance will cover the costs in some instances for moving or storing contents (except basement contents) after a flood warning is issued. Wet floodproofing measures are often less costly than other types of retrofitting. Wet floodproofing does not require the additional land that may be needed for floodwalls and levees. The appearance of the building is usually not adversely affected.	Wet floodproofing may be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law only if the areas of the building below the FPE are used solely for parking, storage, or building access. Preparing the building and its contents for an impending flood requires adequate warning time and human intervention. A building with wet floodproofing will get wet inside and possibly contaminated by sewage, chemicals, and other materials conveyed in floodwaters. Extensive cleanup may be necessary. Periodic maintenance of wet floodproofing measures is likely necessary. The building must not be occupied during a flood, and it may be uninhabitable for some time afterward. Uses in the floodable area of the building must be limited. Pumping floodwaters out of a wet floodproofed basement too soon after a flood may lead to structural damage.[1] Wet floodproofing does not minimize the potential damage from high-velocity flood flow and wave action.

[1]**WARNING.** After floodwaters recede from the area around a building with a wet floodproofed basement, the owner will usually want to pump out the water that filled the basement during the flood. If the soil surrounding the basement walls and below the basement floor is still saturated with water, however, removing the water in the basement too quickly can be dangerous. As the water level in the basement drops, the outside pressure on the basement walls becomes greater than the inside pressure and damage can result (e.g., the walls can collapse and/or the floor can be pushed up or cracked).

6.6.4 Dry Floodproofing

In some situations, a building can be made watertight below the FPE, so that floodwaters cannot enter. This method is called dry floodproofing. Making a building watertight requires sealing the walls with waterproof coatings, impermeable membranes, or supplemental layers of masonry or concrete. Also, doors, windows, and other openings below the FPE must be equipped with permanent or removable shields, and backflow valves must be installed in sewer lines and drains (see Figure 4-9). Flood characteristics that affect the success of dry floodproofing are flood depth, flood duration, flow velocity, and the potential for wave action and flood-borne debris.

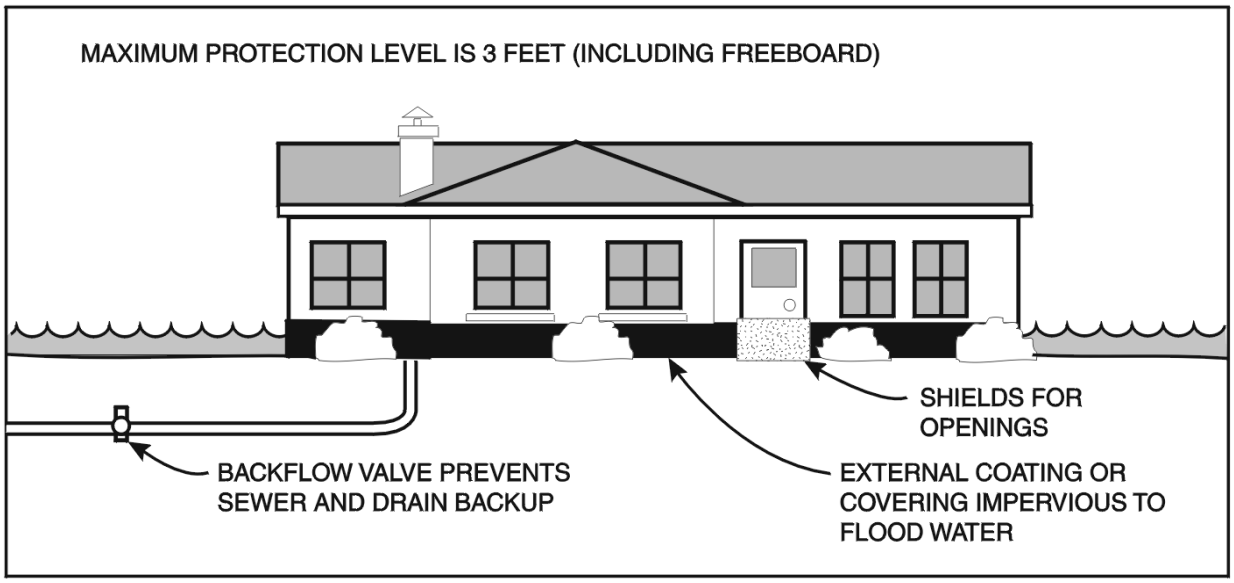

Figure 4-9. Example of a dry floodproofed structure

Flood depth is important because of the hydrostatic pressure that floodwaters exert on walls and floors. Since water is prevented from entering a dry floodproofed building, the exterior pressure on walls and floors is not counteracted as it is in a wet floodproofed building. The ability of building walls to withstand the pressure exerted by floodwaters depends in large part on their construction. Typical masonry and masonry veneer walls, without reinforcement, can usually withstand the pressure exerted by water up to about 3 feet deep. When flood depths exceed 3 feet, unreinforced masonry and masonry veneer walls are much more likely to crack or collapse. In addition, in most cases, the buoyancy force exerted by water with a depth greater than 3 feet is enough to crack a slab or push it up.

An advantage of masonry and masonry veneer walls is that their exterior surfaces are resistant to damage by moisture and can be made watertight relatively easily with sealants. In contrast, typical frame walls are likely to fail at lower flood depths, are more difficult to make watertight, and are more vulnerable to damage from moisture. As a result, it is not recommended to rely upon dry floodproofing for buildings with frame walls that will be damaged by moisture. Dry floodproofing is not an appropriate method to protect a residential structure from flood depths greater than 3 feet.

Dry floodproofing may not be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law. Advantages and disadvantages of dry floodproofing are summarized in Table 4-4.

Table 4-4. Advantages and disadvantages of dry floodproofing

Advantages	Disadvantages
Dry floodproofing prevents damage to the building interior, unlike some other methods (e.g., wet floodproofing, which does not protect the interior contents of the building from damage). Dry floodproofing may be less costly than other retrofitting methods. Dry floodproofing does not require the additional land that may be needed for levees and floodwalls.	Dry floodproofing may not be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law. Ongoing maintenance of the dry floodproofing measures is required. Flood insurance premiums are not reduced for residential structures. Installing temporary protective measures, such as flood shields, requires adequate warning time and human intervention.[1] If the protective measures fail or the FPE is exceeded, the effect on the building will be the same as if there were no protection at all. If design loads are exceeded, walls may collapse, floors may buckle, and the building may even float, potentially resulting in more damage than if the building was allowed to flood. The building must not be occupied during a flood. Flood shields may not be aesthetically pleasing. Damage to the exterior of the building and other property may not be reduced. Shields and sealants may leak, which could result in damage to the building and its contents. Dry floodproofing does not minimize the potential damage from high-velocity flood flow and wave action.

[1]**WARNING.** Because dry floodproofing requires human intervention, one must be willing and able to install all flood shields and carry out all other activities required for the successful operation of the dry floodproofing system. As a result, not only must one be physically capable of carrying out these activities, one must be in the building or able to go there in time to do so before floodwaters arrive.

6.6.5 Relocation

Relocation, or moving a building to ground located outside the flood hazard area, is the most effective floodproofing method described in the USDCM. If space permits, it may be possible to move a building to another location on the same piece of property.

Relocating a building typically involves jacking the building up and placing it on a wheeled vehicle for transport to the new site. Since the original foundation cannot be moved, it is demolished and a new foundation is built at the new site. The building is installed on the new foundation and utility lines are connected.

Relocation is particularly appropriate in areas where the flood hazard is severe. Severe flood hazards are often characterized by deep water, rapid rates of rise and fall, short warning times, wave action, high flow velocities, high debris flow, and long durations. Relocation is also appropriate for those who want less worry about damage from future floods that may exceed a specific FPE.

Although similar to the elevation floodproofing method, relocation requires additional steps that typically make it more expensive. These steps include moving the building, buying and preparing a new site (including building the new foundation and providing the necessary utilities), and restoring the old site (including demolishing the old foundation and properly capping and abandoning old utility lines).

Advantages and disadvantages of relocation are summarized in Table 4-5.

Table 4-5. Advantages and disadvantages of relocation

Advantages	Disadvantages
Relocation allows a substantially damaged or substantially improved building to be brought into compliance with a community's floodplain management ordinance or law. Relocation significantly reduces flood risk to the building and its contents. Relocation can either eliminate the need to purchase flood insurance or reduce the amount of the premium. Relocation techniques are well known, and qualified contractors are often readily available.	Relocation costs may be prohibitive. A new site (preferably outside the flood hazard area) must be located and purchased. The flood-prone lot on which the building was formerly located must be sold or otherwise disposed of. Many types of buildings are not suitable for being relocated. Additional costs are likely if the building must be brought into compliance with current code requirements for plumbing, electrical, and energy systems.

6.6.6 Levees and Floodwalls

Levees and floodwalls are both types of flood protection barriers. However, it is important to recognize that both CWCB and UDFCD discourage the use of levees. In 2007, UDFCD formally adopted a levee policy which discourages local governments from authorizing or permitting levees for new development and states that these levees will not be eligible for UDFCD maintenance assistance. The policy will allow the use of levees as a last resort to protect existing structures.

A levee is typically a compacted earthen structure; a floodwall is an engineered structure typically constructed of concrete, masonry, or a combination of both (see Figure 4-10). When these barriers are built to protect a building, they are usually referred to as residential, individual, or on-site levees and floodwalls. The practical heights of levees and floodwalls are usually limited to 6 feet and 4 feet, respectively. These limits are the result of the following considerations:

As the height of a levee or floodwall increases, so does the depth of water that can build up behind it. Greater depths result in greater water pressures. Taller levees and floodwalls must be designed and constructed to withstand the increased pressures. Meeting this need for additional strength greatly increases the cost of the levee or floodwall, usually beyond what an individual homeowner can afford.

Since taller levees and floodwalls must be stronger, they occupy more space and typically require more space than is likely to be available on an individual residential lot. This is especially true of levees.

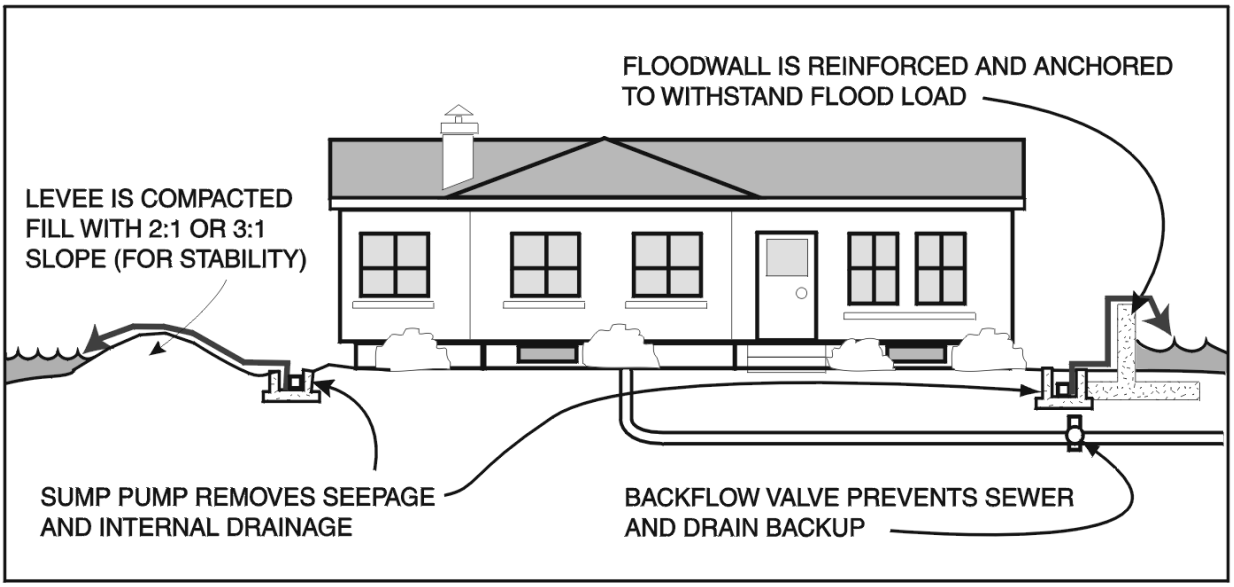

Figure 4-10. Example of levee and floodwall protection

Both levees and floodwalls should be constructed to provide at least 3 feet of freeboard above the BFE. Levees do not meet federal requirements for flood protection if they do not extend 3 feet above the BFE.

Levees: For a levee to be effective over time, it must be constructed of soils that cannot be easily penetrated by floodwaters. Furthermore, it must have proper side slopes for stability and it must be periodically inspected and maintained. In areas where flow velocities are sufficient to cause erosion, the side of the levee exposed to floodwater is usually protected with riprap or other erosion-resistant material. Levees can surround a building, or they may be built only across low areas and tied into existing high ground.

Floodwalls: A floodwall can surround a building, or depending on flood depths, site topography, and design preferences, it can protect isolated openings such as doors, windows, and basement entrances, including entry doors and garage doors in walkout-on-grade basements. Per unit length, floodwalls are typically more expensive than levees. Consequently, floodwalls are normally considered only for sites where there is not enough room for a levee or where high flow velocities may erode a levee.

As discussed previously, levees and floodwalls are discouraged by both the CWCB and the UDFCD. They are considered to be floodproofing measures of last resort. Recognizing this, their relative advantages and disadvantages are listed in Table 4-6.

Table 4-6. Advantages and disadvantages of levees and floodwalls

(Note: Levees and floodwalls are both considered to be floodproofing measures of last resort.)

Advantages	Disadvantages
Levees and floodwalls provide protection from inundation to the building and area around it (provided that the design flood is not exceeded). No significant changes to the building are required. Floodwaters are prevented from reaching the building or other structures in the protected area and therefore prevent damage from inundation, hydrodynamic pressure, erosion, scour, or debris impact. The building can be occupied during construction of levees and floodwalls.	The use of levees for property protection, flood control, and flood hazard mitigation is discouraged by the CWCB. Levees should be considered only if other mitigation alternatives are not viable. The UDFCD Board of Directors adopted a levee policy in February 2007 which discourages local governments from authorizing or permitting levees for new development. The policy states that new levees will not be eligible for UDFCD maintenance assistance. The policy will allow the use of levees as a last resort to protect existing structures. Levees and floodwalls may not be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law. Costs may be prohibitive. Periodic maintenance is required. Adequate warning time and human intervention are required to close any openings in a levee or floodwall. If a levee or floodwall fails or is overtopped by floodwaters, the effect on the building will be the same as if there were no protection at all. An interior drainage system must be provided. Local drainage can be affected, possibly creating or worsening flood problems for others. The building must not be occupied during a flood. A levee or floodwall may restrict access to the building. Levees and floodwalls do not reduce flood insurance rates. Floodplain management requirements may make levees and floodwalls violations of codes and/or regulations. A large area may be required for construction, especially for levees. Hydrostatic pressure on below-ground portions of a building may still be a problem, making levees and floodwalls an undesirable option for buildings with basements.

6.6.7 Demolition

Demolition, as a floodproofing method, involves tearing down a damaged building and either rebuilding properly (i.e., compliant with floodplain regulations) somewhere on the same property or moving to a building on other property outside the regulatory floodplain. This retrofitting method may be the most practical of all those described in the USDCM when a building has sustained extensive damage, especially if severe structural damage has occurred.

Whether rebuilding or moving, the damaged building must be torn down and the site restored. Site restoration generally involves filling in the basement or foundation, grading the site, and landscaping. The services of demolition and grading contractors will likely be required. All demolition, construction, and site restoration work must be done according to the regulatory requirements of the community. Permits may be required for all or part of this work.

The advantages and disadvantages of demolition depend on the decision regarding where to rebuild the structure.

6.7 Engineering Considerations for Floodproofing Methods

Engineering considerations for a proposed floodproofing method include evaluating the site and building characteristics, determining the flooding characteristics, and analyzing the potential loads on the structure during a flood event. These topics are addressed in Sections 6.7.1 through 6.7.3.

6.7.1 Flood Hazard Analysis

Determining the potential depth of flooding is the first and most logical step in assessing flood hazards, since it is often the primary factor in evaluating the potential for flood damage. The depth of flooding is also critical in determining the extent of retrofitting that will be needed and which method(s) will be the most appropriate for a given site. Detailed flood information is provided in the FIS and FIRM where such studies are available and can be obtained from the FHAD.

The second step in assessing flood hazards is to calculate the forces acting upon a structure during a flood. These forces include hydrostatic, hydrodynamic, and impact loads. Hydrostatic forces include lateral water pressure, saturated soil pressures, combined water and soil pressures, equivalent hydrostatic pressures due to low velocity flows (< 10 ft/sec), and buoyancy pressures. Hydrodynamic forces consist of frontal impact by the mass of moving water against the projected width and height of the obstruction represented by the structure, drag effect along the sides of the structure, and eddies or negative pressures on the downstream side of the structure. Impact loads are imposed on the structure by objects carried by moving water.

6.7.2 Site Characteristics

Important site characteristics to evaluate include the location of the structure relative to sources of potential flooding and geotechnical considerations. The site location should be evaluated with respect to mapped floodplains and floodways and the potential for local flooding from stormwater conveyance elements.

Soil properties during conditions of flooding are important factors in the design of any surface intended to resist flood loads. These properties include saturated soil pressures, allowable bearing capacity, potential for scour, frost zone location, permeability, and shrink-swell potential.

6.7.3 Building Characteristics

The building should be evaluated with respect to the type of construction and the condition of the structure. The type of foundation, foundation materials, wall materials, and the method of connection all play a role in deciding which retrofitting method is most applicable. Operations involving a building in poor condition may further damage the building and result in costs that exceed its original value.

6.8 Selection of Floodproofing Method

In addition to engineering considerations described above, selection of the floodproofing method depends on several factors described below:

6.8.1 Regulatory Considerations

Federal, state, and local regulations may restrict the choice of retrofitting measures. Such regulations may include state and local building codes, floodplain management ordinances or laws, zoning ordinances, federal regulations concerning the alteration of buildings classified as historic structures, deed restrictions, and the covenants of homeowners associations.

Federal Regulations: The NFIP limits certain types of floodproofing. For example, the NFIP prohibits obstructions, such as berms and floodwalls, in floodways. The NFIP also requires floodproofing for buildings that are substantially improved or substantially damaged. "Substantially damaged" is defined as "damage of any origin sustained by a structure whereby the cost of restoring the structure to its prior condition would equal or exceed 50 percent of the market value of the structure before the damage occurred." Buildings that have been substantially damaged or are being substantially improved (renovated) must be elevated to a level at or above the 100-year flood level. Nonresidential buildings must be elevated or dry floodproofed.

Other federal agencies, such as the U. S. Army Corps of Engineers (USACE), U. S. Geological Survey, and Natural Resources Conservation Service, also publish floodproofing information, as do some state and local agencies. The USACE provides engineering and construction standards in the publication *Floodproofing Regulations (*1995b). Additional USACE publications (1984, 1988, 1990, 1993, 1994, 1995a, 1996, 1998) provide information on case studies and detailed engineering applications of floodproofing methods.

State and Local Regulations: State and local regulations may require a retrofitted building to be upgraded to meet current code requirements, unrelated to the floodproofing measures. Examples of potentially required upgrades include the electrical, plumbing, and/or the heating/ventilation/air conditioning systems (e.g., an electrical panel might require an upgrade from fuses to circuit breakers). These changes are required for the safety of the homeowner. Other code-required upgrades include those

necessary for increased energy efficiency. Any required upgrade can add to the scope and cost of the retrofitting project.

Every community that is a member of the NFIP must adopt minimum NFIP requirements. Many communities choose to adopt ordinances which are stricter than the minimum requirements of the NFIP. The local government floodplain administrator can identify the ordinances that apply to a specific project.

6.8.2 Appearance

Following retrofitting, the final appearance of a building and property will depend largely on the retrofitting method used and the FPE. For example, elevating a building several feet will change its appearance much more than elevating it only 1 or 2 feet. Also, a building elevated on an open foundation will appear much different than one elevated on extended foundation walls.

6.8.3 Accessibility

Accessibility refers to the ease with which a building can be accessed after a retrofitting project is completed. The retrofitting methods described in the USDCM affect accessibility in different ways. For example, elevating a building will usually require the addition of stairs, which may be unacceptable to some. Wet floodproofing will have little, if any, effect on accessibility. The effect of relocation on accessibility will depend on the location and configuration of the new site.

6.8.4 Requirement for Human Intervention

Retrofitting methods that require human intervention make it necessary for owners to be willing, able, and prepared to take the necessary action, such as placing flood barriers across the doors of a dry floodproofed building or operating a closure mechanism in a floodwall. These actions require that the owner have adequate warning of a coming flood and be able to reach the building and take action before floodwaters arrive. If these conditions cannot be met, retrofitting methods that require human intervention should be eliminated from consideration.

6.8.5 Benefit/Cost Analysis

The cost of retrofitting will depend largely on the retrofitting method used and the FPE. For some methods, the construction type (frame, masonry, etc.) and foundation type (crawl space, slab, etc.) will also affect the cost. In general, costs will increase as the FPE increases, but there may be tradeoffs between alternative methods. For example, elevating may be less expensive than relocating when a building is raised only 1 or 2 feet but may become more expensive at greater heights. The benefits considered in a floodproofing measure are the future damages and losses that are expected to be avoided as a result of the measure.

6.8.6 Other Considerations

Building owners may need to consider other factors, such as the availability of federal, state, and local financial assistance; the current value of the building versus the inconvenience and cost of retrofitting; the amount of time required to complete the retrofitting project; and the need to move out of the building during construction (including the availability and cost of alternative housing).

6.9 Cases Where Floodproofing is Not Appropriate

Except for demolition and relocation, floodproofing methods should not be considered in certain situations. For example, structures located within a regulatory floodway cannot be retrofitted with any substantial improvements that would result in an increase in flood levels during the base flood discharge. Under these conditions, the structure should be relocated out of the floodway and, preferably, out of the floodplain.

7.0 Assistance for Property Owners

7.1 Decision-Making Process for Property Owners

The decision regarding which floodproofing method to use will be based mainly on a combination of legal requirements, the technical limitations of the methods, and cost. Other considerations include the appearance of the building after retrofitting and any inconvenience resulting from retrofitting.

7.1.1 Identification of Flood Hazards

Information about flood hazards in a specific area is available from UDFCD and local community officials. Community officials, design professionals, and contractors can use this information, along with the flood hazard information developed by FEMA and other agencies, to provide advice about retrofitting options.

7.1.2 Structure Inspection

Structures being considered for floodproofing should be inspected to determine the construction method and type of foundation. Four characteristics of a building that are particularly important in retrofitting are: 1) construction type, 2) foundation type, 3) lowest floor elevation, and 4) condition. A key requirement of the inspection is performing a "Low Point of Entry" determination (see Figure 4-11).

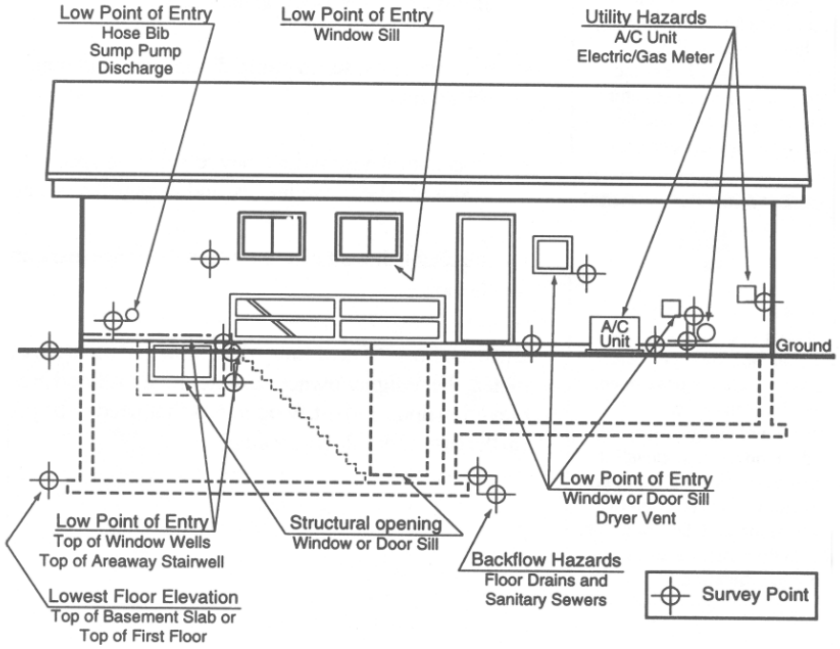

Figure 4-11. Example of a low point of entry survey

7.1.3 Consultation with Local Officials

UDFCD and local officials have copies of the FIS and FIRM published for the community by FEMA. UDFCD or community officials can determine whether a building is in the regulatory floodplain and, if so, the FPE/BFE at the location of the building.

Local officials will provide federal, state, and local regulations, codes, and other requirements that determine what retrofitting methods will be allowed. Officials can also provide information about federal, state, and local programs that provide financial assistance for homeowner retrofitting projects. If the property is 50 or more years old and federal financial assistance is being received for a retrofitting project, then the State Historic Preservation Office should also be contacted.

7.1.4 Consultation with Design Professional

The owner of a structure that needs floodproofing will need to consult with a design professional and a contractor in order to choose the appropriate floodproofing method and ensure that the method is properly constructed. Table 4-7 shows the types of contractors and design professionals that may be required for each of the retrofitting methods.

7.2 Potential Sources of Financial Assistance at Federal, State, and Local Levels

FEMA and other federal agencies have a wide array of financial assistance programs that help states, communities, and individual property owners mitigate the negative effects of flood hazards. Property owners may be eligible to receive financial assistance for a retrofitting project through one or more of these programs. If a presidential declaration of a major disaster has been issued for the area, property owners should seek information from FEMA and the state and local government representatives supporting the post-disaster recovery of the community.

The community's floodplain management ordinance or law includes requirements concerning construction in the community's regulatory floodplain. These requirements apply not only to new buildings but also to existing buildings that have been substantially damaged or that are being substantially improved. If the structure falls into one of the latter two categories, one of the following will be required:

- Elevate the building so that its lowest floor is at or above the FPE (Elevation Method).
- Move the building out of the regulatory floodplain (Relocation Method).
- Wet-floodproof the part of the building that is below the FPE (Wet Floodproofing Method). (This alternative is allowed only if the part of the building that is below the FPE is used solely for parking, storage, and building access and is not a basement as defined by the NFIP).
- Communities with more restrictive floodplain management ordinances or laws may require a greater level of protection.

Although the substantial damage/substantial improvement requirement helps protect lives and property, it has at times placed an additional burden on property owners who were trying to repair their damaged buildings. Under the original terms and conditions of the NFIP Standard Flood Insurance Policy (SFIP), the owner of a substantially damaged building was reimbursed for the costs of repairing the damage but not for the costs of complying with state and local requirements concerning substantially damaged structures. For example, the homeowner would not have been reimbursed for the cost of elevating the building, even though state or local ordinances or laws required elevating.

Table 4-7. Requirements for contractor and design professional services

Method	Need for Contractor and/or Design Professional	Primary Services
Elevation	Design Professional	Evaluating the condition, stability, and strength of the existing foundation to determine whether it can support the increased load of the elevated building, including any wind and seismic loads.
	Contractor: Building Elevation Contractor	Disconnecting utilities, jacking up the building, increasing the height of the foundation, and connecting utilities.
Wet Floodproofing	Design Professional	Designing any necessary replacements of vulnerable structural materials and relocated utility systems.
	Contractor: General Construction Contractor	Replacing vulnerable structural and finishing materials below the FPE with flood-resistant materials, raising utilities and appliances to a location above the FPE, and installing openings required to allow the entry of floodwaters.
Relocation	Design Professional	Designing any new building, foundation, and site improvements that may be required, such as new utility systems.
	Contractor: Building Moving Contractor	Jacking up the building, moving it to the new site, and installing it on the new foundation.
	Contractor: General Construction Contractor	Preparing the new site (including grading, foundation construction, and utilities) and cleaning up the old site (including demolition).
Dry Floodproofing	Design Professional	For masonry walls to be dry floodproofed higher than 3 feet and for masonry veneer or frame walls to be dry floodproofed higher than 2 feet, evaluating the condition, stability, and strength of the existing walls to determine whether they can withstand the pressure from floodwaters at the FPE; designing or selecting flood shields for openings.
	Contractor: General Construction Contractor	Applying waterproof sealants and membranes, installing flood shields over openings below the FPE, installing backflow valves in sewer and water lines, and, if necessary, bracing or modifying walls so that they can withstand the pressure from floodwaters at the FPE.
Levees and Floodwalls	Design Professional	Assessing the adequacy of soils at the site and preparing the engineering design to ensure that the levee or floodwall, including any closures required, will be structurally stable under the expected flood loads and will be able to resist erosion, scour, and seepage.
	Contractor: General Construction Contractor	Constructing the levee or floodwall.
Demolition	Design Professional	Designing any new building, foundation, and site improvements that may be required, such as new utility systems.
	Contractor: Demolition Contractor	Disconnecting and capping utility lines, tearing down the damaged building, hauling away debris, and cleaning up the old site.
	Contractor: General Construction Contractor	Building the new building on the new site (May also be able to do all demolition work).

In 1997, to provide relief for the owners of houses substantially damaged by flooding, Congress authorized the inclusion of Increased Cost of Compliance (ICC) coverage in the SFIP. With this change in effect, the SFIP reimburses homeowners not only for the cost of repairing flood damage but also for the additional cost, up to a maximum amount stated in the SFIP, of meeting certain state and local floodplain management requirements concerning substantial damage and repetitive losses. Other sources of assistance include:

Small Business Administration (SBA): In areas declared a major disaster area by the President, the SBA provides low-interest disaster assistance loans to individuals for both businesses and private residences. These loans cover the cost of rebuilding a damaged building, including the cost of bringing the building into compliance with applicable ordinances and laws. The loans can pay for retrofitting of substantially damaged buildings required by ordinances or laws (including elevating flood-prone buildings and rebuilding badly damaged flood-prone buildings at an alternative location), as well as some mitigation projects that are not required by ordinances or laws. At the applicant's request, the amount of the loan may be increased by up to 20 percent for hazard mitigation measures not required by the community's ordinances or laws.

Department of Housing and Urban Development (HUD): In an area declared a major disaster area by the President, HUD may provide additional, or allow for the reprogramming of existing, community development block grants. If a community wishes, these grants may be used for retrofitting substantially damaged or substandard buildings (including elevating flood-prone buildings and acquiring badly damaged flood-prone buildings).

U.S. Army Corps of Engineers (USACE): The USACE has the statutory authority to participate in flood protection projects that may include residential retrofitting (including elevating flood-prone buildings and acquiring badly damaged flood-prone buildings).

Natural Resources Conservation Service (NRCS): The NRCS has the statutory authority to participate in small watershed flood protection projects that may include residential retrofitting.

8.0 Glossary

A Zone: See Zone A.

Alluvial fan: An area at the base of a valley where the slope flattens out, allowing the floodwater to decrease in speed and spread out, dropping sediment and rock over a fan-shaped area.

Amendment: A change to a FEMA floodplain map that removes an area that was inadvertently included in the Special Flood Hazard Area.

Approximate studies: Flood hazard mapping done using approximate study methods that show the approximate outline of the base floodplain. An approximate study does not produce a base flood elevation.

B Zone: See Zone B.

Base flood depth: A measurement of the base flood in feet above ground, used for shallow flooding.

Base flood: The flood having a 1% chance of being equaled or exceeded in any given year. Also referred as the 100-year flood. The base flood is used by the NFIP as the basis for mapping, insurance rating, and regulating new construction.

Basement: Any area of the building having its floor subgrade (below ground level) on all sides.

Base floodplain: The area of water and land inundated by the base flood.

Basin: See watershed.

Bathymetry: The measurement of depths of water in the ocean or lakes.

Bench marks: Monuments on the ground that show the elevation of the spot above sea level.

Building: A walled and roofed structure including a gas or liquid storage tank that is principally above ground as well as a manufactured home. This is equivalent to the term “structure” in the federal regulations (44 CFR 59.1).

Building condition survey: A windshield survey conducted to obtain a preliminary evaluation of the extent and severity of damage to buildings after a disaster.

C Zone: See Zone C.

CAP: Community Assistance Program.

Catchment area: See watershed.

cfs: Cubic feet per second, the unit by which discharges are measured (a cubic foot of water is about 7.5 gallons).

CLOMA: Conditional Letter of Map Amendment.

CLOMR: Conditional Letter of Map Revision.

Closed basin lake: A lake that has either no outlet or a relatively small one, where rainfall or groundwater can cause the lake's level to rise faster than it can drain.

Community Assistance Program: A FEMA program that funds state activities that help communities in the NFIP.

Community Rating System: A program that provides a flood insurance premium rate reduction based on a community's floodplain management activities.

Community: A city, county, township, Indian tribe or authorized tribal organization, Alaska Native village or authorized native organization, or other local government with the statutory authority to adopt and enforce floodplain regulations and participate in the National Flood Insurance Program.

Conditional Letter of Map Amendment: A statement from FEMA that if a project is constructed as planned, a Letter of Map Amendment can be issued later.

Conditional Letter of Map Revision: A statement from FEMA that if a project is constructed as planned, a Letter of Map Revision can be issued later.

Contour map: A topographic map that shows points with the same elevation as connected by a contour line.

Contour: A line of equal elevation on a topographic (contour) map.

Conveyance shadow: An area upstream or downstream of an existing obstruction to flood flows.

Cross section: Surveyed information that describes the stream and the floodplain at a particular point along the stream.

CRS: Community Rating System.

Dam breach inundation area: The area flooded by a dam failure.

Damage Survey Report: A form completed by disaster assistance staff to determine the repair and reconstruction needs of public and private nonprofit facilities.

Datum: A common vertical elevation reference point, usually in relation to sea level.

Detailed studies: Flood hazard mapping studies that are done using hydrologic and hydraulic methods that produce base flood elevations, floodways, and other pertinent flood data.

Development: Any man-made change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations or storage of equipment and materials.

DFIRM: Digital Flood Insurance Rate Map. An official map of a community on which FEMA has delineated both the Special Flood Hazard Areas and the risk premium zones applicable to the community.

Discharge: The amount of water that passes a point in a given period of time. Rate of discharge is usually measured in cubic feet per second (cfs).

DSR: Damage survey report.

Elevation reference marks: See bench marks.

Emergency Operations Center: A facility that houses communications equipment that is used to coordinate the response to a disaster or emergency.

Eminent domain: Governmental power to acquire a property without the owner's consent.

Encroachment review: An analysis to determine if a project will increase flood heights or cause increased flooding downstream.

EOC: Emergency Operations Center.

FBFM: Flood Boundary Floodway Map. An official map of a community on which FEMA has delineated the regulatory floodway. Recent Flood Insurance Studies show the floodway on the FIRM and do not include an FBFM.

FEMA: Federal Emergency Management Agency.

FHBM: Flood Hazard Boundary Map. An official map of a community published by FEMA that delineates the approximate boundary of the floodplain. An FHBM is generally the initial map provided the community and is eventually superseded by a FIRM.

FIA: Federal Insurance Administration. FIA was the part of FEMA, which administered the National Flood Insurance Program. This is now the responsibility of FEMA's Mitigation Division.

FIRM: Flood Insurance Rate Map. An official map of a community on which FEMA has delineated both the Special Flood Hazard Areas and the risk premium zones applicable to the community.

Flash flood: A flood in hilly and mountainous areas that may come minutes after a heavy rain. One can also occur in urban areas where pavements and drainage improvements speed runoff to a stream.

Flood: A general and temporary condition of partial or complete inundation of normally dry land areas.

Flood fringe: The portion of the floodplain lying outside of the floodway.

Flood hazard mitigation: All actions that can be taken to reduce property damage and the threat to life and public health from flooding.

Flood Insurance Study: A report published by FEMA for a community issued along with the community's Flood Insurance Rate Map (FIRM). The study contains such background data as the base flood discharges and water surface elevations that were used to prepare the FIRM.

Flood Mitigation Assistance: A grant program that supports plans and projects for mitigating losses to insured buildings funded by the National Flood Insurance Program.

Flood of record: The highest known flood level for the area, as recorded in historical documents.

Floodplain: Any land area susceptible to being inundated by flood waters from any source.

Floodproofing: Protective measures added to or incorporated in a building that is not elevated above the base flood elevation to prevent or minimize flood damage. "Dry floodproofing" measures are designed to

keep water from entering a building. “Wet floodproofing” measures minimize damage to a structure and its contents from water that is allowed into a building.

Floodway: The channel of a river or other watercourse and that portion of the adjacent floodplain that must remain open to permit passage of the base flood without cumulatively increasing the water surface elevation more than a designated height (historically this was 1 foot, but it is now 0.5 foot in Colorado, per the CWCB Rules and Regulations for Regulatory Floodplains that became effective in 2011).

FMA: Flood Mitigation Assistance.

Freeboard: A margin of safety added to the base flood elevation to account for waves, debris, variability, and/or lack of data.

Geographic information system: Computer based map systems that allow the user to keep a map updated easily and to correlate geographic information with other data, such as tax records on properties.

GIS: Geographic Information System.

Hazard Mitigation Grant Program: A FEMA disaster-assistance grant that funds mitigation projects.

HEC-2: A computer model used to conduct a hydraulic study, which produces flood elevations, velocities and floodplain widths.

HEC-RAS: A computer model used to conduct a hydraulic study, which produces flood elevations, velocities and floodplain widths.

Home rule: A community authorized to do anything that is not prohibited by statute.

Human intervention: Actions that must be taken by one or more persons before floodwaters arrive in order for a building to be floodproofed.

Hydrodynamic force: The force of moving water, including the impact of debris and high velocities.

Hydrologic cycle: The natural cycle that circulates water throughout the environment to maintain an overall balance between water in the air, on the surface and in the ground.

Hydrology: The science dealing with the waters of the earth. A flood discharge is developed by a hydrologic study.

Hydrostatic pressure: The pressure put on a structure by the weight of standing water. The deeper the water, the more it weighs and the greater the hydrostatic pressure.

Ice floe: Large chunks of ice that can cause a great deal of damage when a frozen river or lake begins to melt and break up.

Ice jam: Flooding that occurs when warm weather and rain break up frozen rivers and the broken ice floats downriver until it is blocked by an obstruction, creating an ice dam that blocks the channel and causes flooding upstream.

Increased Cost of Compliance: An additional claim payment made to a flood insurance policy holder to help cover the cost of bringing a substantially damaged or repetitively damaged building into compliance with the community’s floodplain management ordinance.

Individual and Family Grants: A disaster assistance grant that helps people with their unmet needs (i.e., needs not helped by other disaster assistance programs).

Inverse condemnation: See "taking."

ISO: The Insurance Services Office, Inc., an insurance organization that provides support to FEMA on implementation of the Community Rating System.

Lateral pressure: The amount of pressure imposed sideways by standing water. Deeper water exerts more lateral pressure than shallower water.

Letter of Map Amendment (**LOMA**): An official revision to a FEMA map done by describing the property affected. LOMAs are generally issued when properties have been inadvertently included in the floodplain.

Letter of Map Change (**LOMC**): A Letter of Map Amendment or a Letter of Map Revision.

Letter of Map Revision (**LOMR**): An official revision to a FEMA map done by describing the property affected.

Limited Map Maintenance Project: A small-scale restudy of a Flood Insurance Study.

LOMA: Letter of Map Amendment.

LOMR: Letter of Map Revision.

Lowest Floor: The lowest floor of the lowest enclosed area (including basement) of a building.

Market value: The price a willing buyer and seller agree upon.

Meander: A curve in a river.

Mitigation Division: The FEMA office that sets national policy for the NFIP and administers the mapping program.

M-O-M: Multi-objective management.

Movable bed streams: A type of flooding that features uncertain flow paths.

Mudslide (i.e., mudflow): A condition where there is a river, flow or inundation of liquid mud down a hillside.

Mudflow: See mudslide.

Multi-objective management: An approach to planning and funding local programs that involves a variety of local interests and concerns.

NEPA: The National Environmental Policy Act, a federal law that requires agencies to evaluate the environmental impact of a proposed project.

NGVD: National Geodetic Vertical Datum of 1929, the national datum used by the National Flood Insurance Program. NGVD is based on mean sea level. It was known formerly as the "Mean Sea Level Datum of 1929 (MSL)."

No-rise Certification: A certification by an engineer that a project will not cause a set increase in flood heights.

Non-structural flood protection measures: Administrative tools for controlling flooding and flood damage, including regulations on development, building codes, property acquisition and structure relocation, and modification of existing buildings.

Ordinance: The generic term for a law passed by a local government.

Overbank flooding: Flooding that occurs when downstream channels receive more rain or snowmelt from their watershed than normal, or a channel is blocked by an ice jam or debris. Excess water overloads the channels and flows out onto the floodplain.

Planned unit development (PUD): A regulatory approach that allows a developer to design the entire area while individual requirements may be relaxed to allow for open space, mixed land uses, and other variances to traditional zoning rules.

Post-FIRM building: For insurance rating purposes, a post-FIRM building was constructed or substantially improved after December 31, 1974, or after the effective date of the initial Flood Insurance Rate Map of a community, whichever is later. For a community that participated in the NFIP when its initial FIRM was issued, post-FIRM buildings are the same as new construction and must meet the National Flood Insurance Program's minimum floodplain management standards.

Pre-FIRM building: For insurance rating purposes, a pre-FIRM building was constructed or substantially improved on or before December 31, 1974, or before the effective date of the initial Flood Insurance Rate Map of the community, whichever is later. Most pre-FIRM buildings were constructed without taking the flood hazard into account.

Probability: A statistical term having to do with the size of a flood and the odds of that size of flood occurring in any year.

Profile: A graph that shows elevations of various flood events.

Public/Infrastructure Assistance: A disaster assistance grant that helps public agencies and nonprofit organizations finance repairs and reconstruction of public infrastructure.

Q3 Flood Data Product: A graphical representation of certain features of a FIRM in digital format.

Reconstruction: Building a new structure on the old foundation or slab of a structure that was destroyed, damaged, purposefully demolished or razed. The term also applies when an existing structure is moved to a new site.

Regular Program: Also called the Regular Phase. The phase of community participation in the National Flood Insurance Program that begins on the date of the Flood Insurance Rate Map or when the community adopts an ordinance that meets the minimum requirements of the NFIP and adopts the technical data provided with the FIRM, whichever is later. Nearly all communities participating in the NFIP are in the Regular Program.

Rehabilitation: An improvement made to an existing structure which does not affect its external dimensions.

Restudy: A new Flood Insurance Study for all or part of a community that has already had a Flood

Insurance Study.

Retrofitting: Retrofitting techniques include floodproofing, elevation, construction of small levees, and other modifications made to an existing building or its yard to protect it from flood damage.

Revision: A change to a floodplain map based on new data submitted to FEMA.

Riverine: Of or produced by a river. Riverine floodplains have readily identifiable channels. Floodway maps can only be prepared for riverine floodplains.

Roughness: A measure related to ground surface conditions that reflects changes in floodwater velocity due to ground friction.

Runoff: Rainfall and snowmelt that reaches a stream.

SFHA: Special Flood Hazard Area.

Sheet flow: Floodwater that spreads out over a large area that does not have defined channels at a somewhat uniform depth.

Special Flood Hazard Area: The base floodplain displayed on FEMA maps. It includes the A and V Zones.

Stafford Act: The Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988, as amended, which authorizes FEMA's current disaster assistance programs and the Hazard Mitigation Grant Program. The Disaster Mitigation Act of 2000 made extensive changes to the Stafford Act.

Stationing: Determining the distance along a stream.

Statutory authority: The powers granted to a local government by state law.

Stillwater flood elevations: Show the elevations of various coastal floods, not counting waves.

Storm surge: Water that is pushed toward shore by persistent high wind and changes in air pressure. Storm surges can result from hurricanes and other coastal storms.

Stormwater management: Efforts to reduce the impact of increased runoff that results from new development.

Stormwater detention: Storing stormwater runoff for release at a restricted rate after the storm subsides.

Stormwater retention: Storing stormwater runoff for later use in irrigation or groundwater recharge, or to reduce pollution.

Structural flood control: Measures that control floodwaters by construction of barriers or storage areas or by modifying or redirecting channels.

Submit to rate: A process used when an insurance agent cannot complete the rate calculation for a flood insurance policy. The application is sent to the WYO Company or FEMA to be individually rated.

Substantial damage: Damage of any origin sustained by a structure whereby the cost of restoring the structure to its before damaged condition would equal or exceed 50 percent of the market value of the

structure before the damage occurred.

Substantial improvement: Any reconstruction, rehabilitation, addition or other improvement to a structure, the total cost of which equals or exceeds 50 percent of the market value of the structure before the start of construction of the improvement. The definition of "substantial improvement" includes buildings that have incurred "substantial damage" regardless of the actual repair work performed.

Taking: Obtaining private property with or without compensating the owner. The term also includes reducing the value of private property to such an extent that the owner is deprived of all economic interest.

Thalweg: The bottom of a river channel.

Topographic map: See contour map.

Transect: A survey of topographic conditions used in coastal flood studies.

Tsunami: A large wave caused by an underwater earthquake or volcano which can raise water levels as much as 15 feet.

V Zone: See "Zone V."

Variance: A grant of relief by a community from the terms of a land use, zoning, or building code regulation.

Velocity: The speed of moving water; a force that is measured in feet per second.

Watershed: An area that drains into a lake, stream, or other body of water.

X Zone: See "Zone X."

Zone A: The Special Flood Hazard Area (except coastal V Zones) shown on a community's Flood Insurance Rate Map. There are five types of A Zones:

A: SFHA where no base flood elevation is provided.

A1-30: Numbered A Zones (e.g., A7 or A14), SFHA where the FIRM shows a base flood elevation in relation to NGVD.

AE: SFHA where base flood elevations are provided. AE Zone delineations are now used on new FIRMs instead of Numbered A Zones.

AO: SFHA with sheet flow, ponding, or shallow flooding. Base flood depths (feet above grade) are provided.

AH: Shallow flooding SFHA. Base flood elevations in relation to NGVD are provided.

Zone B: Area of moderate flood hazard, usually depicted on Flood Insurance Rate Maps as between the limits of the base and 500-year floods. B Zones are also used to designate base floodplains of little hazard, such as those with average depths of less than 1 foot.

Zone C: Area of minimal flood hazard, usually depicted on Flood Insurance Rate Maps as above the

500-year flood level. B and C Zones may have flooding that does not meet the criteria to be mapped as a Special Flood Hazard Area, especially ponding and local drainage problems.

Zone D: Area of undetermined but possible flood hazard.

Zone V: The Special Flood Hazard Area subject to coastal high hazard flooding. There are three types of V Zones: V, V1-30, and VE, and they correspond to the A Zone designations.

Zone X: Newer Flood Insurance Rate Maps show Zones B and C (see above) as Zone X.

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Chapter 5
Rainfall

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1.0 Overview

The purpose of this chapter is to provide rainfall depth, duration, intensity, and frequency data and analytical methods used to develop the rainfall information needed to carry out the hydrological analyses described in the *Runoff* chapter of the Urban Storm Drainage Criteria Manual (USDCM). Specifically, this chapter describes:

- The basis of point precipitation values for locations within the Urban Drainage and Flood Control District (UDFCD),
- Temporal distributions of point rainfall to develop the hyetographs necessary for the Colorado Urban Hydrograph Procedure (CUHP) hydrological modeling, and
- Intensity-duration-frequency (IDF) data and relationships used in Rational Method hydrologic computations.

This chapter includes analysis of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return storm events. If information is needed regarding other storm return periods or for areas in Colorado but outside UDFCD, the reader is directed to NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 8 Version 2.0 (NOAA Atlas 14) published by the National Oceanic and Atmospheric Administration (NOAA) in 2013, which contains a more complete description of rainfall analysis in the State of Colorado.

History of the Rainfall Chapter

The USDCM that was originally published in 1969 contained rainfall depth-duration-frequency maps for the 2-, 10-, and 100-year events and guidelines for developing design rainstorms and I-D-F curves for any location within UDFCD. The NOAA Atlas 2, Volume III, published in 1973, was based on a longer period of record and a large number of gages. Unfortunately, the maps in the USDCM and the NOAA Atlas did not agree.

Since 1977 UDFCD has studied the rainfall and runoff relationships in the Denver metropolitan area, including analysis of the (then) 73-year period at the Denver rain gage. This analysis indicated that the NOAA Atlas 2 maps, although not perfect, were more in line with the rainfall frequency distribution of the long-term record than the maps in the original USDCM.

As the 1982 version of CUHP was being developed, UDFCD developed methods to convert the information in the NOAA Atlas 2 into a family of design rainstorms by distributing these design storms in a manner that yielded peak runoff recurrence frequency distributions consistent with observed rainfall-runoff characteristics in the Denver metropolitan area. For the above-stated reasons and to use rainfall information consistent with the information being used by the State of Colorado, it was concluded that the NOAA Atlas 2 rainfall information should also be used within UDFCD.

In 2013, the new *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 8-Midwestern States* was published with new precipitation values. UDFCD provided peer review of NOAA's work. In 2016, UDFCD used *NOAA Atlas 14* values in a CUHP recalibration effort and decided to adopt the new values at that time.

2.0 Rainfall Depth-Duration-Frequency

To apply CUHP or the Rational Method as outlined in the *Runoff* Chapter, 1-hour point rainfall data for the area of interest are needed. To apply CUHP to watersheds larger than 15-square miles in size, 3-hour and 6-hour point rainfall depths are also required.

2.1 Rainfall Depth-Duration-Frequency

Access NOAA Atlas 14 at http://hdsc.nws.noaa.gov/hdsc/pfds/ to obtain rainfall depth-duration-frequency values for the UDFCD region. The website includes durations of 5, 10, 15, 30, and 60 minutes as well as 2, 3, 6, 12, and 24 hours. It also includes several durations from 2 to 60 days. Recurrence intervals included in the new Atlas include intervals of 1, 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years. New with the Atlas 14 update, 2-hour and 3-hour depths are now provided. Previous versions of this manual provided equations to calculate these depths based on the 1-hour and 6-hour depths. These equations are still used in CUHP to calculate the third hour of the 3-hour temporal distribution as described in Section 3.1.

3.0 Design Storm Distribution for CUHP

The 1-hour point precipitation values from NOAA Atlas 14 are distributed into 5-minute increments (see Table 5-2) to develop temporal distributions for use with CUHP. The rainfall duration used with CUHP varies with the size of the watershed being analyzed as shown in Table 5-1. For larger storms, Depth Reduction Factors (DRFs)[1] are applied to the incremental precipitation depths to take into account averaging effects for larger watershed sizes. For the 2-, 5-, and 10-year events (minor events), DRFs can be applied to watersheds 2-square miles or larger. For the 25-, 50-, 100-, and 500-year events, DRFs are applicable to watersheds 15-square miles and larger. Table 5-1 provides design storm durations and applicability of DRFs based on watershed area.

Table 5-1. Storm duration and area adjustment for CUHP modeling

Design Storm	Watershed Area (square miles)	Recommended Storm Duration	Apply DRF?
2-, 5-, and 10-Year	$A \leq 2.0$	2 hours	No
	$2.0 < A < 15.0$	2 hours	Yes – Use Table 5-3
	$A \geq 15.0$	6 hours	Yes – Use Table 5-3
25-, 50-, 100-, and 500-Year	$A < 15.0$	2 hours	No
	$A \geq 15.0$	6 hours	Yes – Use Table 5-4

[1] The term Depth Reduction Factor (DRF) is used in this text but is interchangeable with the terms Depth Area Reduction Factor (DARF) and Area Reduction Factor (ARF) used by others.

3.1 Temporal Distribution

The current version of CUHP was designed to be used with the 1-hour rainfall depths from NOAA Atlas 14. To obtain a temporal distribution for a design storm, the 1-hour depth is converted into a 2-hour design storm by multiplying the 1-hour depth(s) by the percentages for each time increment given in Table 5-2. This conversion is handled automatically in CUHP for the 1-hour depth specified in the CUHP input file.

The temporal distribution presented in Table 5-2 represents a design storm for use with a distributed rainfall-runoff routing model. The distribution is the result of a calibration process performed by UDFCD to provide, in conjunction with the use of CUHP, peak runoff rates and runoff volumes of the same return period as the design storm (Urbonas 1978). The 1-hour values are "embedded" in the 2-hour and other duration design storms. The first hour of the rainfall distribution includes the most intense rainfall (25% of the 1-hour point rainfall depth is assumed to occur over a 5-minute period). The 2-hour precipitation total is approximately 116% of the 1-hour rainfall depth for all recurrence intervals included in this chapter, as shown in the totals at the bottom of Table 5-2. It should be noted that the 2-hour point rainfall depth provided in the NOAA Atlas may differ slightly from the summation of the incremental depths from the 2-hour distribution in CUHP.

CUHP prepares a temporal distribution of the Design Rainfall for the 2-, 5-, 10-, 25-, 50-, 100- and 500-yr events within the UDFCD boundary including depth reduction factors (DRFs) for use with SWMM modeling. CUHP may provide slightly different results for the rainfall distribution than the procedure outlined in this chapter due to a smoothing method implemented in the programming which eliminates potential dips in the hyetograph.

To develop the temporal distribution for the 6-hour design storm (watersheds greater than 15.0 square miles), first prepare a 3-hour design storm. Developing the 3-hour storm is an intermediate step in deriving the 6-hour temporal distribution. To develop the temporal distribution for the 3-hour design storm, first prepare the 2-hour design storm distribution using the 1-hour storm point precipitation and the temporal percentage distribution shown in Table 5-2. The 2-hour distribution provides the first two hours of the 3-hour design storm. The difference between the 3-hour point precipitation and the 2-hour point precipitation is then distributed evenly over the third hour of the storm (i.e., the period of 125 minutes to 180 minutes). It should be noted that CUHP uses equations derived from NOAA Atlas 2, Volume III (1973) to calculate the difference between the 3-hour and 2-hour point precipitation values. For this reason, the values used by CUHP may not match the published values in NOAA Atlas 14.

The 3-hour distribution provides the first three hours of the 6-hour design storm. The difference between the 6-hour point precipitation (provided on the NOAA website) and the 3-hour point precipitation (calculated by summation of the incremental depths from the 3-hour distribution) is distributed evenly over the period of 185 minutes to 360 minutes (i.e. the last three hours of the 6-hour design storm).

Basis for Design Storm Distribution

The orographic effects of the Rocky Mountains and the high plains near the mountains as well as the semi-arid climate influence rainfall patterns in the Denver area. Rainstorms often have an "upslope" character where the easterly flow of moisture settles against the mountains. These types of rainstorms have durations that can exceed six hours and, although they may produce large amounts of total precipitation, they are rarely intense. Although upslope storms may cause local drainage problems or affect the flood levels of large watersheds, typically they are not the cause of 2- through 100-year type of flooding of small urban catchments in the Denver area.

Very intense rainfall in the Denver area typically results from convective storms or frontal stimulated convective storms. The most intense periods of rainfall for these types of storms often occur in periods that are less than one or two hours. These storms can produce brief periods of very high rainfall intensities. These short-duration, high-intensity rainstorms cause most of the flooding problems in the great majority of urban catchments.

Analysis of a 73-year record of rainfall at the Denver rain gage revealed that an overwhelming majority of the intense rainstorms produced their greatest intensities in the first hour of the storm. In fact, of the 73 most intense storms analyzed, 68 had the most intense period begin and end within the first hour of the storm, and 52 had the most intense period begin and end within the first half hour of the storm. These types of storms have been categorized as "leading intensity" storm events. The data clearly show that the "leading intensity" storms predominate among the "non-upslope" type storms in the Denver region.

The recommended design storm distribution takes into account the observed "leading intensity" nature of the convective storms. In addition, the temporal distributions for the recommended design storms were designed to be used with CUHP (1982 and later), the published NOAA 1-hour precipitation values (NOAA 1973) and Horton's infiltration loss equation. They were developed to approximate the recurrence frequency of peak flows and runoff volumes (i.e., 2- through 100-years) that were found to exist for the watersheds for which rainfall-runoff data were collected. The procedure for the development of these design storm distributions and the preliminary results were reported in literature and UDFCD publications (Urbonas 1978; Urbonas 1979).

Table 5-2. Design storm distributions of 1-hour precipitation

Time Minutes	Percent of 1-hour precipitation depth (%)				
	2-Year	5-Year	10-Year	25- and 50-Year	100- and 500-Year
5	2.0	2.0	2.0	1.3	1.0
10	4.0	3.7	3.7	3.5	3.0
15	8.4	8.7	8.2	5.0	4.6
20	16.0	15.3	15.0	8.0	8.0
25	25.0	25.0	25.0	15.0	14.0
30	14.0	13.0	12.0	25.0	25.0
35	6.3	5.8	5.6	12.0	14.0
40	5.0	4.4	4.3	8.0	8.0
45	3.0	3.6	3.8	5.0	6.2
50	3.0	3.6	3.2	5.0	5.0
55	3.0	3.0	3.2	3.2	4.0
60	3.0	3.0	3.2	3.2	4.0
65	3.0	3.0	3.2	3.2	4.0
70	2.0	3.0	3.2	2.4	2.0
75	2.0	2.5	3.2	2.4	2.0
80	2.0	2.2	2.5	1.8	1.2
85	2.0	2.2	1.9	1.8	1.2
90	2.0	2.2	1.9	1.4	1.2
95	2.0	2.2	1.9	1.4	1.2
100	2.0	1.5	1.9	1.4	1.2
105	2.0	1.5	1.9	1.4	1.2
110	2.0	1.5	1.9	1.4	1.2
115	1.0	1.5	1.7	1.4	1.2
120	1.0	1.3	1.3	1.4	1.2
Totals	115.7%	115.7%	115.7%	115.6%	115.6%

3.2 Depth Reduction Factor (DRF) Adjustments

A Depth Reduction Factor (DRF) adjustment can be used when applying a point precipitation value to an entire watershed area for a given recurrence interval. Since average rainfall over a large watershed is generally lower than point rainfall, a DRF is applied to reduce point precipitation values to area-average precipitation values. The NOAA Atlas provides guidelines for adjusting the rainfall depths with increasing catchment area. These guidelines were provided in NOAA Altas 2, Volume III and did not change with the release of NOAA Atlas 14. Area-depth adjustments are given in the Atlas for durations of ½-, 1-, 3-, 6- and 24-hours. Figure 5-1 is based on the NOAA Atlas. The 15-minute curve was extrapolated by UDFCD from the information shown for other storm durations on Figure 5-1. The fast response times of urbanized watersheds and sharp rainstorm distribution gradients in the UDFCD region require adjustments of rainfall depths for storm durations that are less than ½-hour. Figure 5-1 provides DRF curves that can be applied to the 25-, 50-, 100- and 500-year events (NOAA 1973).

For more-frequently occurring storm events, including the 2- through 10-year events, UDFCD analyzed results from a 2010 study conducted by Carlton Engineering, Inc. on behalf of the City of Colorado Springs *Fountain Creek Rainfall Characterization Study* (Carlton 2010). The Carlton study developed cell-centered DRFs[2] based on extensive analysis of radar data in the Fountain Creek watershed. UDFCD analyzed the data provided in this report to develop geographically-fixed DRF estimates for the 2- through 10-year events, by averaging recommended DRFs from the Carlton report and the NOAA Atlas. Figure 5-2 provides these curves.

The DRF adjustment factors are provided in Table 5-3 (2-, 5-, and 10-year design storms) and Table 5-4 (25-, 50-, 100, and 500-year design storms) to assist with DRF calculations.

[2] DRFs are commonly classified as "cell-centered" or "geographically-fixed" depending on how the factors were developed. Cell-centered DRFs are determined by analyzing gridded storm-cell data to determine the ratio of the average depth of rainfall produced by the overall storm cell (average of all grid point depths) to the maximum point rainfall depth (maximum grid point depth). A geographically-fixed DRF represents the ratio of average precipitation of a geographic area (watershed) to the maximum point rainfall depth occurring in the watershed. The difference between the two is the point of reference. For a cell-centered DRF, the point of reference is the storm cell itself, which may pass over many watersheds along the storm track. For a geographically-fixed DRF, the point of reference is the watershed, which receives precipitation as a storm cell passes over the watershed.

Table 5-3. DRFs for design rainfall distributions 2-, 5-, and 10-year design rainfall

Time (minutes)	Correction Factor by Watershed Area in Square Miles[1]								
	2	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**75**
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	1.00	0.97	0.94	0.91	0.90	0.85	0.75	0.65	0.56
20	1.00	0.86	0.75	0.68	0.61	0.55	0.48	0.42	0.35
25	1.00	0.86	0.75	0.68	0.61	0.55	0.48	0.42	0.35
30	1.00	0.86	0.75	0.68	0.61	0.55	0.48	0.42	0.42
35	1.00	0.97	0.94	0.91	0.90	0.90	0.90	0.90	0.89
40	1.00	0.97	0.94	0.91	0.90	0.90	0.90	0.90	0.89
45	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
50	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
55	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
60	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
65	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
70	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
75	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
80	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
85	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
90	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
95	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
100	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
105	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
110	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
115	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
120	1.00	1.00	1.00	1.02	1.02	1.01	1.01	1.01	1.00
125-180	N/A	N/A	N/A	1.00	1.00	1.00	1.00	1.00	1.00
185-360	N/A	N/A	N/A	1.23	1.28	1.30	1.32	1.33	1.33

[1]For areas between the values listed in the table, correction factors can be obtained through linear interpolation between columns.

Table 5-4. DRFs for design rainfall distributions 25-, 50-, 100-, and 500-year design rainfall

Time (minutes)	Correction Factor by Watershed Area in Square Miles[1]					
	15	20	30	40	50	75
5	1.15	1.15	1.15	1.15	1.15	1.10
10	1.15	1.15	1.15	1.15	1.15	1.10
15	1.15	1.15	1.15	1.15	1.15	1.10
20	1.25	1.18	1.10	1.05	1.00	0.90
25	0.73	0.69	0.64	0.60	0.58	0.55
30	0.73	0.69	0.64	0.60	0.58	0.55
35	0.73	0.69	0.64	0.60	0.58	0.55
40	1.05	1.02	0.95	0.90	0.85	0.80
45	1.20	1.20	1.20	1.15	1.05	0.95
50	1.15	1.15	1.15	1.15	1.05	0.95
55	1.15	1.15	1.15	1.15	1.15	1.15
60	1.15	1.15	1.15	1.15	1.15	1.15
65	1.08	1.10	1.13	1.15	1.15	1.15
70	1.08	1.10	1.13	1.15	1.15	1.15
75	1.08	1.10	1.13	1.15	1.15	1.15
80	1.08	1.10	1.13	1.15	1.15	1.15
85	1.08	1.10	1.13	1.15	1.15	1.15
90	1.08	1.10	1.13	1.15	1.15	1.15
95	1.08	1.10	1.13	1.15	1.15	1.15
100	1.08	1.10	1.13	1.15	1.15	1.15
105	1.08	1.10	1.13	1.15	1.15	1.15
110	1.08	1.10	1.13	1.15	1.15	1.15
115	1.08	1.10	1.13	1.15	1.15	1.15
120	1.08	1.10	1.13	1.15	1.15	1.15
125-180	1.08	1.10	1.13	1.15	1.25	1.25
185-360	1.05	1.10	1.10	1.10	1.10	1.13

[1]For areas between the values listed in the table, correction factors can be obtained through linear interpolation between columns.

4.0 Intensity-Duration Curves for Rational Method

To develop depth-duration curves or intensity-duration curves for the Rational Method of runoff analysis take the 1-hour depth(s) obtained from NOAA Atlas 14 and apply Equation 5-1 for the duration (or durations) of interest:

$$I = \frac{28.5\, P_1}{(10 + T_d)^{0.786}} \qquad \text{Equation 5-1}$$

Where:

I = rainfall intensity (inches per hour)

P_1 = 1-hour point rainfall depth (inches)

T_d = storm duration (minutes)

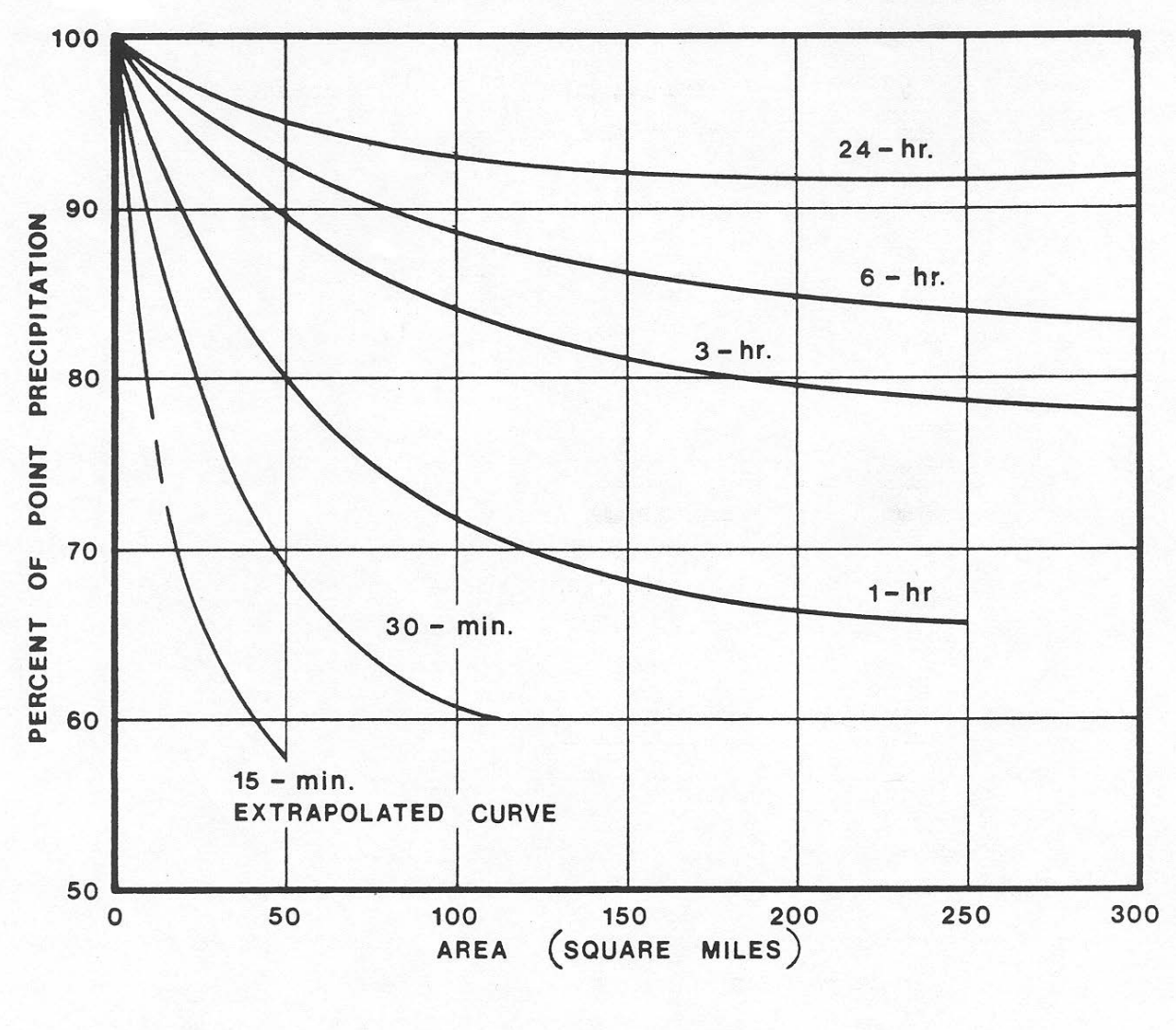

Figure 5-1. Depth reduction factor (DRF) curves for infrequent storm events

(25-, 50-, 100- and 500-year events) (NOAA Atlas 2, Volume III 1973 with extrapolation for 15-minute curve)

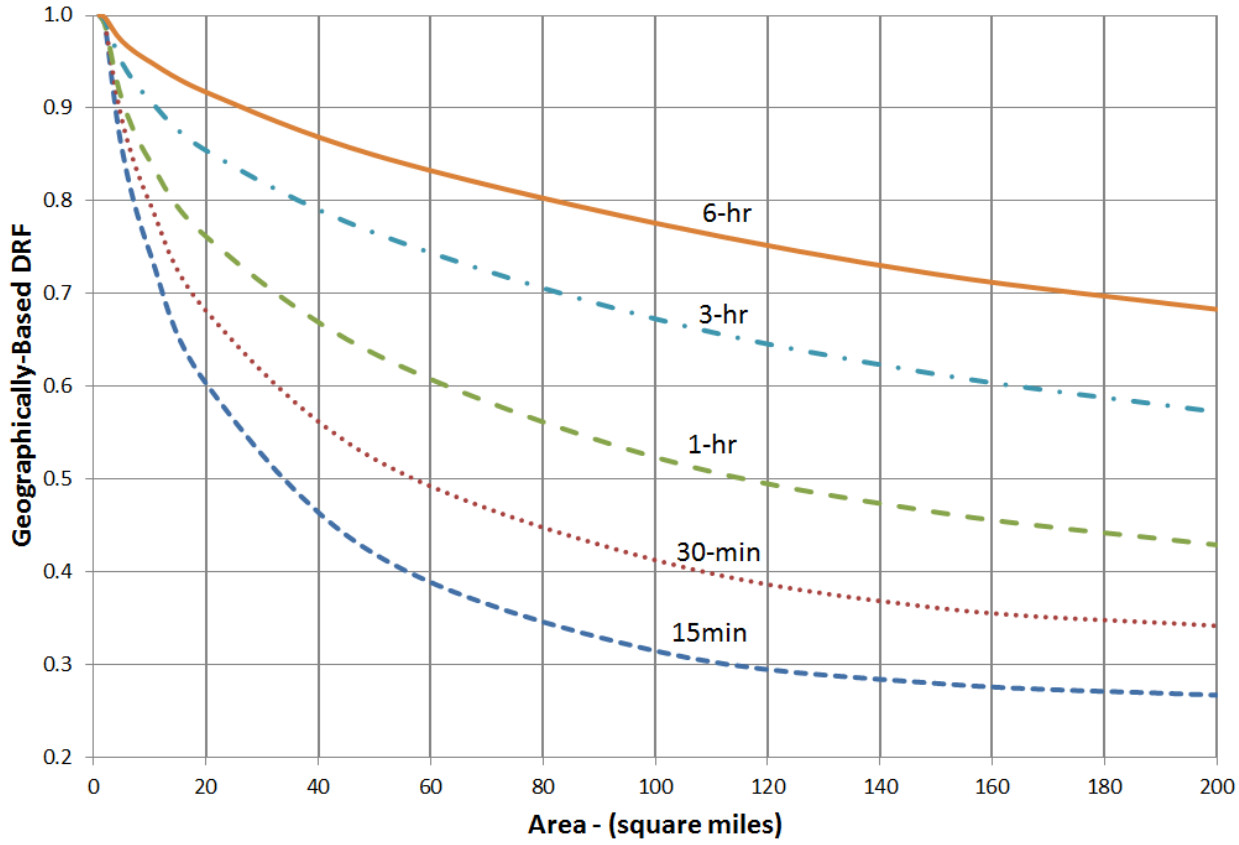

Figure 5-2. Depth reduction factor (DRF) curves for minor storm events (2-, 5-, and 10-year events)

(Carlton 2010)

5.0 Examples

5.1 Example preparation of intensity-duration-frequency curve

Use Equation 5-1 to plot rainfall intensity-duration curves for the 500-year, 100-year, 10-year, 5-year, and 2-year precipitation events in Denver. One-hour point precipitation values in Denver are as follows: 500-year (3.14), 100-year (2.31-inch), 10-year (1.33-inch), 5-year (1.09 inches), and 2-year (0.83-inches).

Calculations are prepared using Equation 5-1.

Duration (minutes)	**Rainfall Intensity (inches/hour)**	
5	$28 \times 3.14/(10+5)^{0.786}=$	10.46
10	$28 \times 3.14/(10+10)^{0.786}=$	8.35
15	$28 \times 3.14/(10+15)^{0.786}=$	7.00
30	$28 \times 3.14/(10+30)^{0.786}=$	4.84
60	$28 \times 3.14/(10+60)^{0.786}=$	3.12

Repeat this exercise for each return period.

Duration	**P_1**	**5**	**10**	**15**	**30**	**60**
2-year	0.83	2.77	2.21	1.85	1.28	0.82
5-year	1.09	3.63	2.90	2.43	1.68	1.08
10-year	1.33	4.43	3.54	2.97	2.05	1.32
25-year	1.69	5.63	4.49	3.77	2.61	1.68
50-year	1.99	6.63	5.29	4.44	3.07	1.98
100-year	2.31	7.70	6.14	5.15	3.56	2.29
500-year	3.14	10.46	8.35	7.00	4.84	3.12

The values from Equation 5-1 are plotted in Figure 5-15.

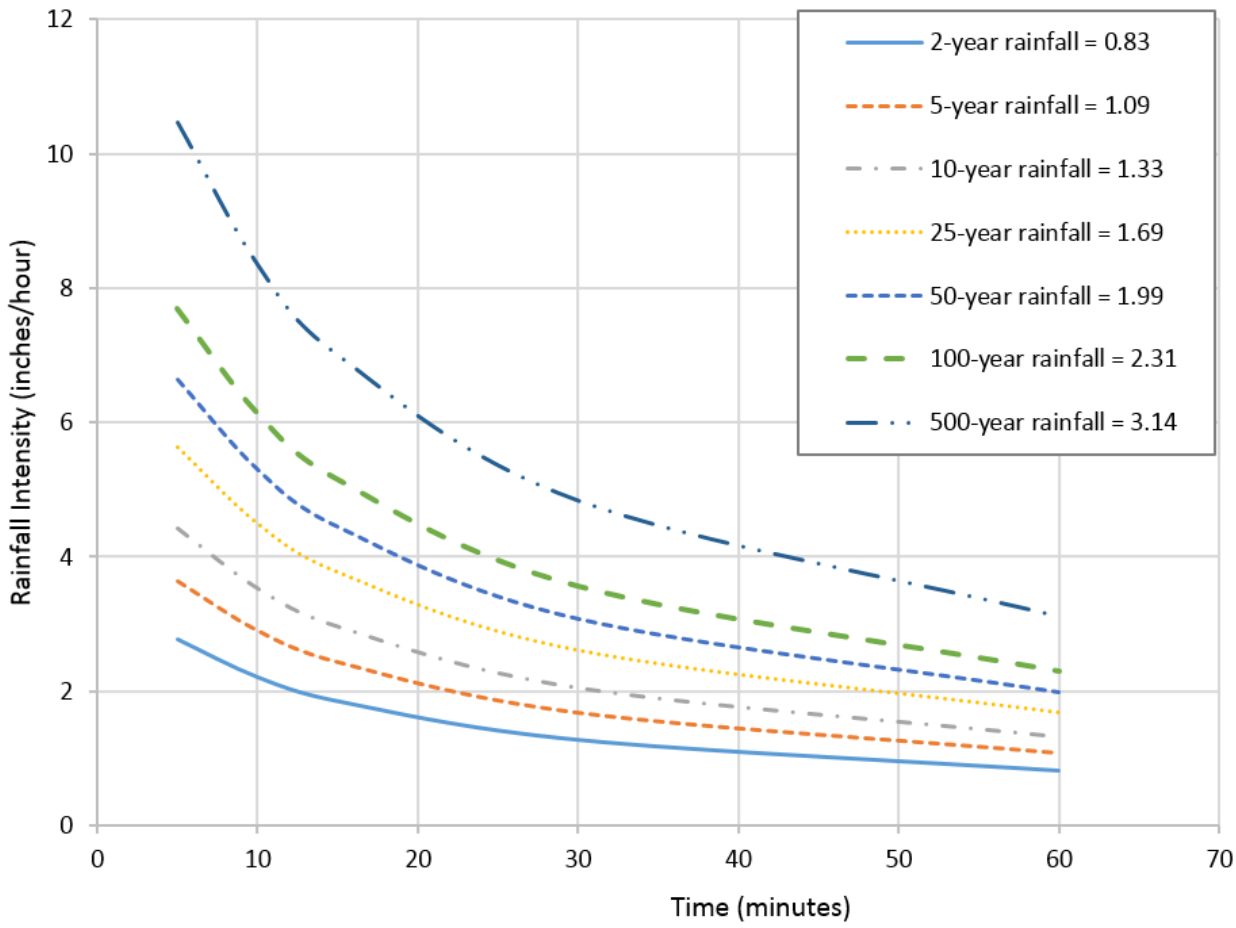

Figure 5-15. Example rainfall intensity-duration curves

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Chapter 6
Runoff

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1.0 Overview

Photograph 6-1. Devastating flooding from Gregory Canyon Creek in Boulder in September 2013 emphasizes the importance of accurate flood flow projections.

The importance of accurate runoff quantification cannot be overstated. Estimates of peak rate of runoff, runoff volume, and the time distribution of flow provide the basis for all planning, design, and construction of drainage facilities. Erroneous hydrology results in infrastructure that is either undersized, oversized, or out of hydraulic balance. At the same time it is important to understand that the result of the runoff analysis is an approximation. Thus, the intent of this chapter is to provide a reasonably dependable and consistent method of approximating the characteristics of urban runoff for areas of Colorado and the United States having similar meteorology and hydrology to what is found within the Urban Drainage and Flood Control District (UDFCD) region. Five methods of hydrologic analysis are described in the Urban Storm Drainage Criteria Manual (USDCM):

1. The Rational Method,
2. The Colorado Urban Hydrograph Procedure (CUHP) for generating hydrographs from watersheds,
3. The EPA's Storm Water Management Model (SWMM), mostly for combining and routing the hydrographs generated using CUHP,
4. Use of published runoff information, and
5. Statistical analyses.

Most of this chapter focuses on the Rational Method and CUHP in combination with SWMM routing. Table 6-1 provides a summary of applicability for both methods.

The Rational Method can be used to analyze the design storm runoff from urban catchments that are not complex and that are generally 90 acres or less and when only the peak flow rate is needed (e.g., storm drain sizing). Calculations for the Rational Method can be carried out by hand or using the UD-Rational Excel workbook available at www.udfcd.org.

Since 1969, CUHP has been used extensively in this region. It has been calibrated for the UDFCD region using data collected for a variety of watershed conditions. The vast majority of major drainage systems within UDFCD are designed based upon the hydrology calculated using CUHP and a customized version of the EPA's Stormwater Management Model (SWMM), runoff block, named the Urban Drainage Stormwater Model (UDSWM). In 2005, UDFCD began using and recommending the EPA's SWMM Version 5 and upgraded the CUHP software to be compatible with that model. CUHP and SWMM should be used for larger catchments or when a hydrograph of the storm event is needed.

There have been hydrologic studies carried out for a majority of the major drainage systems within UDFCD and published flow data are available for most of these systems.

Statistical analyses may be used in certain situations outside the UDFCD boundary. The use of this approach requires the availability of acceptable, appropriate, and adequate data.

Table 6-1. Applicability of hydrologic methods

Watershed Size (acres)	Is the Rational Method Applicable?	Is CUHP Applicable?
0 to 90	Yes	Yes
90 to 160	No	Yes
160 to 3,000	No	Yes[1]
Greater than 3,000	No	Yes (subdividing into smaller catchments required)[1]

1. Subdividing into smaller subcatchments and routing the resultant hydrographs using SWMM may be needed to accurately model a catchment with areas of different soil types or percentages of imperviousness.

When modeling large watersheds, the subcatchment sizes can influence results. If heterogeneous land uses are "lumped" together into large subcatchments, the models may not accurately account for the "flashy" nature of runoff from impervious surfaces and peak rates of runoff may be underestimated. On the other hand, defining very small subcatchments can lead to complicated and unrealistic routing that can overestimate peak rates of runoff.

The quantity of stormwater runoff from an urban site is also related to site characteristics (e.g., lot size, soil type, slope, vegetation, impervious area) and stormwater measures used to control runoff from the site (e.g., site grading, disconnecting impervious areas from the drainage system, detention facilities, buffer zones, low impact development practices, and other structural and nonstructural best management practices). Implementation of Low Impact Development (LID) strategies, including measures to "minimize directly connected impervious areas" (MDCIA), reduces runoff peaks and volumes from urban areas. These practices involve site planning to minimize impacts to sensitive site features, methods to reduce the overall amount of impervious areas, and routing of runoff from impervious surfaces over permeable areas to slow runoff (increase time of concentration) and promote onsite storage and infiltration. Volume 3 of the USDCM contains additional information on LID practices.

2.0 Rational Method

For urban catchments that are not complex and are generally 90 acres or less in size, it is acceptable to use the Rational Method for design storm analysis. Most engineering offices in the United States continue to use this method originally introduced in 1889. Even though this method has frequently come under academic criticism for its simplicity, no other practical drainage design method has evolved to such a level of general acceptance by the practicing engineer. The Rational Method, properly understood and applied, can produce satisfactory results for urban storm drain design and small on-site detention design and for sizing of street inlets and storm drains.

2.1 Rational Formula

The Rational Method is based on the Rational Formula:

$$Q = CIA \qquad \text{Equation 6-1}$$

Where:

Q = the peak rate of runoff (cfs)

C = Runoff coefficient–a non-dimensional coefficient equal to the ratio of runoff volume to rainfall volume

I = average intensity of rainfall for a duration equal to the time of concentration, t_c (inches/hour)

A = tributary area (acres).

Actually, Q has a unit of inches per hour per acre (in/hour/ac); however, since this rate of acre-inches/hour differs from cubic feet per second (cfs) by less than one percent, the more common units of cfs are used. The time of concentration is defined as the time required for water to flow from the most remote point of the tributary area to the design point, and is determined for the selected flow length that represents the longest waterway through a rural watershed or the most representative flow path through the impervious portion in an urban catchment.

The general procedure for Rational Method calculations for a single catchment is as follows:

1. Delineate the catchment boundary and determine its area.

2. Define the flow path from the upper-most portion of the catchment to the design point. Divide the flow path into reaches of similar flow type (e.g., overland flow, shallow swale flow, gutter flow, etc.). Determine the length and slope of each reach.

3. Determine the time of concentration, t_c, for the selected waterway.

4. Find the rainfall intensity, I, for the design storm using the calculated t_c and the rainfall intensity-duration-frequency curve (see *Rainfall* chapter).

5. Determine the runoff coefficient, C.

6. Calculate the peak flow rate, Q, from the catchment using Equation 6-1.

2.2 Assumptions

The basic assumptions for the application of the Rational Method include:

1. The computed maximum rate of runoff to the design point is a function of the average rainfall rate during the time of concentration to that point.

2. The hydrologic losses in the catchment are homogeneous and uniform. The runoff coefficients vary with respect to type of soils, imperviousness percentage, and rainfall frequencies. These coefficients represent the average antecedent soil moisture condition.

3. The depth of rainfall used is one that occurs from the start of the storm to the time of concentration. The design rainfall depth during that period is converted to the average rainfall intensity for that period.

4. The maximum runoff rate occurs when the entire area is contributing flow. This assumption is not valid where a more intensely developed portion of the catchment with a shorter time of concentration produces a higher rate of runoff than the entire catchment with a longer time of concentration.

2.3 Limitations

The Rational Method is the simplistic approach for estimating the peak flow rate and total runoff volume from a design rainstorm in a given catchment. Under the assumption of uniform hydrologic losses, the method is limited to catchments smaller than 90 acres. Under the condition of composite soils and land uses, use an area-weighted method to derive the catchment's hydrologic parameters.

The greatest drawback to the Rational Method is that it normally provides only one point (the peak flow rate) on the runoff hydrograph. When the areas become complex and where subcatchments come together, the Rational Method will tend to overestimate the actual flow, which results in oversizing of drainage facilities. The Rational Method provides no means or methodology to generate and route hydrographs through drainage facilities. One reason the Rational Method is limited to small areas is that good design practice requires the routing of hydrographs for larger catchments to achieve an economically sound design.

Another disadvantage of the Rational Method is that with typical design procedures, one normally assumes that all of the design flow is collected at the design point and that there is no water running overland to the next design point. This is not an issue of the Rational Method but of the design procedure. Use additional analysis to account for this scenario.

2.4 Time of Concentration

One of the basic assumptions underlying the Rational Method is that runoff is linearly proportional to the average rainfall intensity during the time required for water to flow from the most remote part of the drainage area to the design point. In practice, the time of concentration is empirically estimated along the selected waterway through the catchment.

To calculate the time of concentration, first divide the waterway into overland flow length and channelized flow lengths, according to the channel characteristics. For urban areas (tributary areas of greater than 20 percent impervious), the time of concentration, t_c, consists of an initial time or overland flow time, t_i, plus the channelized flow travel time, t_t, through the storm drain, paved gutter, roadside ditch, or channel. For non-urban areas, the time of concentration consists of an overland flow time, t_i, plus the time of travel in a defined drainage path, such as a swale, channel, or stream. Estimate the channelized travel time portion, t_t, of the time of concentration from the hydraulic properties of the conveyance element. Initial or overland flow time, on the other hand, will vary with surface slope, depression storage, surface cover, antecedent rainfall, and infiltration capacity of the soil, as well as distance of surface flow. Compute the time of concentration for both urban and non-urban areas using Equation 6-2:

$$t_c = t_i + t_t \qquad \text{Equation 6-2}$$

Where:

t_c = computed time of concentration (minutes)

t_i = overland (initial) flow time (minutes)

t_t = channelized flow time (minutes).

2.4.1 Initial or Overland Flow Time

The initial or overland flow time, t_i, may be calculated using Equation 6-3:

$$t_i = \frac{0.395(1.1 - C_5)\sqrt{L_i}}{S_o^{0.33}} \qquad \text{Equation 6-3}$$

Where:

t_i = overland (initial) flow time (minutes)
C_5 = runoff coefficient for 5-year frequency (from Table 6-4)
L_i = length of overland flow (ft)
S_o = average slope along the overland flow path (ft/ft).

Equation 6-3 is adequate for distances up to 300 feet in urban areas and 500 feet in rural areas. Note that in a highly urbanized catchment, the overland flow length is typically shorter than 300 feet due to effective man-made drainage systems that collect and convey runoff.

2.4.2 Channelized Flow Time

The channelized flow time (travel time) is calculated using the hydraulic properties of the conveyance element. The channelized flow time, t_t, is estimated by dividing the length of conveyance by the velocity. The following equation, Equation 6-4 (Guo 2013), can be used to determine the flow velocity in conjunction with Table 6-2 for the conveyance factor.

$$t_t = \frac{L_t}{60K\sqrt{S_o}} = \frac{L_t}{60V_t} \qquad \text{Equation 6-4}$$

Where:

t_t = channelized flow time (travel time, min)
L_t = waterway length (ft)
S_o = waterway slope (ft/ft)
V_t = travel time velocity (ft/sec) = $K\sqrt{S_o}$
K = NRCS conveyance factor (see Table 6-2).

Table 6-2. NRCS Conveyance factors, K

Type of Land Surface	Conveyance Factor, K
Heavy meadow	2.5
Tillage/field	5
Short pasture and lawns	7
Nearly bare ground	10
Grassed waterway	15
Paved areas and shallow paved swales	20

The time of concentration, t_c, is the sum of the initial (overland) flow time, t_i, and the channelized flow time, t_t, as per Equation 6-2.

2.4.3 First Design Point Time of Concentration in Urban Catchments

Equation 6-4 was solely determined by the waterway characteristics and using a set of empirical formulas. A calibration study between the Rational Method and the Colorado Urban Hydrograph Procedure (CUHP) suggests that the time of concentration shall be the lesser of the values calculated by Equation 6-2 and Equation 6-5 (Guo and Urbonas 2013).

$$t_c = (26 - 17i) + \frac{L_t}{60(14i + 9)\sqrt{S_t}} \qquad \text{Equation 6-5}$$

Where:

t_c = minimum time of concentration for first design point when less than t_c from Equation 6-1.
L_t = length of channelized flow path (ft)
i = imperviousness (expressed as a decimal)
S_t = slope of the channelized flow path (ft/ft).

Equation 6-5 is the regional time of concentration that warrants the best agreement on peak flow predictions between the Rational Method and CUHP when the imperviousness of the tributary area is greater than 20 percent. It was developed using the UDFCD database that includes 295 sample urban catchments under 2-, 5-, 10-, 50, and 100-yr storm events (MacKenzie 2010). It suggests that both initial flow time and channelized flow velocity are directly related to the catchment's imperviousness (Guo and MacKenzie 2013).

The first design point is defined as a node where surface runoff enters the storm drain system. For example, all inlets are "first design points" because inlets are designed to accept flow into the storm drain.

Typically, but not always, Equation 6-5 will result in a lesser time of concentration at the first design point and will govern in an urbanized watershed. For subsequent design points, add the travel time for each relevant segment downstream.

2.4.4 Minimum Time of Concentration

Use a minimum t_c value of 5 minutes for urbanized areas and a minimum t_c value of 10 minutes for areas that are not considered urban. Use minimum values even when calculations result in a lesser time of concentration.

2.4.5 Common Errors in Calculating Time of Concentration

A common mistake in urbanized areas is to assume travel velocities that are too slow. Another common error is to not check the runoff peak resulting from only part of the catchment. Sometimes a lower portion of the catchment or a highly impervious area produces a larger peak than that computed for the whole catchment. This error is most often encountered when the catchment is long or the upper portion contains grassy open land and the lower portion is more developed.

2.5 Rainfall Intensity

The calculated rainfall intensity, *I*, is the average rainfall rate in inches per hour for the period of maximum rainfall having a duration equal to the time of concentration.

After the design storm recurrence frequency has been selected, a graph should be made showing rainfall intensity versus time. The procedure for obtaining the local data and plotting such a graph is explained and illustrated in the *Rainfall* chapter of the USDCM. The UD-Rain Excel workbook can also be used for calculating the intensity. This workbook is available for download at www.udfcd.org.

Photograph 6-2. Urbanization (impervious area) increases runoff volumes, peak discharges, frequency of runoff, and receiving stream degradation.

2.5.1 Runoff Coefficient

Each part of a watershed can be considered as either pervious or impervious. The pervious part is the area where water can readily infiltrate into the ground. The impervious part is the area that does not readily allow water to infiltrate into the ground, such as areas that are paved or covered with buildings and sidewalks or compacted unvegetated soils. In urban hydrology, the percentage of pervious and impervious land is important. Urbanization increases impervious area causing rainfall-runoff relationships to change significantly. In the absence of stormwater management methods such as low impact development and green infrastructure, the total runoff volume increases, the time to the runoff peak rate decreases, and the peak runoff rate increases.

When analyzing a watershed for planning or design purposes, the probable future percent of impervious area must be estimated. A complete tabulation of recommended values of the total percent of imperviousness is provided in Table 6-3.

The runoff coefficient, *C*, represents the integrated effects of infiltration, evaporation, retention, and interception, all of which affect the volume of runoff. The determination of *C* requires judgment based on experience and understanding on the part of the engineer.

Volume-based runoff coefficients were derived to establish the optimal consistency between CUHP and the Rational Method for peak flow predictions (Guo, 2013). Using the percentage imperviousness, the equations in Table 6-4 can be used to calculate the runoff coefficients for hydrologic soil groups A, B, and C/D for various storm return periods.

Table 6-3. Recommended percentage imperviousness values

Land Use or Surface Characteristics	Percentage Imperviousness (%)
Business:	
Downtown Areas	95
Suburban Areas	75
Residential lots (lot area only)**:**	
Single-family	
2.5 acres or larger	12
0.75 – 2.5 acres	20
0.25 – 0.75 acres	30
0.25 acres or less	45
Apartments	75
Industrial:	
Light areas	80
Heavy areas	90
Parks, cemeteries	10
Playgrounds	25
Schools	55
Railroad yard areas	50
Undeveloped Areas:	
Historic flow analysis	2
Greenbelts, agricultural	2
Off-site flow analysis (when land use not defined)	45
Streets:	
Paved	100
Gravel (packed)	40
Drive and walks	90
Roofs	90
Lawns, sandy soil	2
Lawns, clayey soil	2

Table 6-4. Runoff coefficient equations based on NRCS soil group and storm return period

NRCS Soil Group		Storm Return Period					
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
A	$C_A = 0.84i^{1.302}$	$C_A = 0.86i^{1.276}$	$C_A = 0.87i^{1.232}$	$C_A = 0.88i^{1.124}$	$C_A = 0.85i+0.025$	$C_A = 0.78i+0.110$	$C_A = 0.65i+0.254$
B	$C_B = 0.84i^{1.169}$	$C_B = 0.86i^{1.088}$	$C_B = 0.81i+0.057$	$C_B = 0.63i+0.249$	$C_B = 0.56i+0.328$	$C_B = 0.47i+0.426$	$C_B = 0.37i+0.536$
C/D	$C_{C/D} = 0.83i^{1.122}$	$C_{C/D} = 0.82i+0.035$	$C_{C/D} = 0.74i+0.132$	$C_{C/D} = 0.56i+0.319$	$C_{C/D} = 0.49i+0.393$	$C_{C/D} = 0.41i+0.484$	$C_{C/D} = 0.32i+0.588$

Where:

i = % imperviousness (expressed as a decimal)

C_A = Runoff coefficient for Natural Resources Conservation Service (NRCS) HSG A soils

C_B = Runoff coefficient for NRCS HSG B soils

$C_{C/D}$ = Runoff coefficient for NRCS HSG C and D soils.

The values for various catchment imperviousness and storm return periods are presented graphically in Figures 6-1 through 6-3, and are tabulated in Table 6-5. These coefficients were developed for the Denver region to work in conjunction with the time of concentration recommendations in Section 2.4. Use of these coefficients and this procedure outside of the semi-arid climate found in the Denver region may not be valid. The UD-Rational Excel workbook performs all the needed calculations to find the runoff coefficient given the soil type and imperviousness and the reader may want to take advantage of this macro-enabled Excel workbook that is available for download from the UDFCD's website www.udfcd.org.

See Examples 7.1 and 7.2 that illustrate the Rational Method.

Table 6-5. Runoff coefficients, *c*

Total or Effective % Impervious	NRCS Hydrologic Soil Group A						
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
2%	0.01	0.01	0.01	0.01	0.04	0.13	0.27
5%	0.02	0.02	0.02	0.03	0.07	0.15	0.29
10%	0.04	0.05	0.05	0.07	0.11	0.19	0.32
15%	0.07	0.08	0.08	0.1	0.15	0.23	0.35
20%	0.1	0.11	0.12	0.14	0.2	0.27	0.38
25%	0.14	0.15	0.16	0.19	0.24	0.3	0.42
30%	0.18	0.19	0.2	0.23	0.28	0.34	0.45
35%	0.21	0.23	0.24	0.27	0.32	0.38	0.48
40%	0.25	0.27	0.28	0.32	0.37	0.42	0.51
45%	0.3	0.31	0.33	0.36	0.41	0.46	0.54
50%	0.34	0.36	0.37	0.41	0.45	0.5	0.58
55%	0.39	0.4	0.42	0.45	0.49	0.54	0.61
60%	0.43	0.45	0.47	0.5	0.54	0.58	0.64
65%	0.48	0.5	0.51	0.54	0.58	0.62	0.67
70%	0.53	0.55	0.56	0.59	0.62	0.65	0.71
75%	0.58	0.6	0.61	0.64	0.66	0.69	0.74
80%	0.63	0.65	0.66	0.69	0.71	0.73	0.77
85%	0.68	0.7	0.71	0.74	0.75	0.77	0.8
90%	0.73	0.75	0.77	0.79	0.79	0.81	0.84
95%	0.79	0.81	0.82	0.83	0.84	0.85	0.87
100%	0.84	0.86	0.87	0.88	0.88	0.89	0.9
Total or Effective % Impervious	**NRCS Hydrologic Soil Group B**						
	2-Year	**5-Year**	**10-Year**	**25-Year**	**50-Year**	**100-Year**	**500-Year**
2%	0.01	0.01	0.07	0.26	0.34	0.44	0.54
5%	0.03	0.03	0.1	0.28	0.36	0.45	0.55
10%	0.06	0.07	0.14	0.31	0.38	0.47	0.57
15%	0.09	0.11	0.18	0.34	0.41	0.5	0.59
20%	0.13	0.15	0.22	0.38	0.44	0.52	0.61
25%	0.17	0.19	0.26	0.41	0.47	0.54	0.63
30%	0.2	0.23	0.3	0.44	0.49	0.57	0.65
35%	0.24	0.27	0.34	0.47	0.52	0.59	0.66
40%	0.29	0.32	0.38	0.5	0.55	0.61	0.68
45%	0.33	0.36	0.42	0.53	0.58	0.64	0.7
50%	0.37	0.4	0.46	0.56	0.61	0.66	0.72
55%	0.42	0.45	0.5	0.6	0.63	0.68	0.74
60%	0.46	0.49	0.54	0.63	0.66	0.71	0.76
65%	0.5	0.54	0.58	0.66	0.69	0.73	0.77
70%	0.55	0.58	0.62	0.69	0.72	0.75	0.79
75%	0.6	0.63	0.66	0.72	0.75	0.78	0.81
80%	0.64	0.67	0.7	0.75	0.77	0.8	0.83
85%	0.69	0.72	0.74	0.78	0.8	0.82	0.85
90%	0.74	0.76	0.78	0.81	0.83	0.84	0.87
95%	0.79	0.81	0.82	0.85	0.86	0.87	0.88
100%	0.84	0.86	0.86	0.88	0.89	0.89	0.9

Table 6-5. Runoff coefficients, *c* (continued)

Total or Effective % Impervious	NRCS Hydrologic Soil Group C						
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
2%	0.01	0.05	0.15	0.33	0.40	0.49	0.59
5%	0.03	0.08	0.17	0.35	0.42	0.5	0.6
10%	0.06	0.12	0.21	0.37	0.44	0.52	0.62
15%	0.1	0.16	0.24	0.4	0.47	0.55	0.64
20%	0.14	0.2	0.28	0.43	0.49	0.57	0.65
25%	0.18	0.24	0.32	0.46	0.52	0.59	0.67
30%	0.22	0.28	0.35	0.49	0.54	0.61	0.68
35%	0.26	0.32	0.39	0.51	0.57	0.63	0.7
40%	0.3	0.36	0.43	0.54	0.59	0.65	0.71
45%	0.34	0.4	0.46	0.57	0.62	0.67	0.73
50%	0.38	0.44	0.5	0.6	0.64	0.69	0.75
55%	0.43	0.48	0.54	0.63	0.66	0.71	0.76
60%	0.47	0.52	0.57	0.65	0.69	0.73	0.78
65%	0.51	0.56	0.61	0.68	0.71	0.75	0.79
70%	0.56	0.61	0.65	0.71	0.74	0.77	0.81
75%	0.6	0.65	0.68	0.74	0.76	0.79	0.82
80%	0.65	0.69	0.72	0.77	0.79	0.81	0.84
85%	0.7	0.73	0.76	0.79	0.81	0.83	0.86
90%	0.74	0.77	0.79	0.82	0.84	0.85	0.87
95%	0.79	0.81	0.83	0.85	0.86	0.87	0.89
100%	0.83	0.85	0.87	0.88	0.89	0.89	0.9

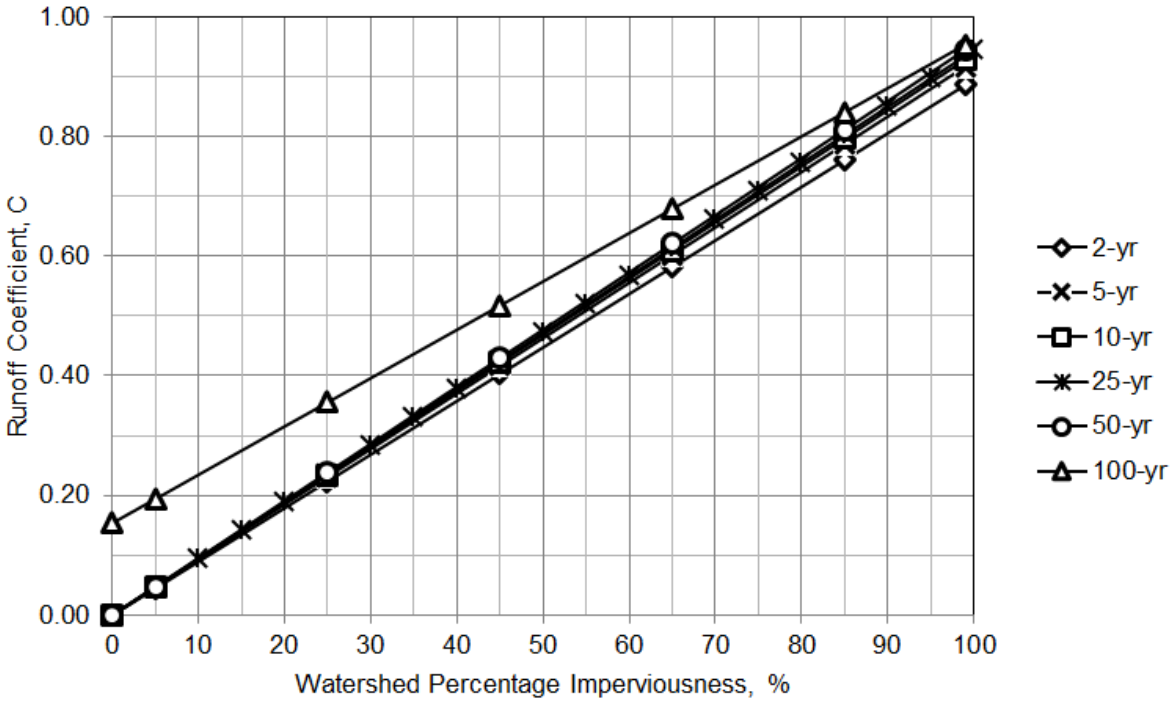


Figure 6-1. Runoff coefficient vs. watershed imperviousness NRCS HSG A

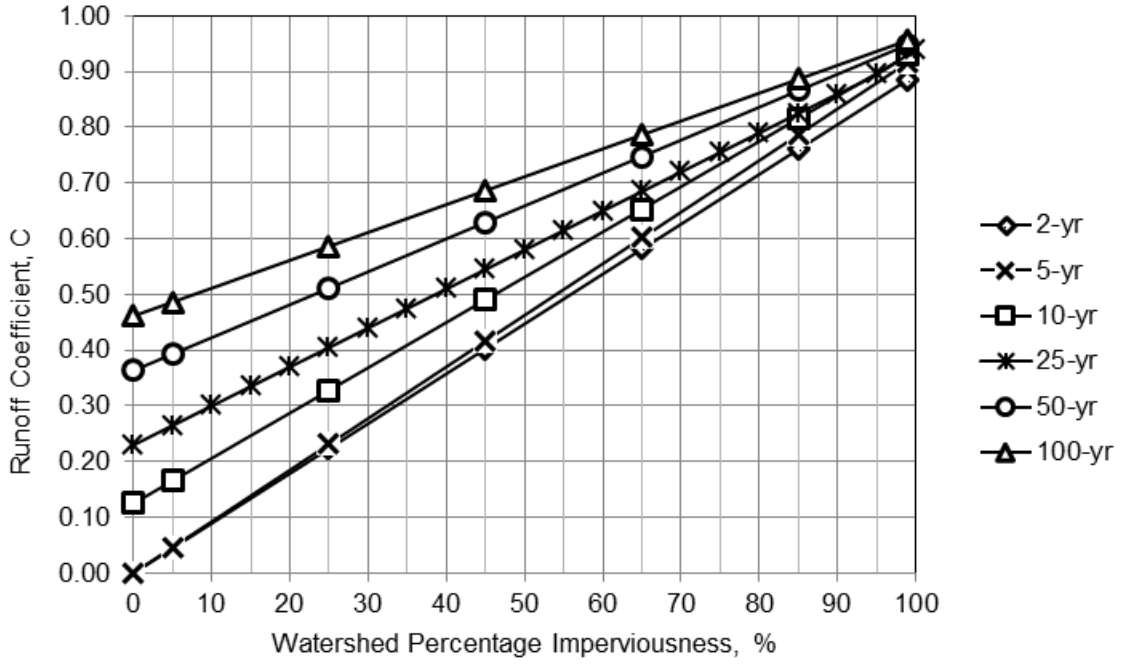


Figure 6-2. Runoff coefficient vs. watershed imperviousness NRCS HSG B

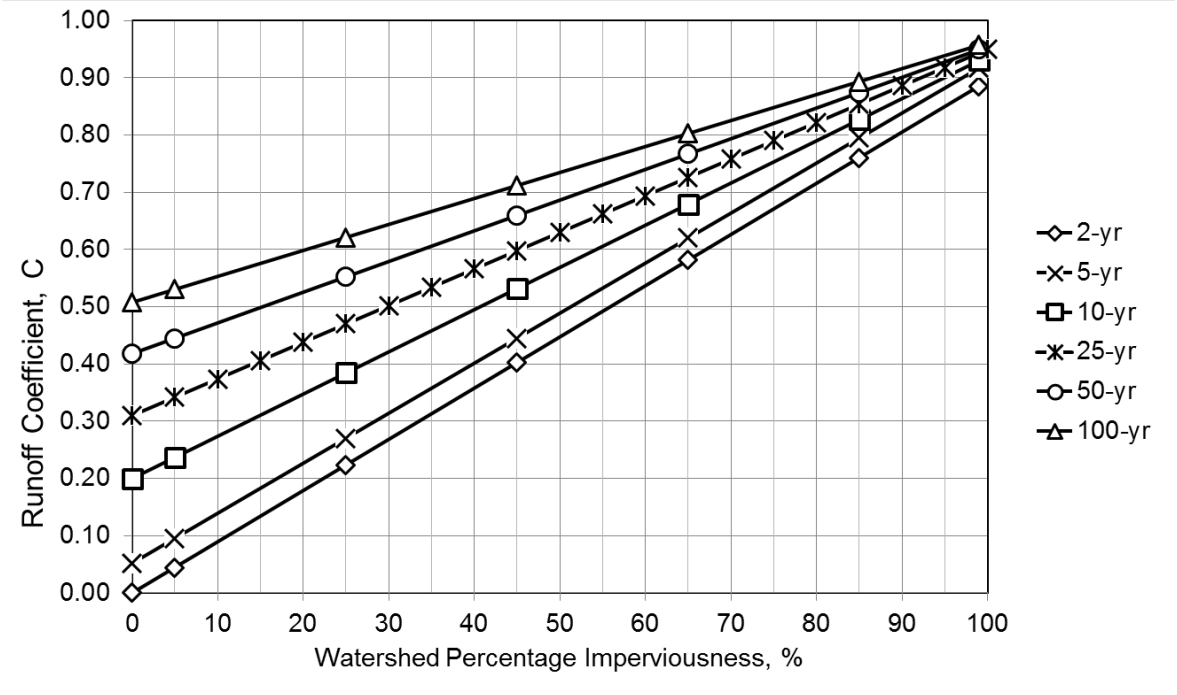


Figure 6-3. Runoff coefficient vs. watershed imperviousness NRCS HSG C and D

3.0 Colorado Urban Hydrograph Procedure

3.1 Background

The Colorado Urban Hydrograph Procedure (CUHP) is a method of hydrologic analysis based upon the unit hydrograph principle. A unit hydrograph is defined as the hydrograph of one inch of direct runoff from the tributary area resulting from a storm of a given duration. The unit hydrograph thus represents the integrated effects of factors such as tributary area, shape, street pattern, channel capacities, and street and land slopes. The basic premise of the unit hydrograph is that individual hydrographs resulting from the successive increments of excess rainfall that occur throughout a storm period will be proportional in discharge throughout their runoff period. Thus, the hydrograph of total storm discharge is obtained by summing the ordinates of the individual sub-hydrographs.

CUHP has been developed and calibrated using rainfall-runoff data collected in Colorado (mostly in the Denver/Boulder metropolitan area). This section provides a general background in the use of the computer version of CUHP to perform stormwater runoff calculations. A detailed description of the CUHP method and the assumptions and equations used, including a hand calculation example, are provided in the CUHP User Manual. The latest version of the CUHP 2005 macro-enabled Excel workbook and User Manual are available for download from www.udfcd.org.

3.2 Effective Rainfall for CUHP

Effective rainfall is that portion of precipitation during a storm event that runs off the land to streams. Those portions of precipitation that do not reach a stream are called abstractions and include interception by vegetation, evaporation, infiltration, storage in all surface depressions, and extended duration surface retention. The total design rainfall depth for use with CUHP should be obtained from the *Rainfall* chapter of the USDCM. This chapter illustrates a method for estimating the amount of rainfall that actually becomes surface runoff whenever a design rainstorm is used.

3.2.1 Pervious-Impervious Areas

As described in Section 2.5.1, the urban landscape is comprised of pervious and impervious surfaces. The degree of imperviousness is the primary variable that affects the volumes and rates of runoff calculated using CUHP. When analyzing a watershed for design purposes, the probable future percent of impervious area must first be estimated. A complete tabulation of recommended values of total percentage imperviousness is provided in Table 6-3 and Figures 6-1 through 6-3. References to impervious area and all calculations in this chapter are based on the input of total impervious areas. The pervious-impervious area relationship can be further refined for use in CUHP as follows:

- **DCIA**: Impervious area portion directly connected to the drainage system.
- **UIA:** Impervious area portion that drains onto or across pervious surfaces.
- **RPA**: The portion of pervious area receiving runoff from impervious portions.
- **SPA:** The separate pervious area portion not receiving runoff from impervious surfaces.

This further refinement is explained in more detail in the CUHP User Manual and in Chapter 3 of the USDCM Volume 3.

3.2.2 Depression Losses

Rainwater that is collected and held in small depressions and does not become part of the general surface runoff is called depression loss. Most of this water eventually infiltrates or evaporates. Depression losses also include water intercepted by trees, bushes, other vegetation, and all other surfaces. The CUHP method requires numerical values of depression loss as inputs to calculate the effective rainfall. Table 6-6 can be used as a guide in estimating the amount of depression (retention) losses to be used with CUHP.

Table 6-6. Typical depression losses for various land covers

(All values in inches for use with the CUHP.)

Land Cover	Range in Depression (Retention) Losses	Recommended
Impervious:		
Large paved areas	0.05 - 0.15	0.1
Roofs-flat	0.1 - 0.3	0.1
Roofs-sloped	0.05 - 0.1	0.05
Pervious:		
Lawn grass	0.2 - 0.5	0.35
Wooded areas and open fields	0.2 - 0.6	0.4

When an area is analyzed for depression losses, the pervious and impervious loss values for all parts of the watershed must be considered and accumulated in proportion to the percent of aerial coverage for each type of surface.

3.2.3 Infiltration

Flow of water into the soil surface is called infiltration. In urban hydrology much of the infiltration occurs on areas covered with grass. Urbanization can increase or decrease the total amount of infiltration depending on how the runoff is managed, historic use of the area and other factors.

Soil type is the most important factor in determining the infiltration rate. When the soil has a large percentage of well-graded fines, the infiltration rate is low. In some cases of extremely tight soil there may be, from a practical standpoint, essentially no infiltration. If the soil has several layers or horizons, the least permeable layer near the surface will control the maximum infiltration rate. The soil cover also plays an important role in determining the infiltration rate. Vegetation, lawn grass in particular, tends to increase infiltration by loosening the soil near the surface. Other factors affecting infiltration rates include slope of land, temperature, quality of water, age of lawn, and soil compaction. Of these, CUHP considers only the slope.

As rainfall continues, the infiltration rate decreases. When rainfall occurs on an area that has little antecedent moisture and the ground is dry, the infiltration rate can be much higher than it is with high antecedent moisture resulting from previous storms or land irrigation such as lawn watering. Although antecedent precipitation is important when calculating runoff from smaller storms in non-urbanized areas, the runoff data from urbanized watersheds indicates that antecedent precipitation has a smaller effect on runoff peaks and volumes in the urbanized portions of UDFCD.

There are many infiltration models in use by hydrologists. These models vary significantly in complexity. Because of the climatic condition in the semi-arid region and because runoff from urban

watersheds is not very sensitive to infiltration refinements, the infiltration model proposed by Horton was found to provide a good balance between simplicity and reasonable physical description of the infiltration process for use in CUHP. Equation 6-6 describes Horton's infiltration model.

$$f = f_o + (f_i - f_o)e^{-at} \qquad \text{Equation 6-6}$$

Where:

f = infiltration rate at any given time t from start of rainfall (in/hr)

f_o = final infiltration rate (in/hr)

f_i = initial infiltration rate (in/hr)

e = natural logarithm base

a = decay coefficient (1/second)

t = time (seconds).

In developing Equation 6-6, Horton observed that infiltration is high early in the storm and eventually decays to a steady state constant value as the pores in the soil become saturated. The coefficients and initial and final infiltration values are site specific and depend on the soils and vegetative cover. With sufficient rainfall-runoff observations, it is possible to develop these values for a specific site.

Since 1977, UDFCD has analyzed a considerable amount of rainfall-runoff data. Based on this analysis, UDFCD recommends using the values in Table 6-7 within the UDFCD region with CUHP. The NRCS Hydrologic Soil Groups C and D occur most frequently within UDFCD; however, areas of NRCS Group A and B soils also exist. Consult NRCS soil surveys for appropriate soil classifications.

Table 6-7. Recommended Horton's equation parameters

NRCS Hydrologic Soil Group	Infiltration (inches per hour)		Decay Coefficient—a
	Initial—f_i	Final—f_o	
A	5.0	1.0	0.0007
B	4.5	0.6	0.0018
C	3.0	0.5	0.0018
D	3.0	0.5	0.0018

To calculate the maximum infiltration depths that may occur at each time increment, it is necessary to integrate Equation 6-6 and calculate the values for each time increment. Very little accuracy is lost if, instead of integrating Equation 6-6, the infiltration rate is calculated at the center of each time increment. This "central" value can then be multiplied by the unit time increment to estimate the infiltration depth. Although Table 6-7 provides recommended values for various Horton equation parameters, these recommendations are being made specifically for the urbanized or urbanizing watersheds in the Denver metropolitan area and may not be valid in different meteorological and climatic regions.

3.3 CUHP Parameter Selection

3.3.1 Rainfall

The CUHP 2005 Excel workbook requires the input of a design storm, either as a user-defined hyetograph or as a program generated hyetograph using 1-hour and 6-hour rainfall depths. The CUHP program generates a hyetograph using the 1-hour depth and the standard 2-hour temporal distribution recommended in the *Rainfall* chapter of the USDCM. In addition, the program will also generate a 6-hour storm distribution with area corrections accounted for in cases where larger watersheds are studied.

3.3.2 Catchment Description

The following catchment parameters are required for the program to generate a unit and storm hydrograph.

- **Area:** Catchment area in square miles. See Table 6-1 for catchment size limits. Typically, a 5-minute unit hydrograph is used in CUHP. However, for catchments smaller than 90 acres, using a 1-minute unit hydrograph is recommended particularly if significant differences are found between the "excess precipitation" and "runoff hydrograph" volumes listed in the summary output. For very small catchments (i.e. smaller than 10 acres), especially those with high imperviousness, the 1-minute unit hydrograph will be needed to preserve runoff volume integrity.

- **Length:** The length in miles from the downstream design point of the catchment or subcatchment along the main flow path to the furthest point on its respective catchment or subcatchment boundary. When subdividing a catchment into a series of subcatchments, the subcatchment length shall include the distance required for runoff to reach the major drainageway from the farthest point in the subcatchment.

- **Length to Centroid:** Distance in miles from the design point of the catchment or subcatchment along the stream path to its respective catchment or subcatchment centroid.

- **Slope:** The length-weighted, corrected average slope of the catchment in feet per foot.

    - There are natural processes at work that limit the time to peak of a unit hydrograph as a natural stream or vegetated channel becomes steeper. To account for this phenomenon, it is recommended that the slope used in CUHP for streams and vegetated channels be adjusted using Figure 6-4.

    - When a riprap channel is evaluated, use the measured (i.e., uncorrected) average channel invert slope.

    - In concrete-lined channels and buried conduits, the velocities can be very high. For this reason, UDFCD recommends use of the average ground slope (i.e., not flow-line slope) where concrete-lined channels and/or storm drains dominate. There is no correction factor or upper limit recommended to the slope for concrete-lined channels and buried conduits.

Where the flow-line slope varies along the channel, calculate a weighted sub-catchment slope for use with CUHP. Do this by first segmenting the major drainageway into reaches having similar longitudinal slopes. Then calculate the weighted slope using the Equation 6-7.

$$S = \left[\frac{L_1 S_1^{0.24} + L_2 S_2^{0.24} + ... + L_n S_n^{0.24}}{L_1 + L_2 + L_3 .... L_n} \right]^{4.17}$$ Equation 6-7

Where:

S = weighted basin waterway slopes in ft/ft

$S_1, S_2, \ldots S_n$ = slopes of individual reaches in ft/ft (after adjustments using Figure 6-4)

$L_1, L_2, \ldots L_n$ = lengths of corresponding reaches in ft.

- **Percent Impervious:** The portion of the catchment's total surface area that is impervious, expressed as a percent value between 0 and 100. (See Section 3.2.1 for more details.)
- **Maximum Pervious Depression Storage:** Maximum depression storage on pervious surfaces in inches. (See Table 6-6).
- **Maximum Impervious Depression Storage:** Maximum depression storage on impervious surfaces in inches. (See Table 6-6).
- **Initial Infiltration Rate:** Initial infiltration rate for pervious surfaces the units of which are inches per hour. When entered without a decay coefficient and final infiltration rate, this value becomes a constant infiltration rate throughout the storm (not recommended). (See Table 6-7).
- **Horton's Decay Coefficient:** Exponential decay coefficient in Horton's equation in "per second" units. (See Table 6-7).
- **Final Infiltration Rate:** Final infiltration rate in Horton's equation in inches per hour. (See Table 6-7).

The following catchment parameters are optional inputs and are available to the user to account for the effects of directly connected/disconnected impervious areas:

- **DCIA Level:** Specifies the directly connected impervious area (DCIA) level of practice as defined in the Structural BMPs chapter in Volume 3 of the USDCM. The user may specify 0, 1 or 2 for the level of DCIA to model.
- **Directly Connected Impervious Fraction:** Defines the fraction of the total impervious area directly connected to the drainage system. Values range from 0.01 to 1.0.
- **Receiving Pervious Fraction:** Defines the fraction of total pervious area receiving runoff from the "disconnected" impervious areas. Values range from 0.01 to 1.0.

To assist in the determination of the time to peak and peak runoff for the unit hydrograph, the program computes the coefficients C_T, C_t and C_p; however, override values for these parameters can also be user-specified as an option. The algorithm described in the CUHP 2005 User Manual develops the unit hydrograph.

- **C_T:** An unmodified time to peak coefficient that relates the total imperviousness of a catchment to the time to peak.

- ***C_t*:** Area-adjusted time to peak coefficient obtained by applying an area correction to C_T
- ***C_p*:** Peak runoff rate coefficient determined from C_t and the peaking parameter, P.

The shaping of the unit hydrograph also relies on proportioning the widths at 50% and 75% of the unit hydrograph peak. The proportioning is based on 0.35 of the width at 50% of peak being ahead of the "time to peak" and 0.45 of the width at 75% of peak being ahead of the "time to peak." These proportioning factors were selected after observing a number of unit hydrographs derived from the rainfall-runoff data collected by the USGS for UDFCD. It is possible for the user to override the unit hydrograph widths and the proportioning of these widths built into the program. For drainage and flood studies within UDFCD, the program values should be used. If the user has derived unit hydrographs from reliable rainfall-runoff data for a study catchment and can develop a "calibrated" unit hydrograph for this catchment, this option permits reshaping the unit hydrograph accordingly.

3.3.3 Catchment Delineation Criteria

UDFCD recommends an average catchment size of approximately 100 acres for master planning purposes. Catchments larger than 5 square miles should be subdivided into subcatchments and individual subcatchment storm hydrographs should be routed downstream using appropriate channel routing procedures such as the EPA's SWMM model. The routed hydrographs are then added to develop a single composite storm hydrograph. See Table 6-1 for a description of catchment size limitations for CUHP.

The catchment shape can have a profound effect on the final results and, in some instances, can result in underestimates of peak flows. Experience with the 1982 version of CUHP has shown that, whenever catchment length is increased faster than its area, the storm hydrograph peak will tend to decrease disproportionately. Although hydrologic routing is an integral part of runoff analysis, the data used to develop CUHP are insufficient to say that the observed CUHP response with disproportionately increasing basin length is valid. For this reason, it is recommended to subdivide irregularly shaped or very long catchments (i.e., catchment length to width ratio of four or more) into more regularly shaped subcatchments. A composite catchment storm hydrograph can be developed using appropriate routing and by adding the individual subcatchment storm hydrographs.

3.3.4 Combining and Routing Subcatchment CUHP Hydrographs

When analyzing a number of subcatchments, it is necessary to combine and route the runoff hydrographs subcatchment to determine the flows and volumes throughout the system. CUHP software provides input parameters that identify to which junction in EPA SWMM each subcatchment's hydrograph is to be linked and then generates an output file that SWMM recognizes as an external flow file. The CUHP User Manual covers all these features and more.

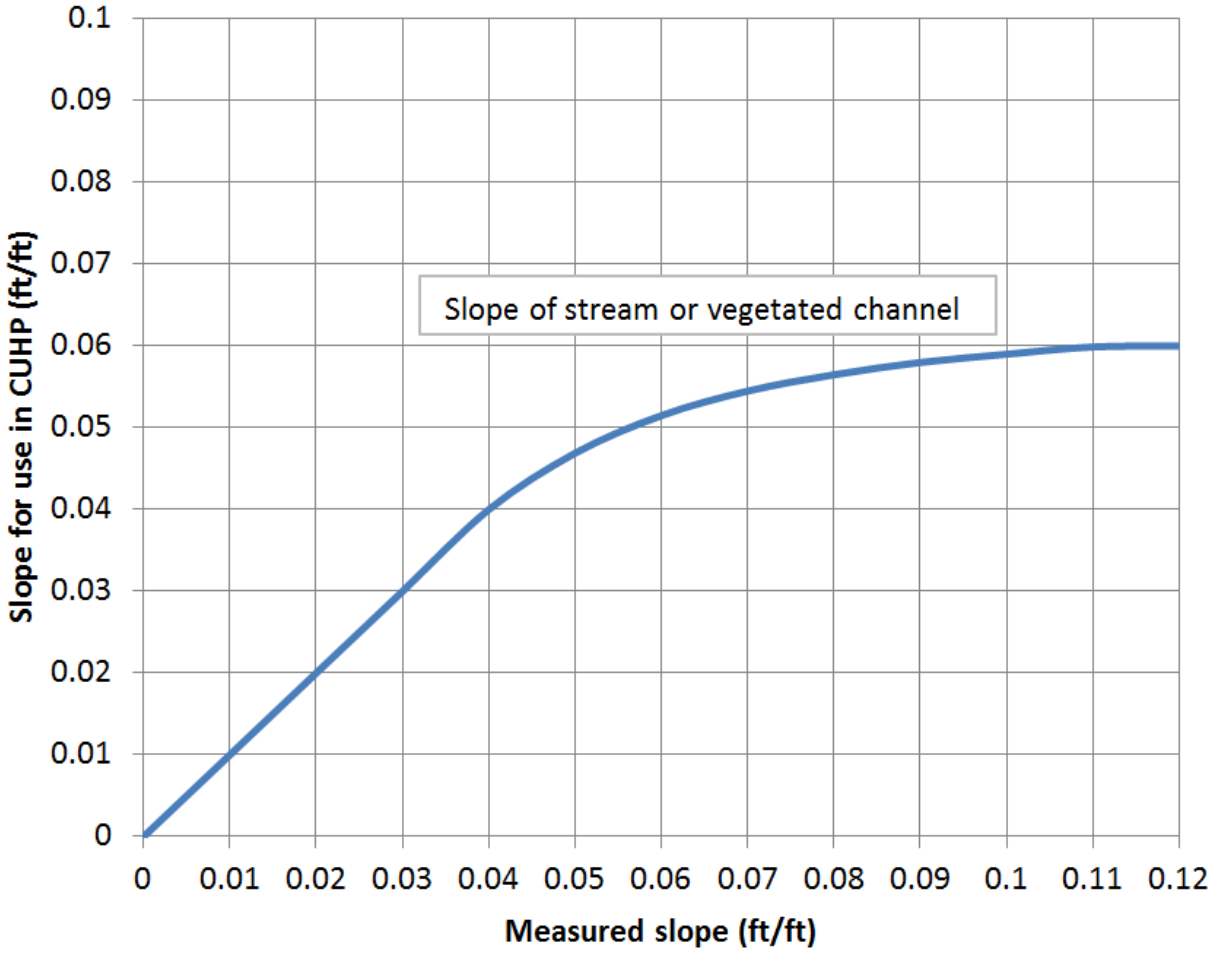


Figure 6-4. Slope correction for streams and vegetated channels

4.0 EPA SWMM And Hydrograph Routing

The Environmental Protection Agency's (EPA's) Stormwater Management Model (SWMM) 5 is a computer model that is used to generate surface runoff hydrographs from subcatchments and then route and combine these hydrographs. The procedure described here is limited to the routing of hydrographs generated using CUHP software. Originally this was done using UDSWM, a modified version of EPA SWMM runoff calculations designed to work with CUHP. In 2005, UDFCD adopted the use of EPA's SWMM 5.0 model and recommends its use for all future hydrology studies.

The purpose of the discussion of SWMM in this chapter is to provide general background on the use of the model with CUHP software to perform more complex stormwater runoff calculations using SWMM. Complete details about this model's use and specifics of data format are provided in the user manual for SWMM. That software, user manual, and other information about EPA's SWMM may be downloaded from http://www2.epa.gov/water-research/storm-water-management-model-swmm.

4.1 Software Description

SWMM represents a watershed by an aggregate of idealized runoff planes, channels, gutters, pipes and specialized units such as storage nodes, outlets, pumps, etc. The program can accept rainfall hyetographs and make a step-by-step accounting of rainfall infiltration losses in pervious areas, surface retention, overland flow, and gutter flow leading to the calculation of hydrographs. However, this portion of the model is normally not used by UDFCD because the resulting peak flows and volumes of runoff would not be calibrated to UDFCD regional rainfall-runoff observations the way CUHP storm hydrographs are. Instead, the calculation of hydrographs for each subcatchment is carried out using the CUHP software. If the user wants to use SWMM to calculate runoff, the model must be calibrated against the CUHP calculations for each subcatchment being studied.

After CUHP software is used to calculate hydrographs from a number of subcatchments, the resulting hydrographs from these subcatchments can be combined and routed through a series of links (i.e., channels, gutters, pipes, dummy links, etc.) and nodes (i.e., junctures, storage, diversion, etc.) to compute the resultant hydrographs at any number of design points within the watershed.

4.1.1 Surface Flows and Flow Routing Features

Stormwater runoff hydrographs generated using CUHP can be routed through a system of stormwater conveyance, diversion, storage, etc. elements of a complex urban watershed. In setting up the SWMM model, it is critical that overflow links for storm sewers and diversion junctions are provided in the model. The combination of these allows the user to model flows accurately when pipes and/or channels that do not have the capacity to convey higher flows, at which time the excess flows are diverted to the overflow channels. This method avoids "choking" of the flow and errors in the calculated peak flow values downstream are prevented.

There are several types of conveyance elements that one can select from a menu in SWMM. One element that is now available, that was not available in older versions, is a user-defined irregular channel cross-section, similar to the way cross-sections are defined in HEC-RAS. This makes the model very flexible in modeling natural waterways and composite man-made channels. For a complete description of the routing elements and junction types available for modeling, see the SWMM User's Manual published by EPA and available from their website mentioned earlier.

4.1.2 Flow Routing Method of Choice

UDFCD recommends the use of kinematic wave routing as the "routing" option in SWMM for planning purposes. Flood flows are generally dominated by kinematic waves (USACE 1993). Dynamic wave routing for most projects, does not improve the accuracy of the runoff estimates, and can be much more difficult to implement because it requires more information to describe the entire flow routing system. Additionally, it has tendencies to become unstable when modeling the more complex elements and/or junctions. Much of the required detail may not even be available during the planning phase (e.g., location of all drop structures and their crest and toe elevations for which a node must be defined in the model).

The use of dynamic wave routing is appropriate when inertial and pressure forces are important and when evaluating complex existing elements of a larger system. It is an option that can also offer some advantages in final design and its evaluation, as it provides hydraulic grade lines and accounts for backwater effects.

4.2 Data Preparation for the SWMM Software

Use of SWMM requires three basic steps:

Step 1: Identify and define the geometries of the watershed, subcatchments, and conveyance/storage elements.

Step 2: Estimates of roughness coefficients and functional/tabular relationships for storage and other special elements.

Step 3: Prepare input data for the model.

4.2.1 Step 1: Method of Discretization

Discretization is a procedure for the mathematical abstraction of the watershed and of the physical drainage system. Discretization begins with the identification of drainage area boundaries, the location of storm drains, streets, and channels, and the selection of those routing elements to be included in the system. For the computation of hydrographs, the watershed may be conceptually represented by a network of hydraulic elements (i.e., subcatchments, gutters, pipes, etc.). Hydraulic properties of each element are then characterized by various parameters such as size, slope, and roughness coefficient.

Discretizing large catchments into smaller ones:

Discretizing large catchments into smaller ones often results in increased unit discharges. The following recommendations can help eliminate the effect of the increase to provide more realistic hydraulic routing through the conveyance network in the EPA SWMM:

- Carefully estimate the effective longitudinal channel slope instead of relying on the elevations at the two ends of each routing element. If there are drop structures or other forms of vertical offsets in the channel reach, the effective channel slope between drops should be used rather than an overall reach slope between endpoints.
- Select the irregular natural channel option in the SWMM conduit cross-section editor to accurately represent actual channel cross-sections rather than selecting general geometric channels. This will ensure a more accurate wetted perimeter.
- Use appropriate Manning's n values that are reflective of the nuances in channel geometry and other flow controls along its reaches, namely those recommended in Section 7.2.3 of the *Open Channels* Chapter of the USDCM by following these guidelines:
  - For lined channels and pipes, increase Manning's n value by 25% over what would normally be used for the design as described in Section 4.2.2 below.
  - For grass-lined, riprap-lined and natural channels use the higher range of the values for the appropriate type of channel reach as recommended in Table B.2. Manning's Roughness Coefficients for Various Boundaries of the FHWA publication HDS-4, Introduction to Highway Hydraulics.
  - Whenever HEC-RAS sections are available, use the roughness coefficients for the main channel and overbanks from those studies unless the values obtained from item 3.b above are higher.

4.2.2 Step 2: Estimate Coefficients and Functional/Tabular Characteristic of Storage and Outlets

For hydrologic routing through conveyance elements such as pipes, gutters, and channels, the resistance (Manning's *n*) coefficients should not necessarily be the same as those used in performing hydraulic design calculations. As a general rule, it was found that increasing the "typical" values of Manning's *n* by approximately 25 percent was appropriate when using UDSWM in the past and should be appropriate for use in SWMM as well. Thus, if a pipe is estimated to have $n = 0.013$ for hydraulic calculations, it is appropriate to use $n = 0.016$ in SWMM.

When modeling the hydrologic routing of natural streams, grass-lined channels, or riprap-lined channels in Colorado, estimate Manning's *n* for SWMM using Equation 6-8 (Jarrett 1984 and 1985).

$$n = 0.393\, S^{0.38} R^{-0.16} \qquad \text{Equation 6-8}$$

Where:

n = Manning's roughness coefficient
S = friction slope (ft/ft)

R = hydraulic radius (ft).

To estimate the hydraulic radius of a natural, grass-lined, or riprap-lined channel for Equation 6-8, use one-half of the estimated hydrograph peak flow to account for the variable depth of flow during a storm event.

SWMM does not have built-in shapes that define geometries of gutters or streets. The user can use the irregular shape option to define the shape of the gutter and street. For storage junctions, the user can define relationships such as stage vs. storage-surface area using mathematical functions or tables generated by the UD-Detention workbook tool or otherwise developed. For storage outlets or downstream outfalls, the user can use tables or functions to define their stage-discharge characteristics. As an alternative, the user can define geometries and characteristics for weirs and orifices and let the program calculate the functional relationships. Use of the weirs can sometimes be particularly troublesome when the dynamic wave routing option is used.

4.2.3 Step 3: Preparation of Data for Computer Input

The major preparation effort is forming a tree structure of all the runoff and conveyance elements and dividing the watershed into subcatchments. Develop the conveyance elements network using a watershed map, subdivision plans, and "as-built" drawings of the drainage system. Define pipes with little or no backwater effects, channels, reservoirs, or flow dividers as conveyance elements for computation by SWMM. Once the conveyance element system is set and labeled, use CUHP to generate an output text file that contains runoff hydrographs for all subcatchments. SWMM can use this file as an external “inflow interface file” to route the hydrograph data. Users should study the SWMM User’s Manual for complete details about data input preparation.

5.0 Other Hydrologic Methods

5.1 Published Hydrologic Information

UDFCD has prepared hydrologic studies for the majority of the major drainageways within UDFCD boundaries. These studies contain information regarding peak flow and runoff volume from the 2-year through 100-year storm events for numerous design points within the watershed. They also contain information regarding watershed and subcatchment boundaries, soil types, percentage imperviousness, and rainfall. The studies are available at www.udfcd.org. When published flow values are available from UDFCD, use these values for design unless there are compelling reasons to modify the published values.

5.2 Statistical Methods

Statistical analysis of measured streamflow data is also an acceptable means of hydrologic analysis in certain situations outside the UDFCD boundary. Statistical analysis should be limited to streams with a long period of flow data (30 years as a recommended minimum) where there have been no significant changes in land use in the tributary watershed during the period of the flow record (stationarity). Note that there is no generally accepted and widely used way to extrapolate calculated flow from a statistical analysis to estimate the flow for expected future watershed development conditions.

6.0 Software

UDFCD provides the following freeware to help with the calculations and protocols in the USDCM. See www.udfcd.org.

The Colorado Urban Hydrograph Procedure is a macro-enabled Excel workbook, titled CUHP.

An Excel workbook has been prepared to facilitate runoff calculations using the Rational Method, namely, UD-Rational (Guo 1995). Inputs needed include catchment area, runoff coefficient, 1-hour point rainfall depth, and flow reach characteristics (length, slope, and type of ground surface). The workbook then calculates the peak runoff in cfs.

The Rational Method can be used to design the storm drains with the aid of the UD-Sewer software or similar software. This software will pre-size storm drains using the same input mentioned for UD-Rational, except that it permits definition of existing links and that it also checks to ensure that the most critical portions of the catchment are accounted for in sizing the drains. After sizing the drains, or for an existing system, it can be used to analyze the hydraulic and energy grade lines of the system and will generate a profile plot of the sewer, ground line, hydraulic grade line and energy grade line.

UD-Rain is an Excel workbook that helps the user find the rainfall depth-duration-frequency and intensity-duration-frequency curves for any region in Colorado based on site elevation. It also helps the user develop 2-hour design storm distributions for use with CUHP or other models based on the protocols described in the USDCM. It will generate design storm hyetographs for small catchments (i.e., < 5 sq. mi.) all the way up to ones that are 75 sq. mi. in size, using area correction factors for the latter.

The latest release of the EPA SWMM software is available for downloading from EPA's web site at http://www2.epa.gov/water-research/storm-water-management-model-swmm.

Users of these software packages should check for updates on a regular basis. Updates and enhancements are constantly under development.

7.0 Examples

7.1 Rational Method Example 1

Find the 100-year peak flow rate for a 60-acre catchment in an undeveloped grassland area located in Brighton. The upper 400 feet of the catchment is sloped at 2%, the lower 1,500 feet is grassed waterway that is sloped at 1%. The area has type C soils.

From NOAA Atlas 14, the 1-hour point precipitation value is 2.55 inches. The imperviousness is 2% (or 0.02) based on Table 6-3 and using the category "Undeveloped Areas, historic flow analysis."

Determine C_5 from Table 6-4:

$$C_5 = 0.82i + 0.035$$

$$C_5 = 0.82(0.02) + 0.035$$

$$= 0.05$$

Determine t_i from Equation 6-3:

$$t_i = \frac{0.395(1.1 - C_5)\sqrt{L_i}}{S_o^{0.33}}$$

$$t_i = \frac{0.395(1.1 - 0.05)\sqrt{400}}{(0.02)^{0.33}}$$

t_i = 30.2 minutes

Find t_t from Equation 6-4:

$$t_t = \frac{L_t}{60V_t} = \frac{L_t}{60K\sqrt{S_o}}$$

From Table 6-2, K = 15 (grassed waterway), S_o = 0.01 and L=1500 feet from problem statement

$$t_t = \frac{1500}{60(15\sqrt{0.01})}$$

t_t = 16.7 minutes

From Equation 6-2:

$$t_c = t_i + t_t$$

t_c = 30.2 + 16.7

t_c = 46.9 minutes

Note: The first design point time of concentration, Equation 6-5, does not apply for this example because the tributary area is undeveloped and less than 20% impervious.

Determine C_{100} from Table 6-4:

$$C_{100} = 0.41i + 0.484$$

$$C_{100} = 0.41(0.02) + 0.484$$

C_{100} = 0.49

Determine rainfall intensity, *I*, from Equation 4-3 (from the *Rainfall* chapter)

$$I = \frac{28.5P_1}{(10 + t_c)^{0.786}}$$

$$I = \frac{28.5(2.55)}{(10 + 46.9)^{0.786}}$$

I = 3.03 in/hr

Determine *Q* from Equation 6-1:

$$Q = CIA$$

$$Q = (0.49)(3.03)(60)$$

Q = 89 cfs

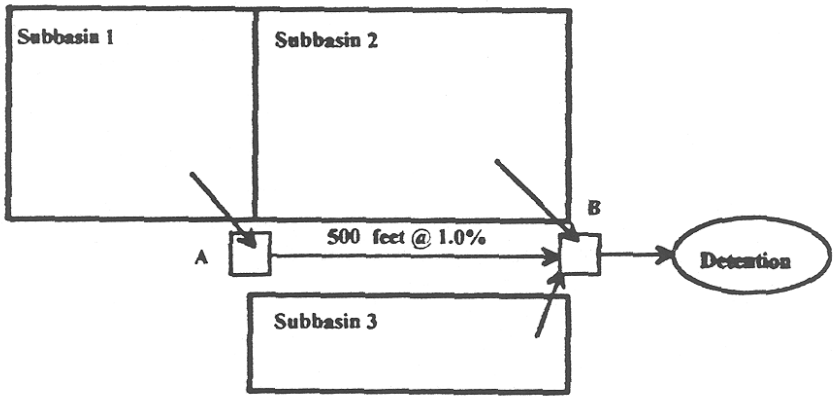
Alternately, use the UD-Rational Excel workbook to calculate the peak flow rate.

7.2 Rational Method Example 2

A watershed contains three subcatchments in the City of Denver. The drainage system collects Subcatchment 1 at Point A, and Subcatchments 2 and 3 at Point B, and then drains into a detention system. Determine the 10-year peak discharge at Point B using the watershed parameters summarized in the table. Assume that the imperviousness is 98 percent.

Subcatchment	Drainage Area A (acres)	Runoff Coefficient C	Time of Concentration T_c (minutes)
1	2.00	0.55	15.00
2	5.00	0.65	22.00
3	1.50	0.81	12.00

As shown in the figure, there are three flow paths to reach Point B. Their flow times are:



From Subcatchment 1: The flow time includes the time of concentration of Subcatchment 1, and the flow time from Point A to Point B through the street. The flow time from Subcatchment 1 to Point B is the sum of the time of concentration of Subcatchment 1 and the flow time through the 500-foot gutter:

$$t_1 = t_i + t_t$$

t_i = 15 minutes

$$t_t = \frac{L_t}{60V_t} = \frac{L_t}{60K\sqrt{S_o}}$$

$$t_1 = 15 + \frac{500}{60(20)\sqrt{0.01}} = 19.2 \text{ minutes}$$

From Problem Statement for Subcatchment 2: t_2 = 22 minutes

From Problem Statement for Subcatchment 3: t_3 = 12 minutes

At Point B, the design rainfall duration t_d = max (t_1, t_2, t_3) = 22 minutes.

The 10-year design rainfall intensity for Denver is (from Equation 5-1 in the *Rainfall* chapter):

$$I = \frac{28.5P_1}{(10 + t_c)^{0.786}}$$

$$I = \frac{28.5\,(1.33)}{(10 + 22)^{0.786}} = 2.48 \text{ in/hr}$$

Area-weighted runoff coefficient, $C_{composite}$ calculation shown below for all of the areas that drain to Point B:

$$C_{composite} = \frac{(C_1A_1 + C_2A_2 + C_3A_3)}{(A_1 + A_2 + A_3)}$$

$$C_{composite} = \frac{((0.55)(2) + (0.65)(5) + (0.81)(1.5))}{(2 + 5 + 1.5)} = 0.65$$

The 10-year peak discharge is:

Q = CIA = (0.65)(2.48)(8.5) = 13.70 cfs

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Chapter 7
Street, Inlets, and Storm Drains

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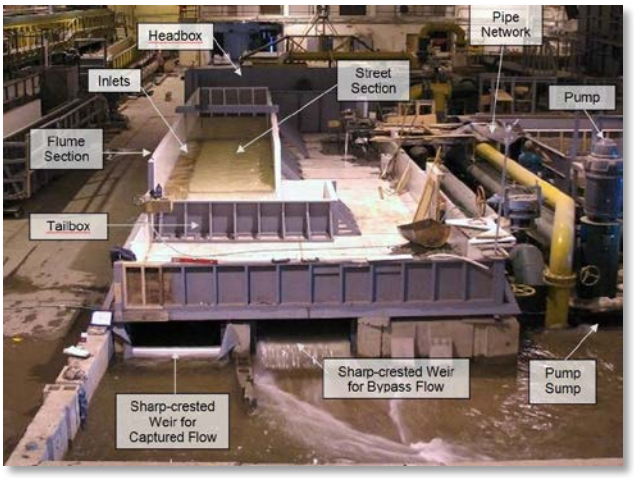
1.0 Introduction

1.1 Purpose and Background

The purpose of this chapter is to provide design guidance for stormwater collection and conveyance utilizing streets and storm drains. Procedures and equations are presented for the hydraulic design of street drainage, locating inlets and determining capture capacity, and sizing storm drains. This chapter also includes discussion on placing inlets to minimize the potential for icing. Examples are provided to illustrate the hydraulic design process and Excel workbook solutions accompany the hand calculations for most example problems.



Photograph 7-1. From 2006 to 2011, hundreds of street and area inlet physical model tests were conducted at the CSU Hydraulics Laboratory, facilitating refinement of the HEC-22 methodology for inlets common to Colorado.

The design procedures presented in this chapter are based upon fundamental hydrologic and hydraulic design concepts. It is assumed that the reader has an understanding of basic hydrology and hydraulics. A working knowledge of the Rational Method (*Runoff* chapter) and open channel hydraulics (*Open Channels* chapter) is particularly helpful. The design equations provided are well accepted and widely used. They are presented without derivations or detailed explanation but are properly referenced if the reader wishes to study their background. Inlet capacity, as presented in this chapter, is based on the FHWA Hydraulic Circular No. 22 (HEC-22) methodology (FHWA 2009), which was subsequently refined through a multi-jurisdictional partnership led by Urban Drainage and Flood Control (UDFCD), where hundreds of physical model tests of inlets commonly used in Colorado were performed at the Colorado State University (CSU) Hydraulics Laboratory. The physical model study is further detailed in technical papers available at www.udfcd.org. Additionally, UDFCD developed an inlet design tool, UD-Inlet, which incorporates the findings of the physical model. UD-Inlet is also available at www.udfcd.org.

1.2 Urban Stormwater Collection and Conveyance Systems

Urban stormwater collection and conveyance systems are critical components of the urban infrastructure. Proper design is essential to minimize flood damage and limit disruptions. The primary function of the system is to collect excess stormwater in street gutters, convey it through storm drains and along the street right-of-way, and discharge it into a detention basin, water quality best management practice (BMP), or the nearest receiving water body (FHWA 2009).

Proper and functional urban stormwater collection and conveyance systems:

- Promote safe passage of vehicular traffic during minor storm events.
- Maintain public safety and manage flooding during major storm events.
- Minimize capital and maintenance costs of the system.

1.3 System Components

Urban stormwater collection and conveyance systems are comprised of three primary components:

1. Street gutters and roadside swales,
2. Storm drain inlets, and
3. Storm drains (with appurtenances like manholes, junctions, etc.).

Street gutters and roadside swales collect runoff from the street (and adjacent areas) and convey the runoff to a storm drain inlet while maintaining the street's level of service.

Photograph 7-2. The capital costs of storm drain construction are high, emphasizing the importance of sound design.

Inlets collect stormwater from streets and other land surfaces, transition the flow into storm drains, and provide maintenance access to the storm drain system. Storm drains convey stormwater in excess of street or swale capacity along the right-of-way and discharge into a stormwater management facility or directly into a receiving water body. In rare instances, stormwater pump stations (the design of which is not covered in this manual) are needed to lift and convey stormwater away from low-lying areas where gravity drainage is not possible. All of these components must be designed properly to achieve the objectives of the stormwater collection and conveyance system.

1.4 Minor and Major Storms

Rainfall events vary greatly in magnitude and frequency of occurrence. Major storms produce large flow rates but rarely occur. Minor storms produce smaller flow rates but occur more frequently. For economic reasons, stormwater collection and conveyance systems are not normally designed to pass the peak discharge during major storm events without some street flooding.

Stormwater collection and conveyance systems are designed to pass the peak discharge of the minor storm event (and smaller events) with minimal disruption to street traffic. To accomplish this, the spread and depth of water on the street is limited to some maximum mandated value during the minor storm event. Inlets must be strategically placed to pick up excess gutter or swale flow once the limiting allowable spread or depth of water is reached. The inlets collect and convey stormwater into storm drains, which are typically sized to pass the peak flow rate (minus the allowable street flow rate) from the minor storm without any surcharge. The magnitude of the minor storm is established by local ordinances or criteria, and the 2- or 5-year storms are commonly specified, based on many factors including street function, traffic load, vehicle speed, etc.

Local ordinances often also establish the return period for the major storm event, generally the 100-year storm (although it may be a lesser event for some retrofit projects with site constraints). During this event, runoff exceeds the minor storm allowable spread and depth in the street and capacity of storm drains, and storm drains may surcharge. Street flooding occurs, and traffic is disrupted as the street functions as an open channel. The designer must evaluate and design for the major event with regard to maintaining public safety and minimizing flood damages.

2.0 Street Drainage

2.1 Street Function and Classification

Although streets play an important role in stormwater collection and conveyance, the primary function of a street or roadway is to provide for the safe passage of vehicular traffic at a specified level of service. If stormwater systems are not designed properly, this primary function will be impaired. To ensure this does not happen, streets are classified for drainage purposes based on their traffic volume, parking practices, and other criteria (Wright-McLaughlin Engineers 1969). The four street classifications are:

- Local: Low-speed traffic for residential or industrial area access.
- Collector: Low/moderate-speed traffic providing service between local streets and arterials.
- Arterial: Moderate/high-speed traffic moving through urban areas and accessing freeways.
- Freeway: High-speed travel, generally over long distances.

Table 7-1 provides additional information on the classification of streets for drainage purposes.

Table 7-1. Street classification for drainage purposes

Street Classification	Function	Speed/Number of Traffic Lanes	Signalization at Intersections	Street Parking
Local	Provides access to residential and industrial areas	Low speed / 2 lanes	Stop signs	One or both sides of the street
Collector	Collects and convey traffic between local and arterial streets	Low to moderate speed / 2 to 4 lanes	Stop signs or traffic signals	One or both sides of the street
Arterial	Delivers traffic between urban centers and from collectors to freeways	Moderate to high speed / 4 to 6 lanes	Traffic signals (controlled access)	Usually prohibited
Freeway	Provides rapid and efficient transport over long distances	High-speed / 4 or more lanes	Separated interchanges (limited access)	Always prohibited

Proper street drainage is essential to:

- Maintain the street's level of service.
- Minimize danger and inconvenience to pedestrians during storm events (FHWA 1984).
- Reduce potential for vehicular skidding and hydroplaning.
- Maintain good visibility for drivers (by reducing splash and spray).

2.2 Design Considerations

Certain design considerations must be taken into account in order to meet street drainage objectives. For the minor storm, the primary design objective is to keep the spread (encroachment onto the pavement) and depth (inundation) of stormwater on the street below acceptable limits for a given return period of flooding. As mentioned previously, when stormwater collects on the street and flows down the gutter, the spread (width) of the water increases as more stormwater is collected and conveyed down the street and gutter. Left unchecked, the spread of water will eventually hinder traffic flow and become hazardous (e.g., hydroplaning, reduced skid resistance, visibility impairment from splash back, engine stalls). Based on these considerations, UDFCD has established encroachment and inundation standards for the minor storm event. These standards were presented in the *Policy* chapter and are repeated in Table 7-2 for convenience.

Table 7-2. Pavement encroachment and inundation standards for the minor storm

Street Classification	Maximum Encroachment and Inundation
Local	No curb overtopping. Flow may spread to crown of street.
Collector	No curb overtopping. Flow spread must leave at least one lane free of water.
Arterial	No curb overtopping. Flow spread must leave at least one lane free of water in each direction, and should not flood more than two lanes in each direction.
Freeway	No encroachment is allowed onto any traffic lanes.

During the major event, flood protection and human safety replace drivability as the design criteria with regard to street inundation (depth of flow). UDFCD has established street inundation standards during the major storm event. These standards were given in the *Policy* chapter and are repeated in Table 7-3 for convenience.

Table 7-3. Street inundation standards for the major (i.e., 100-year) storm

Street Classification	Maximum Depth and Inundated Area
Local and Collector	Residential dwellings and public, commercial, and industrial buildings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of the building. The depth of water over the gutter flow line should not exceed 12 inches.
Arterial and Freeway	Residential dwellings and public, commercial, and industrial buildings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of the building. The depth of water should not exceed the street crown to allow operation of emergency vehicles. The depth of water over the gutter flow line should not exceed 12 inches.

Standards for the major storm and street cross-flows are also required. These standards apply at intersections, sump locations, and for culvert or bridge overtopping scenarios. The major storm needs to be assessed to determine the potential for flooding and public safety. Street cross-flows also need to be regulated for traffic flow and public safety reasons. These allowable street cross-flow standards were given in the *Policy* chapter and are repeated in Table 7-4 for convenience.

Table 7-4. Allowable street cross-flow

Street Classification	Initial Storm Flow	Major (100-Year) Storm Flow
Local	6 inches of depth in cross-pan.	12 inches of depth above gutter flow line.
Collector	Where cross-pans allowed, depth of flow should not exceed 6 inches.	12 inches of depth above gutter flow line.
Arterial/Freeway	None.	No cross-flow. Maximum depth at upstream gutter on road edge of 12 inches.

Once the allowable spread (pavement encroachment) and allowable depth (inundation) have been established for the minor storm, the placement of inlets can be determined. The inlets will remove some or all of the excess stormwater and thus reduce the spread and depth of flow. The placement of inlets is covered in Section 3.0. It should be noted that proper drainage design seeks to maximize the full allowable capacity of the street gutter in order to minimize the cost of inlets and storm drains.

Two additional design considerations are gutter geometry and street slope. Most urban streets incorporate curb and gutter sections. Various types exist, including spill shapes, catch shapes, curb heads, and mountable, a.k.a. “rollover” or “Hollywood” curbs. The shape is chosen for functional, cost, or aesthetic reasons and does not dramatically affect the hydraulic capacity. Swales are used along some semi-urban streets, and roadside ditches are common along rural streets. Cross-sectional geometry, longitudinal slopes and swale/ditch roughness values are important in determining hydraulic capacity and are covered in the next section.

2.3 Hydraulic Evaluation

Hydraulic computations are performed to determine the capacity of roadside swales and street gutters and the encroachment of stormwater onto the street. The design discharge is based on the peak flow rate and usually is determined using the rational method (covered in the next two sections and in the *Runoff* Chapter). Although gutter, swale/ditch and street flows are unsteady and non-uniform, steady, uniform flow is assumed for the short time period of peak flow conditions.

Street Hydraulic Capacity

This term typically refers to the capacity from the face of the curb to the crown (for the minor event).

Typically, the hydraulic computations necessary to determine street capacity and required inlet locations are performed independently for each side of the street. Additionally, flow and street geometry frequently differ from one side of a street to the other.

2.3.1 Curb and Gutter

Both the longitudinal and cross (transverse) slope of a street are important in calculating hydraulic capacity. The capacity of the street increases as the longitudinal slope increases. UDFCD prescribes a minimum longitudinal slope of 0.4% for positive drainage (Wright-McLaughlin 1969). Public safety considerations limit the maximum allowable flow capacity of the gutter on steep slopes. The cross slope represents the slope from the street crown to the interface of the street and gutter, measured perpendicular to the direction of traffic. UDFCD recommends a minimum cross slope of 1% for positive drainage; however, a cross slope of 2% is more typical. Driver comfort and safety considerations limit the maximum cross slope. Use of standard curb and gutter sections typically produces a composite section with milder cross slopes for drive lanes and steeper cross slopes within the gutter width for increased flow capacity.

Each side of the street is evaluated independently. The hydraulic evaluation of street capacity includes the following steps:

1. Calculate the street capacity based upon the allowable spread for the minor storm as defined in Table 7-2.
2. Calculate the street capacity based upon the allowable depth for the minor storm as defined in Table 7-2.
3. Calculate the allowable street capacity by multiplying the value calculated in step two (limited by depth) by the reduction factor provided in Figure 7-3. The lesser value (limited by allowable spread or by depth with a safety factor applied) is the allowable street capacity.
4. Repeat steps one through three for the major storm using criteria in Table 7-3.

Capacity When Gutter Cross Slope Equals Street Cross Slope (Not Typical)
Streets with uniform cross slopes like that shown in Figure 7-1 are sometimes found in older urban areas. Since gutter flow is assumed to be uniform for design purposes, Manning's equation is appropriate with a slight modification to account for the effects of a small hydraulic depth (A/T).

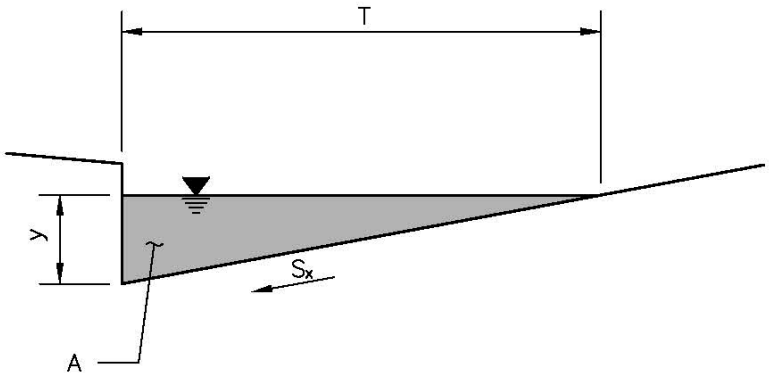


Figure 7-1. Gutter section with uniform cross slope

For a triangular cross section as shown in Figure 7-1, Manning's equation for gutter flow is written as:

$$Q = \frac{1.8}{n} AR^{2/3} S_o^{1/2} = \frac{0.56}{n} S_x^{5/3} S_o^{1/2} T^{8/3} \qquad \text{Equation 7-1}$$

Where:

Q = calculated flow rate for the half-street (cfs)

n = Manning's roughness coefficient (0.016 for asphalt street with concrete gutter, 0.013 for concrete street and gutter)

R = hydraulic radius of wetted cross section = A/P (ft)

A = cross-sectional area (ft^2)

P = wetted perimeter of cross section (ft)

S_x = street cross slope (ft/ft)

S_o = longitudinal slope (ft/ft)

T = top width of flow spread (ft).

The flow depth can be found using:

$$y = TS_x \qquad \text{Equation 7-2}$$

Where:

y = flow depth at the gutter flowline (ft).

Note that the flow depth generally should not exceed the curb height during the minor storm based on Table 7-2. Manning's equation can be written in terms of the flow depth, as:

$$Q = \frac{0.56}{nS_x} S_L^{1/2} y^{8/3} \qquad \text{Equation 7-3}$$

The cross-sectional flow area, *A*, can be expressed as:

$$A = \frac{S_x T^2}{2}$$ Equation 7-4

The gutter velocity at peak capacity may be found from continuity ($V = Q/A$). Triangular gutter cross-section calculations are illustrated in Example 7.1.

Capacity When Gutter Cross Slope is Not Equal to Street Cross Slope (Typical)
Streets with composite cross slopes like that shown in Figure 7-2 are often used to increase the gutter capacity and keep nuisance flows out of the traffic lanes.

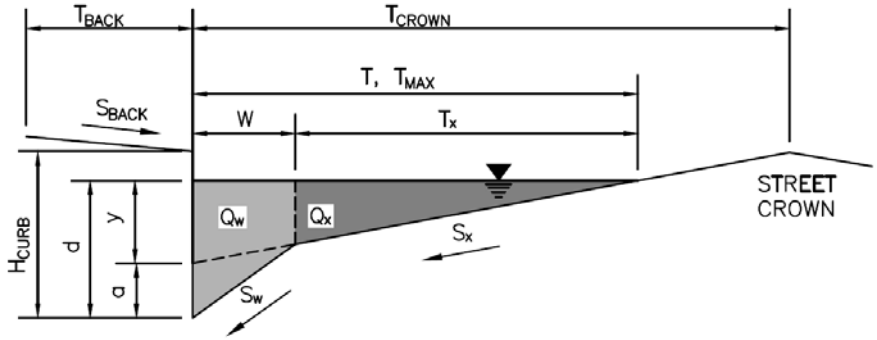


Figure 7-2. Typical gutter section—composite cross slope

For a composite street section:

$$Q = Q_w + Q_x$$ Equation 7-5

Where:

Q_w = flow rate in the depressed gutter section (flow within gutter width, *W*, in Figure 7-2 [cfs])

Q_x = flow rate in the section that is outside the depressed gutter section and within the street width, T_X, in Figure 7-2 (cfs).

In *Hydraulic Engineering Circular No. 22, Third Edition*, the Federal Highway Administration (FHWA 2009) provides the following equations for obtaining the flow rate in streets with composite cross slopes. The theoretical flow rate, *Q*, is:

$$Q = \frac{Q_x}{1 - E_o}$$ Equation 7-6

Where:

$$E_O = \frac{1}{1 + \frac{S_w / S_x}{\left[1 + \frac{S_w / S_x}{(T/W) - 1}\right]^{8/3} - 1}}$$ Equation 7-7

and,

$$S_w = S_x + \frac{a}{W}$$ Equation 7-8

Where:

$E_O = Q_W/Q$, the ratio of gutter flow, Q_W, to total flow Q

W = width of the gutter (typical value = 2 ft)

S_W = the gutter cross slope (typical value = 1/12 or 0.0833 [ft/ft])

a = gutter depression = WS_W - WS_X (typical value for WS_W for a 2-ft gutter section is 0.1667 ft).

Figure 7-2 depicts all geometric variables. From the geometry, it can be shown that:

$$y = a + TS_x$$ Equation 7-9

and,

$$A = \frac{S_x T^2 + aW}{2}$$ Equation 7-10

Where:

y = flow depth above depressed gutter section (ft). Note that the depth of flow at the gutter line is defined as d, where $d = y + a$ (see Figure 7-2).

A = flow area (ft^2)

Due to the complexity of Equation 7-7, care should be taken when calculating E_O. Additionally, E_O cannot be correctly calculated using Equation 7-7 when $T < W$ or when ponding depth exists at the street crown. For these special cases, the principle of similar triangles may be applied in conjunction with Equation 7-1 (see Figure 7-3). Both methods for calculating flow in a composite cross-section are illustrated in the Examples and the end of this chapter (see Examples 7.2 and 7.3).

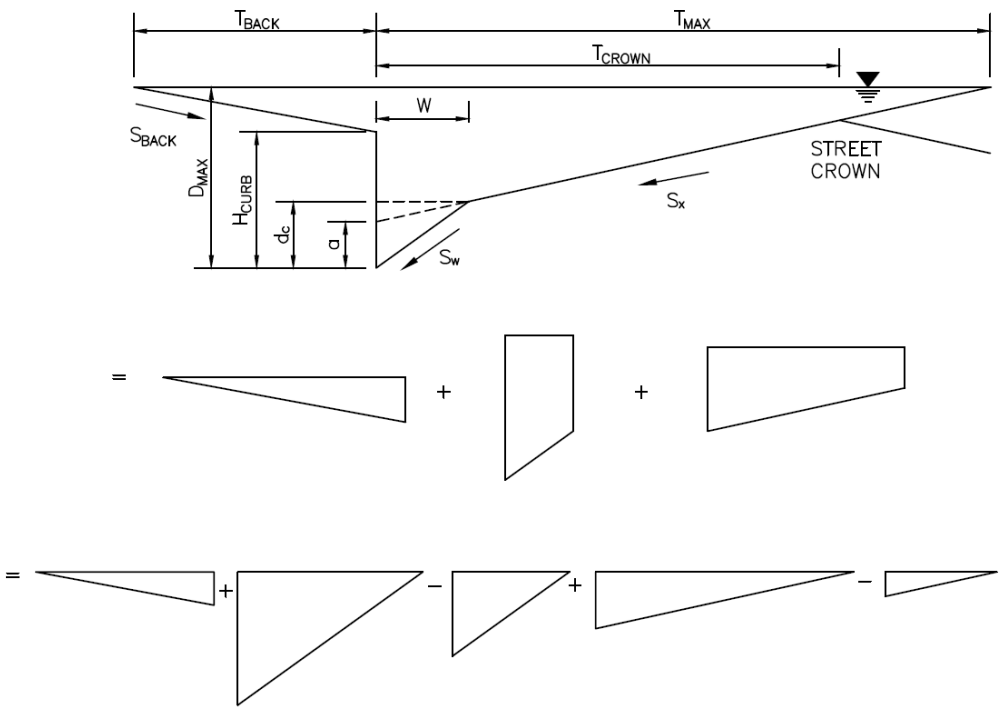


Figure 7-3. Calculation of composite street section capacity: major storm

Allowable Capacity

Stormwater flows along streets exert momentum forces on cars, pavement, and pedestrians. To limit the hazardous nature of large street flows, it is necessary to set limits on flow velocities and depths. As a result, the allowable half-street hydraulic capacity is determined as the lesser of:

$$Q_A = Q_T \qquad \text{Equation 7-11}$$

or

$$Q_A = R\,Q_d \qquad \text{Equation 7-12}$$

Where:

Q_A = allowable street hydraulic capacity (cfs)

Q_T = street hydraulic capacity where flow spread equals allowable spread (cfs)

R = reduction factor (allowable street and gutter flow for safety)

Q_d = street hydraulic capacity where flow depth equals allowable depth (cfs).

There are two sets of safety reduction factors developed for the UDFCD region (Guo 2000b). One is for the minor event, and another is for the major event. Figure 7-4 shows that the safety reduction factor does not apply unless the street longitudinal slope is more than 1.5% for the major event and 2% for the minor event. The safety reduction factor, representing the fraction of calculated gutter flow at maximum depth

that is used for the allowable design flow, decreases as longitudinal slope increases.

It is important for street drainage designs that the allowable street hydraulic capacity be used instead of the calculated gutter-full capacity. Where the accumulated stormwater amount on the street approaches the allowable capacity, a street inlet should be installed.

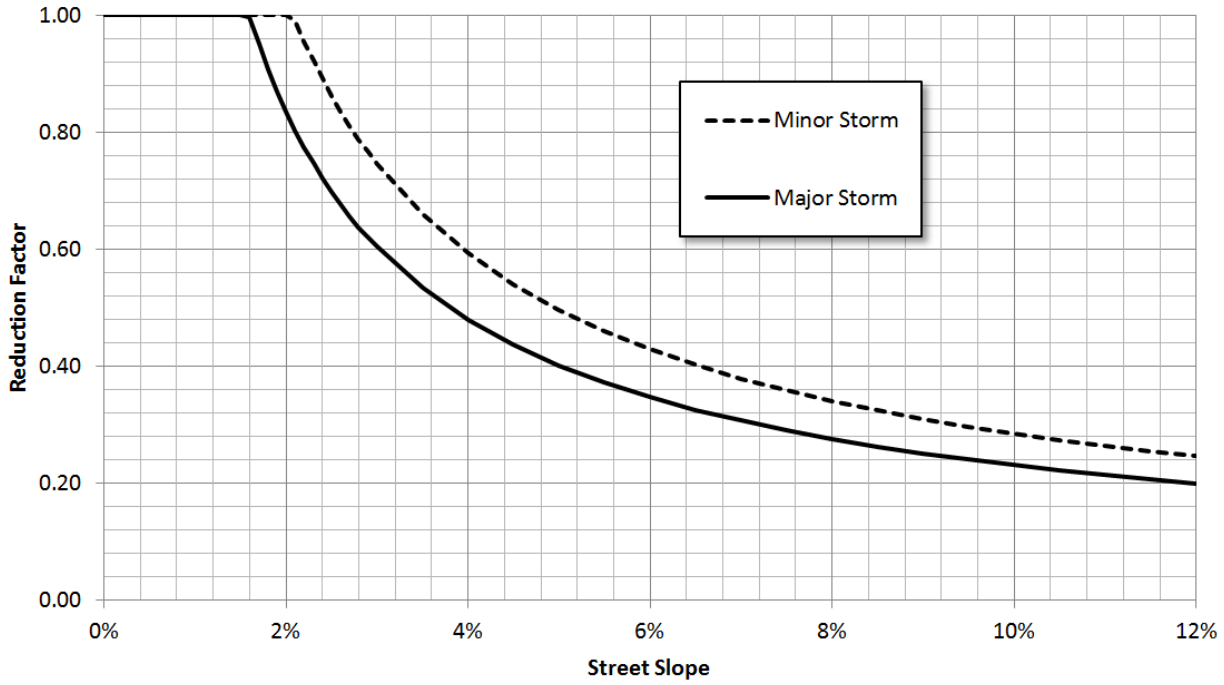


Figure 7-4. Reduction factor for gutter flow (Guo 2000b)

2.3.2 Swale Capacity

Where curb and gutter are not used to contain flow, swales are frequently used to convey runoff and disconnect impervious areas. It is very important that swale depths and side slopes be shallow for safety and maintenance reasons. Street-side drainage swales are not the same as roadside ditches. Street-side drainage swales provide mild side slopes and are frequently designed to provide water quality enhancement. For purposes of disconnecting impervious area and reducing the overall volume of runoff, swales should be considered as collectors of initial runoff for transport to other larger means of conveyance. To be effective, they need to be limited to the velocity, depth, and cross-slope geometries considered acceptable.

Equation 7-1 can be used to calculate the flow rate in a V-section swale (using the appropriate roughness value for the swale lining) with an adjusted cross slope found using:

$$S_x = \frac{S_{x1} S_{x2}}{S_{x1} + S_{x2}} \qquad \text{Equation 7-13}$$

Where:

S_x = adjusted side slope (ft/ft)

S_{x1} = right side slope (ft/ft)

S_{x2} = left side slope (ft/ft).

Figure 7-5 shows the geometric variables, and Examples 7.4 and 7.5 show V-shaped swale calculations.

For safety reasons, paved swales should be designed such that the product of velocity and depth is no more than six for the minor storm and eight for the major storm.

For grass swales, refer to the *Grass Swale Fact Sheet* in the Urban Storm Drainage Criteria Manual (USDCM) Volume 3. During the 2-year event, grass swales designed for water quality should have a Froude number of no more than 0.5, a velocity that does not exceed 1.0 ft/s, and a depth that does not exceed 1.0 foot.

Note that the slope of a roadside ditch or swale can be different than the adjacent street. The hydraulic characteristics of the swale can therefore change from one location to another.

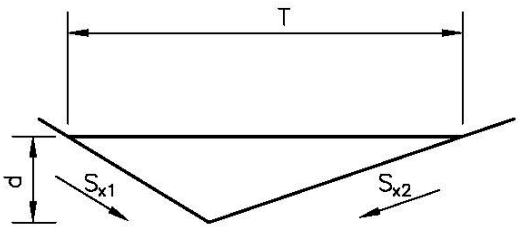


Figure 7-5. Typical v-shaped swale section

3.0 Inlets

3.1 Inlet Function and Selection

Inlets collect excess stormwater from the street, transition the flow into storm drains, and can provide maintenance access to the storm drain system. There are four major types of inlets: grate, curb opening, combination, and slotted (see Figure 7-11). Table 7-5 provides considerations in proper selection.

Table 7-5. Inlet selection considerations

Inlet Type	Applicable Setting	Advantages	Disadvantages
Grate	Sumps and continuous grades (should be made bicycle safe)	Perform well over wide range of grades	Can become clogged Lose some capacity with increasing grade
Curb-opening	Sumps and continuous grades (but not steep grades)	Do not clog easily Bicycle safe	Lose capacity with increasing grade
Combination	Sumps and continuous grades (should be made bicycle safe)	High capacity Do not clog easily	More expensive than grate or curb-opening acting alone
Slotted	Locations where sheet flow must be intercepted.	Intercept flow over wide section	Susceptible to clogging

3.2 Design Considerations

Frequently roadway geometry dictates the location of inlets. Inlets are placed at low points (sumps), median breaks, and at intersections. Additional inlets should be placed where the design peak flow on the street half is approaching the allowable capacity of the street half (see inset). Allowable street capacity will be exceeded and storm drains will be underutilized when inlets are not located properly or not designed for adequate capacity (Akan and Houghtalen 2002).

Allowable Street Capacity

To a great degree, *allowable street capacity* dictates the placement of inlets. This term refers to the lesser of:

- Capacity determined by the allowable spread for the minor event
- Capacity determined by the allowable depth for the minor event, multiplied by a reduction factor

Inlets placed on continuous grades are generally designed to intercept only a portion of the gutter flow during the minor (design) storm (i.e. some flow bypasses to downgradient inlets). The effectiveness of the inlet is expressed as efficiency defined as:

$$E = Q_i / Q \qquad \text{Equation 7-15}$$

Where:

E = inlet efficiency (fraction of gutter flow captured by inlet)

Q_i = intercepted flow rate (cfs)

Q = total half-street flow rate (cfs).

Bypass (or carryover) flow is not intercepted by the inlet. By definition,

$$Q_b = Q - Q_i \qquad \text{Equation 7-16}$$

Where:

Q_b = bypass (or carryover) flow rate (cfs).

The ability of an inlet to intercept flow (i.e., hydraulic capacity) on a continuous grade increases to a degree with increasing gutter flow, but the capture efficiency decreases. In general, the inlet capacity depends upon:

- The inlet type and geometry (length, width, curb opening, etc.),
- The flow rate,
- The longitudinal slope,
- The cross (transverse) slope.

The capacity of an inlet varies with the type of inlet. For grate inlets, the capacity is largely dependent on the amount of water flowing over the grate, the grate configuration and spacing. For curb-opening inlets, the capacity is largely dependent on the length of the opening, street and gutter cross slope, and the flow depth at the curb. Local gutter depression at the curb opening will increase the capacity. Combination inlets on a continuous grade (i.e., not in a sump location) intercept up to 18% more than grate inlets alone and are much less likely to clog completely (CSU 2009). Slotted inlets function in a manner similar to curb-opening inlets (FHWA 2009).

Inlets in sumps operate as weirs at shallow ponding and as orifices as depth increases. A transition region exists between weir flow and orifice flow, much like a culvert. Grate inlets and slotted inlets have a higher tendency to clog with debris than do curb-openings inlets, so calculations should take that into account.

The hydraulic capacity of an inlet is dependent on the type of inlet (grate, curb opening, combination, or slotted) and the location (on a continuous grade or in a sump). The methodology for determination of hydraulic capacity of the various inlet types is described in the following sections.

(a) CDOT Type 13 grated inlet in combination configuration

(b) Denver No. 16 grated inlet in combination configuration

(c) CDOT Type R curb-opening inlet

Photograph 7-3. These three street inlets are the most commonly used in the UDFCD region. Their performance was tested for both on grade conditions and in sump conditions in a 1/3-scale physical model at CSU.

3.2.1 Grate Inlets on a Continuous Grade

The capture efficiency of a grate inlet on a continuous grade is highly dependent on the width of the grate and, to a lesser degree, the length. In general, most of the flow within the width of the grate will be intercepted and most of the flow outside the width of the grate (i.e., in the street) will not. The velocity of gutter flow also affects capture efficiency. If the gutter velocity is low and the spread of water does not exceed the grate width, all of the flow will be captured by the grate inlet. This is not normally the case, even during the minor (design) storm. The spread of water often exceeds the grate width and the flow velocity can be high. Thus, some of the flow within the width of the grate may "splash over" the grate, and unless the inlet is very long, very little of the flow outside the grate width is captured.

In order to determine the efficiency of a grate inlet, flow with respect to the grate is divided into two parts: frontal flow and side flow. Frontal flow is defined as that portion of the flow within the width of the grate. The portion of the flow outside the grate width is called side flow. By using Equation 7-1 for a uniform cross slope, the frontal flow can be evaluated and is expressed as:

$$Q_w = Q\left[1-(1-(W/T))^{2.67}\right] \qquad \text{Equation 7-17}$$

Where:

Q_w = frontal discharge (flow within width W) (cfs)

Q = total gutter flow (cfs) found using Equation 7-1

W = width of grate (ft)

T = total spread of water in the half-street (ft).

For a composite cross section, use Equations 7-5 through 7-8, substituting the grate width for the gutter width. It should be noted that the grate width is generally only slightly less than the depressed section in a composite gutter section. Now by definition:

$$Q_x = Q - Q_w \qquad \text{Equation 7-18}$$

Where:

Q_x = side discharge (i.e., flow outside the depressed gutter or grate) (cfs).

The ratio of the frontal flow intercepted by the inlet to total frontal flow, *Rf*, is expressed as:

$$R_f = \frac{Q_{wi}}{Q_w} = 1.0 - 0.09(V - V_o) \text{ for } V \geq V_o \text{, otherwise } R_f = 1.0 \qquad \text{Equation 7-19}$$

Where:

Q_{wi} = frontal flow intercepted by the inlet (cfs)

V = velocity of flow in the gutter (ft/sec)

V_o = splash-over velocity (ft/sec).

The splash-over velocity is defined as the minimum velocity where some of the water will begin to skip over the full length of the grate. This velocity is a function of the grate length and type. The splash-over velocity can be determined using this empirical formula (Guo 1999):

$$V_o = \alpha + \beta L_e - \gamma L_e^2 + \eta L_e^3 \qquad \text{Equation 7-20}$$

Where:

V_o = splash-over velocity (ft/sec)

L_e = effective length of grate inlet (ft)

$\alpha, \beta, \gamma, \eta$ = constants from Table 7-6.

The splash-over velocity constants for the CDOT Type 13 and the Denver No. 16 grates were derived during the UDFCD-CSU study and are valid for effective lengths up to 15 feet, while the splash-over velocity constants for all other inlet grates are valid only for effective lengths up to four feet. Beyond the maximum effective lengths for which these constants have been validated through physical modeling, the splash-over velocity may be estimated as that maximum validated velocity plus 0.2 ft/s for each additional foot of effective inlet length.

Photograph 7-4. Gutter/street slope is a major design factor for both street and inlet capacity.

Table 7-6. Splash-over velocity constants for various types of inlet grates

Type of Grate	α	β	γ	η
CDOT/Denver 13Valley Grate	0.00	0.680	0.060	0.0023
CDOT Type C Standard Grate	2.22	4.03	0.65	0.06
CDOT Type C Close Mesh Grate	0.74	2.44	0.27	0.02
Denver No. 16 Valley Grate	0.00	0.815	0.074	0.003
Directional Cast Vane Grate	0.30	4.85	1.31	0.15
Directional 45-Degree Bar Grate	0.99	2.64	0.36	0.03
Directional 30-Degree Bar Grate	0.51	2.34	0.2	0.01
Reticuline Riveted Grate	0.28	2.28	0.18	0.01
Wheat Ridge Directional Grate	0.00	0.815	0.074	0.003
1-7/8” Bar Grate, Crossbars @ 8”	2.22	4.03	0.65	0.06
1-7/8” Bar Grate, Crossbars @ 4”	0.74	2.44	0.27	0.02
1-1/8” Bar Grate, Crossbars @ 8”	1.76	3.12	0.45	0.03

The ratio of the side flow intercepted by the inlet to total side flow, R_x, is expressed as:

$$R_x = \frac{1}{1 + \frac{0.15V^{1.8}}{S_x L^{2.3}}} \qquad \text{Equation 7-21}$$

Where:

V = velocity of flow in the gutter (ft/sec)

L = length of grate (ft).

The capture efficiency, E, of the grate inlet may now be determined using:

$$E = R_f\left(Q_w/Q\right) + R_x\left(Q_x/Q\right) \qquad \text{Equation 7-22}$$

Example 7.6 shows grate inlet capacity calculations.

3.2.2 Curb-Opening Inlets on a Continuous Grade

The capture efficiency of a curb-opening inlet is dependent on the length of the opening, the depth of flow at the gutter flow line, street cross slope and the longitudinal gutter slope (see Photograph 7-4). If the curb opening is long, the flow rate is low, and the longitudinal gutter slope is small, all of the flow will be captured by the inlet. It is generally uneconomical to install a curb opening long enough to capture all of the flow during the minor (design) storm. Thus, some water gets by the inlet, and the inlet efficiency needs to be determined.

The hydraulics of curb-opening inlets are less complicated than grate inlets. The efficiency, *E*, of a curb-opening inlet is calculated as:

$$E = 1 - \left[1 - \left(L/L_T\right)\right]^{1.8} \text{ for } L < L_T, \text{ otherwise } E = 1.0 \qquad \text{Equation 7-23}$$

Where:

L = curb-opening length (ft)

L_T = curb-opening length required to capture 100% of gutter flow (ft).

For a curb-opening inlet in a uniform cross slope (see Figure 7-1), L_T can be calculated as:

$$L_T = 0.38Q^{0.51}S_L^{0.058}\left(\frac{1}{nS_x}\right)^{0.46} \qquad \text{Equation 7-24}$$

Where:

Q = total flow (cfs)

S_L = longitudinal street slope (ft/ft)

S_x = street cross slope (ft/ft)

n = Manning's roughness coefficient.

But most curb-opening inlets are in a composite street section and many also have a localized depression, so L_T should then be calculated as:

$$L_T = 0.38Q^{0.51}S_L^{0.058}\left(\frac{1}{nS_e}\right)^{0.46} \qquad \text{Equation 7-25}$$

The equivalent cross slope, S_e, can be determined from:

$$S_e = S_x + \frac{(a + a_{local})}{W} E_o \qquad \text{Equation 7-26}$$

Where:

a = gutter depression (as defined for Equation 7-8)

a_{local} = any additional local depression in the area of the inlet (typically specific to the type of inlet)

W = depressed gutter width as shown in Figure 7-2.

The ratio of the flow in the depressed section to total gutter flow, E_o, can be calculated from Equation 7-7. See Examples 7.6 and 7.7 for curb-opening inlet calculations.

3.2.3 Combination Inlets on a Continuous Grade

Combination inlets take advantage of the debris removal capabilities of a curb-opening inlet and the capture efficiency of a grate inlet. Combination inlets on a continuous grade (i.e., not in a sump location) intercept 18% more than grate inlets alone and are much less likely to clog completely (CSU 2009). A special case combination where the curb opening extends upstream of the grated section is called a sweeper inlet. The inlet capacity is enhanced by the additional upstream curb-opening length, and debris is intercepted there before it can clog the grate. The construction of sweeper inlets is more complicated and costly however, and they are not commonly seen in the UDFCD region. To calculate interception efficiency for a sweeper inlet, the upstream curb-opening efficiency is calculated first and then the interception efficiency for combination section based on the remaining street flow is added to it. To analyze this within UD-Inlet select *user-defined combination*, select a grate type, and check the *sweeper configuration* box.

3.2.4 Slotted Inlets on a Continuous Grade

Slotted inlets can be used in place of curb-opening inlets or can be used to intercept sheet flow that is crossing the pavement in an undesirable location. Unlike grate inlets, they have the advantage of intercepting flow over a wide section. They do not interfere with traffic operations and can be used on both curbed and uncurbed sections. Like grate inlets, they are susceptible to clogging.

Photograph 7-5. Inlets that are located in street vertical sag curves (sumps) are highly efficient.

Slotted inlets placed parallel to flow in the gutter flow line function like side-flow weirs, much like curb-opening inlets. The FHWA (1996) suggests the hydraulic capacity of slotted inlets closely corresponds to curb-opening inlets if the slot openings exceed 1.75 inches. Therefore, the equations developed for curb-opening inlets (Equations 7-23 through 7-26) are appropriate for those slotted inlets.

3.2.5 Grate Inlets in a Sump (UDFCD-CSU Model)

All of the stormwater draining to a sump inlet must pass through an inlet grate or curb opening to enter the storm drain. This means that clogging due to debris can result not only in underutilized pipe conveyance, but also ponding of water on the surface. Surface ponding can be a nuisance or hazard. Therefore, the capacity of inlets in sumps must account for this clogging potential. Grate inlets acting alone are not recommended for this reason. Curb-opening and combination (including sweeper) inlets are more appropriate. In all sump inlet locations, consider the risk and required maintenance associated with a fully clogged condition and design the system accordingly. Photograph 7-5 shows a curb-opening inlet in a sump condition. At this location, if the inlet clogs, standing water will be limited to the elevation at the back of the walk.

The flow through a grated sump inlet varies with respect to depth and continuously changes from weir flow (at shallow depths) to mixed flow (at intermediate depths), and also orifice flow (at greater depths). For CDOT Type 13 grates and Denver No. 16 grates (the most common grated street inlets in the UDFCD region), from the UDFCD-CSU physical model study, the classic formulas for weir and orifice flow were modified with weir length and open area ratios specifically as:

$$Q_w = N_w C_w (2W_g + L_e) D^{3/2} \qquad \text{Equation 7-27}$$

$$Q_o = N_o C_o W_g L_e \sqrt{2gD} \qquad \text{Equation 7-28}$$

Where:

Q_w = weir flow (cfs)

Q_o = orifice flow (cfs)

W_g = grate width (ft)

L_e = effective grate length after clogging (ft)

D = water depth at gutter flow line outside the local depression at the inlet (ft)

N_w = weir length reduction factor

N_o = orifice area reduction factor

C_w = weir discharge coefficient

C_o = orifice discharge coefficient

The transient process between weir and orifice flows is termed mixed flow and is modeled as:

$$Q_m = C_m \sqrt{Q_w Q_o} \qquad \text{Equation 7-29}$$

Where:

Q_m = mixed flow (cfs)

C_m = mixed flow coefficient

The recommended values for the coefficients N_w, N_o, C_w, C_m, and C_o are listed in Table 7-7.

In practice, for the given water depth, it is suggested that the interception capacity, Q_i, for the sump grate be the smallest among the weir, orifice, and mixed flows as:

$$Q_i = \min(Q_w, Q_m, Q_o) \qquad \text{Equation 7-30}$$

3.2.6 Curb-Opening Inlets in a Sump (UDFCD-CSU Model)

Like a grate inlet, a curb-opening inlet operates under weir, orifice, or mixed flow. From the UDFCD-CSU physical model study, the HEC-22 procedure was found to overestimate the capacity of the CDOT Type R, the Denver No. 14, and other, similar curb-opening inlets for the minor storm event, and underestimate capacity for the major event. From the UDFCD-CSU study of these inlets, the interception capacity is based on the depression and opening geometry and can be estimated as:

$$Q_w = C_w N_w L_e D^{3/2} \qquad \text{Equation 7-31}$$

$$Q_o = C_o N_o (L_e H_c)\sqrt{2g(D - 0.5H_c)} \qquad \text{Equation 7-32}$$

Where:

H_c = height of the curb-opening throat (ft)

D = water depth at gutter flow line outside the local depression at the inlet (ft).

The recommended values for the coefficients N_w, N_o, C_w, C_m, and C_o are listed in Table 7-7. Once weir and orifice interception rates are calculated, Equations 7-29 and 7-30 must also be applied to curb-opening inlets in sag locations.

Table 7-7. Coefficients for various inlets in sumps

Inlet Type	N_w	C_w	N_o	C_o	C_m
CDOT Type 13 Grate	0.70	3.30	0.43	0.60	0.93
Denver No. 16 Grate	0.73	3.60	0.31	0.60	0.90
Curb Opening for Type 13 / No. 16 Combination	1.0	3.70	1.0	0.66	0.86
CDOT Type R Curb Opening	1.0	3.60	1.0	0.67	0.93

The UDFCD-CSU study demonstrated a phenomenon referred to as weir performance decay, which is a function of the length of the inlet. It was found that inlets become less effective in weir flow as they grow in length, if the intent is to limit ponding to less than or equal to the curb height. This phenomenon can be expressed mathematically by a multiplier in the weir equation. For the CDOT Type R and Denver No. 14 curb-opening inlets, the weir performance reduction factor (WPRF) multiplier is found by:

$$\text{WPRF}_{14,\text{R}} = \text{Min}\left[1, \frac{D_{FL}}{0.67D_{FL} + 0.24\min(15, L)}\right] \qquad \text{Equation 7-33}$$

Where:

$WPRF_{14,R}$ = multiplier to reduce Q_w in Equation 7-31 for the CDOT Type R and the Denver No. 14 inlet

D_{FL} = gutter depth at flow line away from inlet depression (inches)

L = total inlet length (ft)

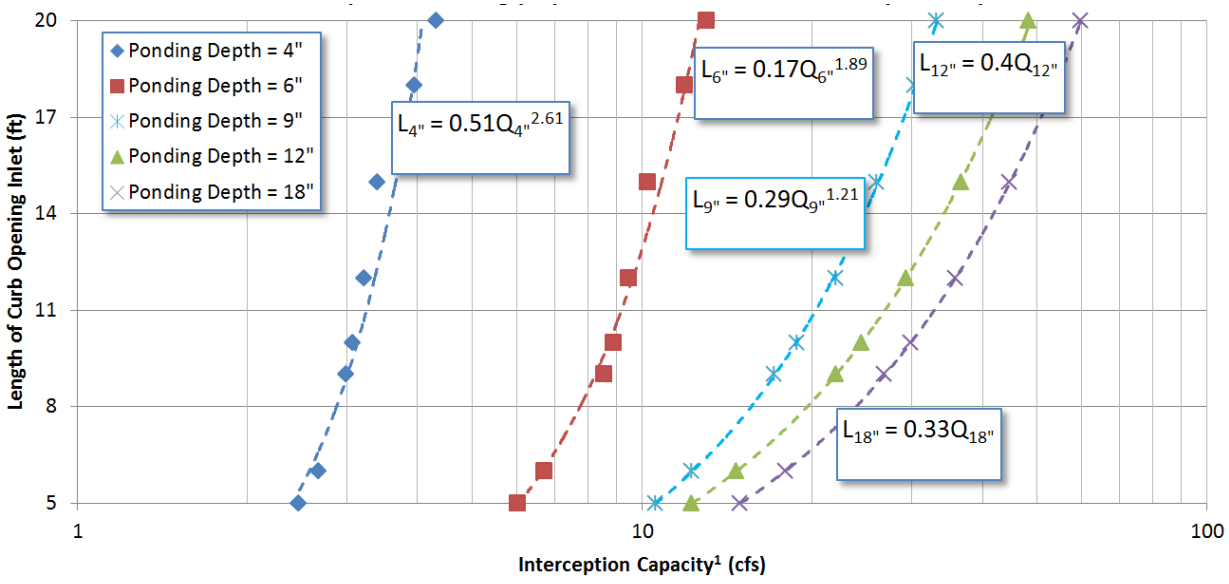
This reduction factor should be applied to weir equations for curb-opening inlet shallow depth interception calculations.

From the UDFCD-CSU study, empirical equations to estimate interception capacity for the CDOT Type R and the Denver No. 14 curb-opening inlets were developed and are shown in Figures 7-5 and 7-6.

Photograph 7-6. Weir performance decay can be observed in this picture as flow appears to enter only the first two inlets while exceeding the height of the upstream curb.

Weir Performance Decay

Inlets become less effective in weir flow as they grow in length. What this means is that adding inlets to reduce the depth of flow will typically not increase total capacity when the inlet is in weir flow. This is important to consider this when designing for the minor event. In an effort to meet minor event depth criteria, the system may need to be extended further upstream.



1 This value assumes inlet clogging per Section 3.2.9.

Figure 7-6. CDOT type r and Denver no. 14 interception capacity in sag

For the CDOT Type 13, the Denver No. 16, and other, similar combination inlets featuring cast iron adjustable-height curb boxes, the curb-opening capacity must be added to the grate capacity as determined in Section 3.3.5. Regardless of how tall the vertical curb opening is, water captured by these curb openings must enter through a narrow horizontal opening under the curb head and in the plane of the grate. Therefore the capacity of the curb opening associated with these combination inlets is estimated based on that horizontal throat opening geometry using Equation 7-31 for the weir condition, and for the orifice condition as:

$$Q_o = C_o N_o (0.W_c L_e)\sqrt{2gD} \qquad \text{Equation 7-34}$$

Where:

W_c = horizontal orifice width (typically 0.44 feet for the CDOT Type 13, the Denver No. 16, and other, similar combination inlets featuring cast iron adjustable-height curb boxes)

Once weir and orifice interception rates are calculated, Equations 7-29 and 7-30 must also be applied to the curb-opening portion of combination inlets in sag locations.

After the controlling interception rate for the grate and for the curb opening have been calculated as the minimum of the weir, orifice, and mixed flows, a reduction factor tied to the geometric mean of the grate and curb-opening capacities should be applied to the algebraic sum of the total interception as:

$$Q_t = Q_g + Q_c - K\sqrt{Q_g Q_c} \qquad \text{Equation 7-35}$$

Where:

Q_t = interception capacity for combination inlet (cfs)

Q_g = interception for grate (cfs)

Q_c = interception for curb opening (cfs)

K = dimensionless reduction factor (= 0.37 for CDOT Type 13 combination inlet, = 0.21 for Denver No. 16 combination inlet).

A higher reduction factor implies higher interference between the grate and the curb opening. The HEC-22 procedure assumes that the grate and curb opening function independently, resulting in a consistent overestimation of the capacity of combination inlets. K is a lumped, average parameter representing the range of observed water depths in the laboratory. During the model tests, it was observed that when the grate surface area is subject to shallow water, the curb opening intercepted the flow only at its two corners, and did not behave as a side weir by collecting flow along its full length. Under deep water, vortex circulation dominates the flow pattern. As a result, the central portion of the curb opening more actively draws water into the inlet box. Equation 7-35 best represents the range of the observed data.

The UDFCD-CSU study demonstrated that the Denver No. 16 and the CDOT Type 13 combination inlets are also subject to weir performance decay, which was described above with regard to the CDOT Type R and Denver No. 14 curb-opening inlets. For the Denver No. 16 and the CDOT Type 13 combination inlets, the WPRF multiplier is found by:

$$WPRF_{13,16} = \text{Min}\left[1, \frac{D_{FL}}{0.7\text{Min}(9, L) + 4.3}\right] \quad \text{Equation 7-36}$$

Where:

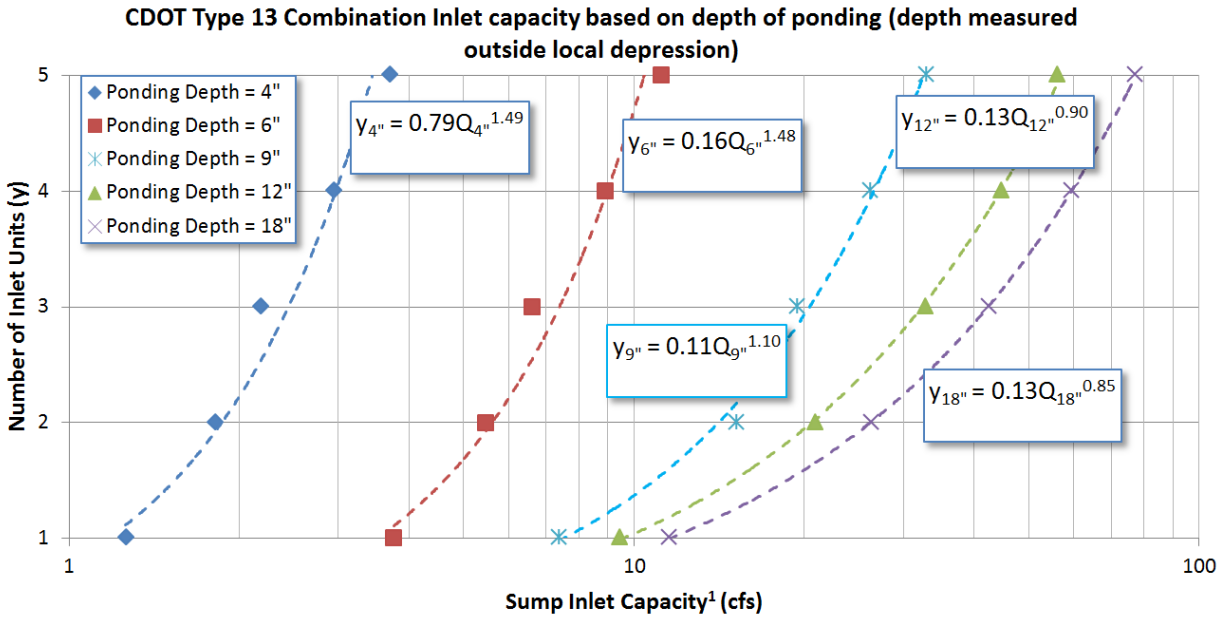
$WPRF_{13,16}$ = multiplier to reduce Q_w in Equation 7-31 for the CDOT Type 13 and the Denver No. 16 inlet

D_{FL} = gutter depth at flow line away from inlet depression (inches)

L = total inlet length (ft).

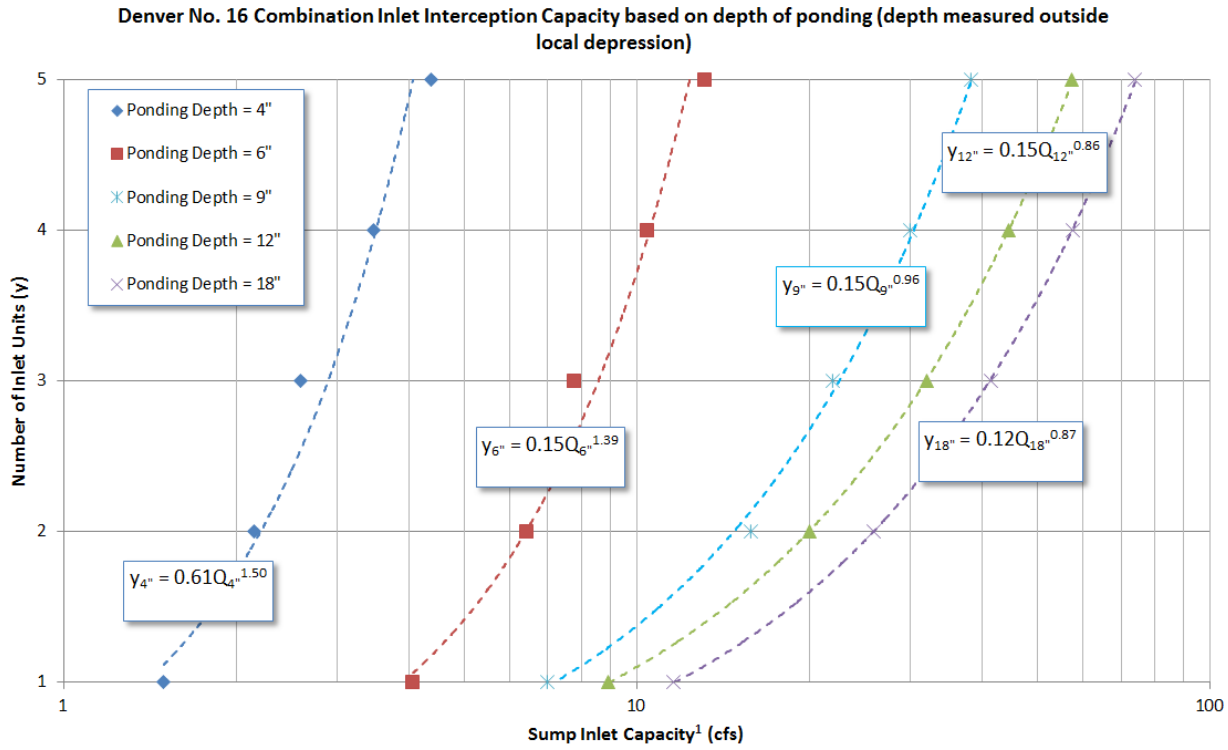
This reduction factor should be applied to both the grate and the curb opening weir equations (Equation 7-31) for combination inlet shallow depth interception calculations.

From the UDFCD-CSU study, empirical equations to estimate interception capacity for the CDOT Type 13 and the Denver No. 16 combination inlets were developed and are shown in Figures 7-7 through 7-10.



[1] This value assumes inlet clogging per Section 3.2.9.

Figure 7-7. CDOT type 13 interception capacity in a sump



[1] This value assumes inlet clogging per Section 3.2.9.

Figure 7-8. Denver no. 16 interception capacity in sump

3.2.7 Other Inlets in a Sump (Not Modeled in the UDFCD-CSU Study)

The hydraulic capacity of grate, curb-opening, and slotted inlets operating as weirs is expressed as:

$$Q_i = C_w L_w \, d^{1.5} \qquad \text{Equation 7-37}$$

Where:

Q_i = inlet capacity (cfs)
C_w = weir discharge coefficient
L_w = weir length (ft)
d = flow depth (ft).

Values for C_w and L_w are presented in Table 7-8 for various inlet types. Note that the expressions given for curb-opening inlets without depression should be used for depressed curb-opening inlets if $L > 12$ feet.

The hydraulic capacity of grate, curb-opening, and slotted inlets operating as orifices is expressed as:

$$Q_i = C_o A_o (2gd)^{0.5} \quad \text{Equation 7-38}$$

Where:

Q_i = inlet capacity (cfs)

C_o = orifice discharge coefficient

A_o = orifice area (ft^2)

d = characteristic depth (ft) as defined in Table 7-8

g = 32.2 ft/sec^2.

Values for C_o and A_o are presented in Table 7-8 for different types of inlets.

Combination inlets are commonly used in sumps. The hydraulic capacity of combination inlets in sumps depends on the type of flow and the relative lengths of the curb opening and grate. For weir flow, the capacity of a combination inlet (grate length equal to the curb opening length) is equal to the capacity of the grate portion only. This is because the curb opening does not add any effective length to the weir. If the curb opening is longer than the grate, the capacity of the additional curb length should be added to the grate capacity. For orifice flow, the capacity of the curb opening should be added to the capacity of the grate.

Table 7-8. Sump inlet discharge variables and coefficients

(Modified From Akan and Houghtalen 2002)

Inlet Type	C_w	L_w[1]	Weir Equation Valid For	Definitions of Terms
Grate Inlet	3.00	$L + 2W$	$d < 1.79(A_o/L_w)$	L = Length of grate (ft) W = Width of grate (ft) d = Depth of water over grate (ft) A_0 = Clear opening area[2] (ft^2)
Curb-opening Inlet	3.00	L	$d < h$	L = Length of curb opening (ft) h = Height of curb opening (ft) $d = d_i - (h/2)$ (ft) d_i = Depth of water at curb opening (ft)
Depressed Curb Opening Inlet[3]	2.30	$L + 1.8W$	$d < (h + a)$	W = Lateral width of depression (ft) a = Depth of curb depression (ft)
Slotted Inlets	2.48	L	$d < 0.2$ ft	L = Length of slot (ft) d = Depth at curb (ft)

[1] The weir length should be reduced where clogging is expected.

[2] Ratio of clear opening area to total area is 0.8 for P-1-7/8-4 and reticuline grates, 0.9 for P-1-7/8 and 0.6 for P-1-1/8 grates. Curved vane and tilt bar grates are not recommended at sump locations unless in combination with curb openings.

[3] If $L > 12$ ft, use the expressions for curb-opening inlets without depression.

	C_o	A_0[4]	Orifice Equation Valid for	Definition of Terms
Grate Inlet	0.67	Clear opening area[5]	$d > 1.79(A_o/L_w)$	d = Depth of water over grate (ft)
Curb-opening Inlet (depressed or undepressed, horizontal orifice throat[6])	0.67	$(h)(L)$	$d_i > 1.4h$	$d = d_i - (h/2)$ (ft) d_i = Depth of water at curb opening (ft) h = Height of curb opening (ft)
Slotted Inlet	0.80	$(L)(W)$	$d > 0.40$ ft	L = Length of slot (ft) W = Width of slot (ft) d = Depth of water over slot (ft)

[4] The orifice area should be reduced where clogging is expected.

[5] The ratio of clear opening area to total area is 0.8 for P-1-7/8-4 and reticuline grates, 0.9 for P-1-7/8 and 0.6 for P-1-1/8 grates. Curved vane and tilt bar grates are not recommended at sump locations unless in combination with curb openings.

[6] See Figure 7-12 for other types of throats.

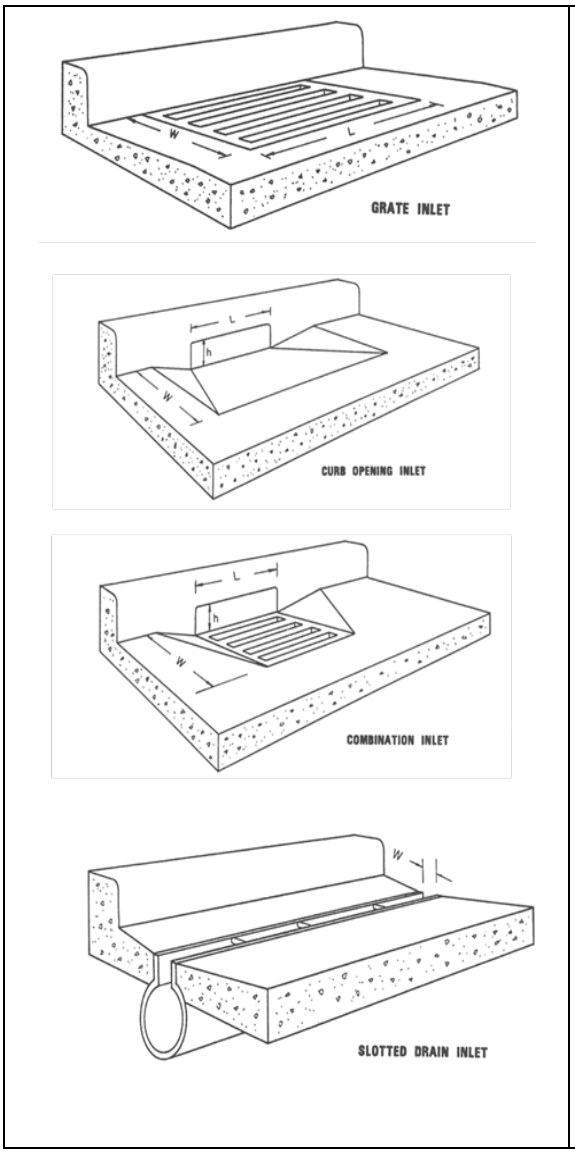


Figure 7-9. Perspective views of grate and curb-opening inlets

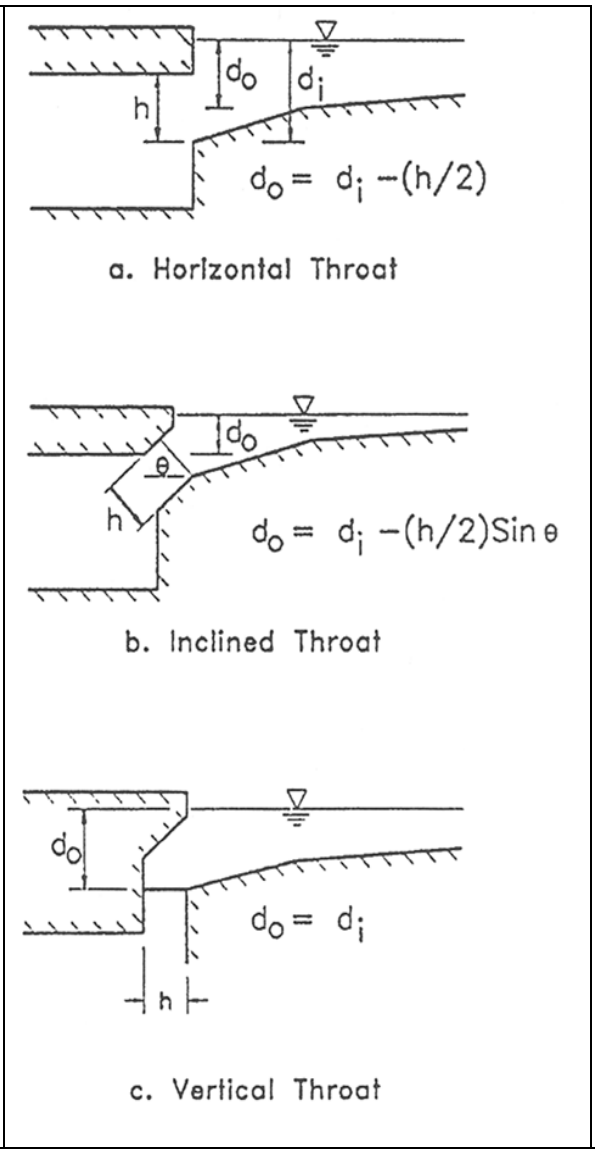


Figure 7-10. Orifice calculation depths for curb-opening inlets
(note that the equation for the inclined throat is also valid for the other cases)

3.2.8 Inlet Clogging

Photograph 7-6. Clogging is an important consideration when designing inlets.

Inlets are subject to clogging effects (see Photograph 7-6). Selection of a clogging factor reflects the condition of debris and trash on the street. During a storm event, street inlets are usually loaded with debris by the first-flush runoff volume. As a common practice for street drainage, 50% clogging is considered for the design of a single grate inlet and 10% clogging is considered for a single curb-opening inlet. Often, it takes multiple units to collect the stormwater on the street. Since the amount of debris is largely associated with the first-flush volume in a storm event, the clogging factor applied to a multiple-unit street inlet should be decreased with respect to the length of the inlet. Linearly applying a single-unit clogging factor to a multiple-unit inlet will lead to an excessive increase in inlet length. For example, if a 50% clogging factor is applied to a six-unit inlet, the inlet would be presumed to function as a three-unit inlet. In reality, the upgradient units of the inlet would be more susceptible to clogging (perhaps at the 50% level) than the downgradient portions. In fact, continuously applying a 50% reduction to the discharge on the street will always leave 50% of the residual flow on the street. This means that the inlet will never reach a 100% capture and leads to unnecessarily long inlets. To address this phenomenon, UDFCD has developed Equation 7-39 which calculates a "decayed" clogging factor when multiple inlet units are used together.

With the concept of first-flush volume, the decay of clogging factor to grate or curb-opening length is described as (Guo 2000a):

$$C = \frac{1}{N}(C_o + eC_o + e^2C_o + e^3C_o + ... + e^{N-1}C_o) = \frac{C_o}{N}\sum_{i=1}^{i=N} e^{i-1} = \frac{KC_o}{N} \qquad \text{Equation 7-39}$$

Where:

C = multiple-unit clogging factor for an inlet with multiple units

C_o = single-unit clogging factor

e = decay ratio less than unity, 0.5 for grate inlet, 0.25 for curb-opening inlet

N = number of grate units, or, for curb openings, L/5

K = clogging coefficient from Table 7-9.

Table 7-9. Clogging coefficient k for single and multiple units[1]

N for Grate Inlets or (L/5) for Curb-Openings	1	2	3	4	5	6	7	8	>8
K for Grate Inlet	1	1.5	1.75	1.88	1.94	1.97	1.98	1.99	2
K for Curb Opening Inlet	1	1.25	1.31	1.33	1.33	1.33	1.33	1.33	1.33

[1] This table is generated by Equation 7-39 with e = 0.5 and e = 0.25.

When N becomes large, Equation 7-39 converges to:

$$C = \frac{C_o}{N(1-e)} \qquad \text{Equation 7-40}$$

For instance, when $e = 0.5$ and $C_o = 50\%$, $C = 1.0/N$ for a large number of units, N. In other words, only the first unit out of N units will be clogged. Equation 7-40 complies with the recommended clogging factor for a single-unit inlet and decays on the clogging effect for a multiple-unit inlet.

The interception of an inlet on a grade is proportional to the inlet length and, in a sump, is proportional to the inlet opening area. Therefore, a clogging factor should be applied to the length of the inlet on a grade as:

$$L_e = (1-C)L \qquad \text{Equation 7-41}$$

in which L_e = effective (unclogged) length (ft). Similarly, a clogging factor should be applied to the opening area of an inlet in a sump as:

$$A_e = (1-C)A \qquad \text{Equation 7-42}$$

Where:

A_e = effective opening area (ft^2)

A = opening area (ft^2).

3.2.9 Nuisance Flows

The location of inlets is important to address the effects of nuisance flows and avoid icing. Nuisance flows are urban runoff flows that are typically most notable during dry weather and come from sources such as over-irrigation and snow melt. Nuisance flows cause problems in both warm and cold weather months. Problems include algae growth and ice. While it is possible to minimize nuisance conditions through design, irrigation practices in the summer and snow and ice removal in the winter make it very difficult to eliminate nuisance flows entirely. Because these practices are largely controlled by residents and business, municipalities should plan for maintenance to address nuisance flow conditions, particularly in the winter when ice accumulation can impede the ability of the drainage system to serve its purpose.

In the summer months, over-irrigation of lawns and landscaping can be a major contributor to nuisance flows. Car washing is another summertime cause of excess flows. In homes with poor or improper drainage, excessive sump pump discharge may also contribute.

In winter months, snow and ice melt are the primary causes of nuisance flows and associated icing problems (see Photograph 7-7). Discharges from sump pumps to the sidewalk and/or street can also lead to icing.

Flows over sidewalks and driveways due to summertime nuisance flows can cause algae growth, especially if fertilizer is being used in conjunction with over-irrigation. Such algae growth is both a safety issue due to increased falling risk resulting from slippery surfaces and an aesthetic issue. Nuisance flows laden with fertilizer, sediment, and other pollutants also have the potential to overload stormwater BMPs, which are generally designed for lower pollutant concentrations found in typical wet weather flows. Additionally, continually moist conditions can create an environment where fecal bacteria thrive, either becoming an on-going dry weather source of bacteria loading or a source that is subsequently mobilized under wet weather conditions, such as in the case of biofilm soughing.

Photograph 7-7. The location of inlets is important to address the effects of nuisance flows.

Public education about proper irrigation rates and irrigation system maintenance (e.g., broken or misaligned sprinkler heads) can help reduce occurrences of excess flow over sidewalks. Additionally, homeowners can be encouraged to direct downspout and sump pump discharges to swales, lawns, and gardens (keeping away from foundation backfill zones) where water can infiltrate. Algae growth is encouraged by the presence of nutrients which can come from fertilizer and organic matter. Algae growth can be reduced by educating homeowners on proper application of fertilizer (both rates and timing of application), using phosphorus-free fertilizer, and sweeping up dead leaves and plant matter on impervious surfaces. Whenever feasible, impervious surfaces should be swept rather than sprayed down with water. When power-washing of outdoor surfaces is conducted, comply with local, state and federal regulations.

Snow and ice melt can re-freeze on streets and sidewalks, where it poses hazards to the public and is difficult to remove. Often, icing is most significant on east-west streets that have less solar exposure in the winter. Trees, buildings, fences and topography can also create shady areas where ice accumulates. Snow and ice may also clog drains and inlets, leading to flooding. Snowmelt has been found to have high pollutant concentrations which can stress treatment facilities. Because many of the issues related to winter nuisance flows are beyond the control of municipalities (especially in areas that are already developed), identifying problem areas and planning for maintenance is often the most effective practice for minimizing nuisance conditions.

Table 7-10 provides the various sources, problems, and avoidance strategies associated with nuisance flows.

Table 7-10. Nuisance flows: sources, problems and avoidance strategies

	Warm Weather	Cold Weather
Examples/Sources	▪ Over-irrigation of lawns and landscaping ▪ Car washing ▪ Sump pump discharge	▪ Snowmelt ▪ Ice Melt ▪ Sump pump discharge (freezing)
Problems	▪ Poor water quality ▪ High nutrient concentration ▪ High pollutant concentration ▪ Algae Growth	▪ Icing leading to inlet blockage and flooding ▪ Ice on streets and sidewalks ▪ High pollutant concentrations
Avoidance Strategies	▪ Irrigation, drainage, and fertilizer education ▪ Proper drainage design ▪ Minimization of directly connected impervious area ▪ Sidewalk chase drains	▪ Inlet and sidewalk maintenance ▪ Prompt and frequent snow and ice removal ▪ Consider additional inlets in strategic locations ▪ Shoveling snow onto grassy areas away from streets and inlets ▪ Locate inlets and sumps away from shaded areas

Homeowners, business owners, maintenance and city workers should be educated and encouraged to use proper snow and ice removal techniques. These include removal of snow and ice promptly and frequently, keeping drains and gutters clear, and placing shoveled snow onto lawns or grassy areas.

Photograph 7-8. Inlets frequently need maintenance.

For new development projects, locating inlets in areas where water can be intercepted before it accumulates or slows down and has the opportunity to freeze is the most effective way to minimize icing from the design perspective. To the extent practical, locate inlets away from areas that will be heavily shaded during winter months (in particular the north side of buildings) to help prevent ice build-up and allow proper flow. For areas where shading is unavoidable, consider providing additional inlet capacity at strategic locations. For example, if a street with a southern exposure will drain to an east-west street that is shaded, having additional inlet capacity at the intersection may be advisable, especially if the flow is intended to turn and follow the east-west street. It is also important to consider potential future vegetative growth when evaluating shading effects. Although trees may be small and have little canopy when originally planted, they will grow and ultimately provide far greater tree canopy far greater than when initially planted. Tree canopy may vary seasonally, depending on the tree species (e.g., deciduous trees lose their leaves in the fall, so less canopy is present in the winter). Ultimately, even with careful placement of inlets and avoidance of shading to the extent practical, icing in some locations will still likely occur due to shading from buildings, fences and other improvements on private property, and maintenance to remove accumulated ice will be necessary. For areas that are already developed, maintenance (i.e., snow and ice removal) to control icing from nuisance flows is the primary method to address icing, and for many municipalities, this is an ongoing part of their street maintenance programs.

During all times of the year, it is important that nuisance flows can be properly conveyed to storm drain outlets. Ponding on streets and sidewalks promotes both ice and algae growth. Sidewalk chase drains may be appropriate to aid in proper drainage of nuisance flows (for sump pump discharges, in particular); however, sidewalk chases can be problematic in terms of clogging and icing if they are located in areas with heavy loads of gross solids (leaves, grocery bags, restaurant litter, etc.) or if they are located in areas with poor solar exposure in winter months.

For more information on nuisance flows, multiple Colorado-based publications are available to provide guidance related to landscape management practices and snow and ice removal. Representative resources include:

- USDCM Volume 3, Source Control BMPs
- GreenCO BMP Manual
- Colorado State University Extension Yard and Garden Fact Sheets.

3.3 Inlet Location and Spacing on Continuous Grades

Although one should always perform interception capacity computations on stormwater inlets, the ultimate location (or positioning) of those inlets is rarely a function of interception alone. Often, inlets are required in certain locations based upon street design considerations, topography (sumps), and local ordinances. One notable exception is the location and spacing of inlets on continuous grades. On a long continuous grade, stormwater flow increases as it moves down the gutter and picks up more drainage area. As the flow increases, so does the spread and depth. Since the spread (encroachment) and depth (inundation) are not allowed to exceed some specified maximum, inlets must be strategically placed to

remove some of the stormwater from the street. Locating these inlets requires design computations by the engineer.

3.3.1 Design Considerations

The primary design considerations for the location and spacing of inlets on continuous grades are the encroachment and inundation limitations. This was addressed in Section 2.2. Table 7-2 lists pavement encroachment and inundation standards for minor storms in the UDFCD region.

Proper design of stormwater collection and conveyance systems makes optimum use of the conveyance capabilities of street gutters, such that an inlet is not needed until the spread (encroachment) and depth (inundation) reach allowable limits during the design (minor) storm. To place an inlet prior to that point on the street is not economically efficient. To place an inlet after that point would violate the encroachment and inundation standards. Therefore, the primary design objective is to position inlets along a continuous grade at the locations where the allowable spread and/or depth is about to be exceeded for the design storm.

3.3.2 Design Procedure

Based on the encroachment and inundation standards and the given street geometry, the allowable street hydraulic capacity can be determined using Equation 7-11 and Equation 7-12. This flow rate is then equated to some hydrologic technique (equation) that contains drainage area. In this way, the inlet is positioned on the street so that it will service the requisite drainage area. The process of locating the inlet is accomplished by trial-and-error. If the inlet is moved downstream (or down gutter), the drainage area increases. If the inlet is moved upstream, the drainage area decreases.

The hydrologic technique most often used in urban drainage design is the rational method. The rational method was discussed in the *Runoff* chapter. The rational method, repeated here for convenience, is:

$$Q = CIA \qquad \text{Equation 7-43}$$

Where:

Q = peak discharge (cfs)

C = runoff coefficient described in the *Runoff* chapter

I = design storm rainfall intensity (in/hr) described in the *Rainfall* chapter

A = drainage area (acres).

The design process starts with the selection of the proposed first inlet in the system. The peak discharge for the half-street at this point is calculated by the rational method, using runoff coefficients and rainfall intensities as described in the *Runoff* Chapter. Next, the allowable peak discharge is found using the allowable spread and depth calculated as functions of the street geometry at the design point. If the allowable peak discharge is less than the watershed peak discharge, the proposed design point is too far downstream in the watershed and must be moved upstream. If the allowable peak discharge is much greater than the calculated peak discharge, no inlet is required at the proposed design point and a new location for the proposed first inlet in the system is selected somewhere downstream of this location. The ultimate goal is to always place an inlet just upstream of the point where the allowable spread and/or depth criteria would otherwise be exceeded.

Once the first inlet location is identified along a continuous grade, an inlet type and size can be specified. The first inlet's hydraulic capacity is then assessed. Generally, it is uneconomical to size an inlet (on

continuous grades) large enough to capture all of the gutter flow. Instead, some carryover flow is expected. This practice reduces the amount of new flow that can be picked up at the next inlet. However, each inlet should be positioned at the location where the spread or depth of flow is about to reach its allowable limit.

The gutter discharge for inlets (other than the most upstream inlet), consists of the carryover (bypassed) flow from the upstream inlet plus the stormwater runoff generated from the intervening local drainage area. The carryover flow from the upstream inlet is added to the peak flow rate obtained from the rational method for the intervening local drainage area. The resulting peak flow is conservatively approximate since the carryover flow peak and the local runoff peak do not necessarily coincide.

4.0 Storm Drain Systems

4.1 Introduction

Once stormwater is collected from the street by an inlet, it is directed into the storm drain system. The storm drain system is comprised of inlets, pipes, manholes, bends, outlets, and other appurtenances. For specific information regarding the applicability of a number of available pipe materials, a document titled "Storm Sewer Pipe Material Technical Memorandum" is available for download at www.udfcd.org.

Apart from inlets, manholes are the most common appurtenance in storm drain systems. Their primary functions include:

- Providing maintenance access.
- Serving as junctions when two or more pipes merge.
- Providing flow transitions for changes in pipe size, slope, and alignment.
- Providing ventilation.

Manholes are generally made of pre-cast or cast-in-place reinforced concrete. They are typically four to five feet in diameter and are required at regular intervals, even in straight sections, for maintenance reasons. Standard size manholes cannot accommodate large pipes, so special junction vaults are constructed for that application.

Occasionally, bends and transitions are accomplished without manholes, particularly for large pipe sizes. These sections provide gradual transitions in size or alignment to minimize energy losses. Outlet structures, covered in the *Hydraulic Structures* chapter, are transitions from pipe flow into open channel flow or still water (e.g., ponds, lakes, etc.). Their primary function is to provide a transition that minimizes erosion in the receiving water body. Occasionally, flap gates or other types of check valves are placed on outlet structures to prevent backflow from high tailwater or flood-prone receiving waters.

4.2 Design Process, Considerations, and Constraints

The design of a storm drain system requires a large data collection effort. The data requirements in the proposed service area include topography, drainage boundaries, imperviousness, soil types, and locations of any existing storm drain conduits, inlets, and manholes. In addition, identification of the type and location of other utilities in the ground is critical. Alternative layouts of a new system (or modifications to an existing system) can be investigated using these data.

System layouts rely largely on street rights-of-way and topography. Most layouts are dendritic (tree)

networks that follow the street pattern. Dendritic networks collect stormwater from a broad area and converge in the downstream direction. Networks with parallel branches are possible but are less common and require full hydraulic modeling. Each layout should depict inlet and manhole locations, drainage boundaries serviced by the inlets, pipe locations, flow directions, and outlet locations. A final layout selection is made from the viable alternatives based on likely system performance and cost.

Once a final layout is chosen, storm drain pipes are sized based on the hydrology (peak flows) and hydraulics (pipe capacities). This is accomplished by designing the upstream pipes first and moving downstream. Pipe diameters less than 15 inches are not recommended for storm drains, and many communities have adopted an 18-inch diameter minimum standard. Pipes generally increase in size moving downstream since the drainage area (and thus flow) is increasing. Downstream pipes should never be smaller than upstream pipes, even if a steeper slope is encountered that will provide sufficient capacity with a smaller pipe. The potential for clogging at the resulting "choke point" is always a concern.

Storm drains are typically sized to convey the minor storm without surcharging, using open channel hydraulics calculations to determine normal depth 100% full pipe depth. Because the maximum capacity of a circular pipe occurs at approximately 93% of the depth of full pipe flow, designing for full flow will result in slightly conservative design. The minor storm typically is defined by a return interval from the 2-year to the 5-year storm depending on the function of the infrastructure being served. Refer to the *Policy* chapter for guidance regarding selection of the design storm.

Manholes are located in the system in conjunction with pipe sizing and inlet placement, where manhole locations are dictated by standard design practices. For example, manholes are required whenever there is a lateral pipe servicing an inlet, and where a change occurs in pipe size, alignment, or slope. In addition, manholes are required at pipe branch junctions. Manholes are also required along long straight sections of pipe for maintenance purposes, with the distance between manholes dependent on pipe size, but not more than 400 feet. The invert of a pipe leaving a manhole should be at least 0.1 foot lower than the incoming pipe to ensure positive low flows through the manhole. Whenever possible, match the pipe soffit elevations when the downstream pipe is larger to minimize backwater effects on the upstream pipe. Additional manholes may be necessary to "step down" a steep grade, allowing pipe slopes to be much flatter than the slope of the street above. This is done to prevent velocities in storm drain pipes from exceeding the recommended maximum velocity of 20 ft/sec.

Once storm drain pipes are sized and manhole locations are determined, the performance of the storm drain system must be evaluated using energy grade line calculations starting at the downstream system outlet. As stormwater flows through the storm drain system, it encounters many flow transitions. These transitions include changes in pipe size, slope and alignment, as well as entrance and exit conditions. All of these transitions consume energy, resulting in energy losses expressed as head losses. These losses must be accounted for to ensure that inlets and manholes do not surcharge to a significant degree (i.e., produce street flooding). This is accomplished using hydraulic grade line (HGL) calculations as a check on pipe sizes and system losses. If significant surcharging occurs, the pipe sizes should be increased. High tailwater conditions at the storm drain outlet may also produce surcharging. This can also be accounted for using HGL calculations.

4.3 Storm Drain Hydrology—Peak Runoff Calculation

The rational method is commonly used to determine the peak flow rates that storm drain systems must be able to convey. It is an appropriate method for the small drainage areas typically involved. It is also relatively easy to use and provides reasonable estimates of peak runoff. The total drainage area contributing flow to a particular storm drain is sometimes divided into smaller subcatchments. The rational method is described in the *Runoff* chapter of the USDCM.

The first pipe in a storm drain system is sized using Equation 7-43 to determine the peak flow. Downstream pipes receive flow from the upstream pipes as well as local inflows. The rational method applied to the downstream pipes is:

$$Q = I\sum_{j=1}^{n} C_j A_j \qquad \text{Equation 7-44}$$

Where:

I = rainfall intensity based on the time of concentration for the total contributing area (in/hr)

n = number of subcatchments above the stormwater pipe

C_j = runoff coefficient of subcatchment j

A_j = drainage area of subcatchment j (acres)

In using this equation, it is evident that the peak flow changes at each design point since the time of concentration, and thus the average intensity, changes at each design point. It is also evident that the time of concentration coming from the local inflow may differ from that coming from upstream pipes. Normally, the longest time of concentration is chosen for design purposes. If this is the case, all of the subcatchments above the design point will be included in Equation 7-44, and it usually produces the largest peak flow. On occasion, the peak flow from a shorter path may produce the greater peak discharge if the downstream areas are heavily developed. It is good practice to check all alternative flow paths and tributary areas to determine the tributary zone that produces the biggest design flow, especially when some of the tributary areas are highly impervious with rapid runoff responses.

4.4 Storm Drain Hydraulics (Gravity Flow in Circular Conduits)

4.4.1 Flow Equations and Storm Drain Sizing

Storm drain flow is unsteady and non-uniform. However, for design purposes it can be assumed to be steady and uniform at the peak flow rate, thereby allowing Manning's equation to be applied for determining pipe capacity:

$$Q = \frac{1.49}{n} AR^{2/3} S_f^{1/2} \qquad \text{Equation 7-45}$$

Where:

Q = flow rate (cfs)

n = Manning's roughness factor

A = flow area (ft^2)

R = hydraulic radius (ft)

S_f = friction slope (normally assumed to be the storm drain slope) (ft/ft)

For full flow in a circular storm drain,

$$A = A_f = \frac{\pi D^2}{4} \quad \text{Equation 7-46}$$

$$R = R_f = \frac{D}{4} \quad \text{Equation 7-47}$$

Where:

D = pipe diameter (ft)

A_f = flow area at full flow (ft^2)

R_f = hydraulic radius at full flow (ft).

If the flow is pressurized (i.e., surcharging at the manholes or inlets is occurring), $S_f \neq S_o$ where S_o is the longitudinal slope of the storm drain pipe. Design of storm drains assumes just-full flow, a reference condition referring to steady, uniform flow with a flow depth, y, nearly equal to the pipe diameter, D. Just-full flow discharge, Q_f , is calculated using:

$$Q_f = \frac{1.49}{n} A_f R_f^{2/3} S_o^{1/2} \quad \text{Equation 7-48}$$

Computations of flow characteristics for partial depths in circular pipes are tedious. Design aids like the UD-Culvert Excel workbook are very helpful when this is necessary.

Storm drains are sized to flow just full (i.e., as open channels using nearly the full capacity of the pipe). The design discharge is determined first using the rational method as previously discussed, then the Manning's equation is used (with $S_f = S_o$) to determine the required pipe size. For circular pipes,

$$D_r = \left[\frac{2.16nQ}{\sqrt{S_o}} \right]^{3/8} \quad \text{Equation 7-49}$$

Where D_r is the minimum size pipe required to convey the design flow and Q is peak design flow. However, the pipe diameter that should be used in the field is the next standard pipe size larger than D_r.

The typical process proceeds as follows. Initial storm drain pipe sizing is performed first using the rational method in conjunction with Manning's equation. The rational method is used to determine the peak discharge that storm drains must convey. The storm drain pipes are then initially sized using Manning's equation assuming uniform, steady flow at the peak. Finally, these initial pipe sizes are checked using the energy equation by accounting for all head losses. If the energy computations detect surcharging at manholes or inlets, the pipe sizes are increased.

4.4.2 Energy Grade Line and Head Losses

Head losses must be accounted for in the design of storm drains in order to find the energy grade line (EGL) and the hydraulic grade line (HGL) at any point in the system. The FHWA (1996) gives the following equation as the basis for calculating the head losses at inlets, manholes, and junctions (h_{LM}, in feet):

$$h_{LM} = K_o C_D C_d C_Q C_p C_B \left(\frac{V_o^2}{2g} \right) \qquad \text{Equation 7-50}$$

Where:

K_o = initial loss coefficient

V_o = velocity in the outflow pipe (ft/sec)

g = gravitational acceleration (32.2 ft/sec^2)

C_D, C_d, C_Q, C_p, and C_B = correction factors for pipe size, flow depth, relative flow, plunging flow and benching.

However, this equation is valid only if the water level in the receiving inlet, junction, or manhole is above the invert of the incoming pipe. Otherwise, another protocol has to be used to calculate head losses at manholes. What follows is a modified FHWA procedure that engineers can use to calculate the head losses and the EGL along any point in a storm drain system.

The EGL represents the energy slope between the two adjacent manholes in a storm drain system. A manhole may have multiple incoming storm drains, but only one outgoing drain. Each drain and its downstream and upstream manholes form a pipe-manhole unit. The entire storm drain system can be decomposed into a series of pipe-manhole units that satisfy the energy conservation principle. The computation of the EGL does this by repeating the energy-balancing process for each pipe-manhole unit.

As illustrated in Figure 7-13, a pipe-manhole unit has four distinctive sections. Section 1 is inside the downstream manhole, Section 2 is the point at the exit of the pipe just upstream of this manhole, Section 3 is just inside the upstream end of the pipe at the upstream manhole, and Section 4 is inside the upstream manhole. For each pipe-manhole unit, the head losses are determined separately in two parts as:

- Friction losses through the pipe, and
- Junction losses at the manhole.

The discussion that follows explains how to apply energy balancing to calculate the EGL through each pipe-manhole unit.

Losses at the Downstream Manhole, Section 1 to Section 2

The continuity of the EGL is determined between the flow conditions at centerline of the downstream manhole, Section 1, and the exit of the incoming pipe, Section 2, as illustrated in Figure 7-13 and idealized EGL and HGL profiles in Figure 7-14.

At Section 2 there may be pipe-full flow, supercritical open channel flow, critical open channel flow, or subcritical open channel flow. If the pipe soffit at the exit is submerged, the EGL at the downstream manhole provides a tailwater condition; otherwise, the manhole drop can create a discontinuity in the EGL. Therefore, it is necessary to evaluate the two possibilities, namely:

$$E_2 = \max\left(\frac{V_2^2}{2g} + Y_2 + Z_2, E_1\right)$$ Equation 7-51

Where:

E_2 = EGL at Section 2 (ft)

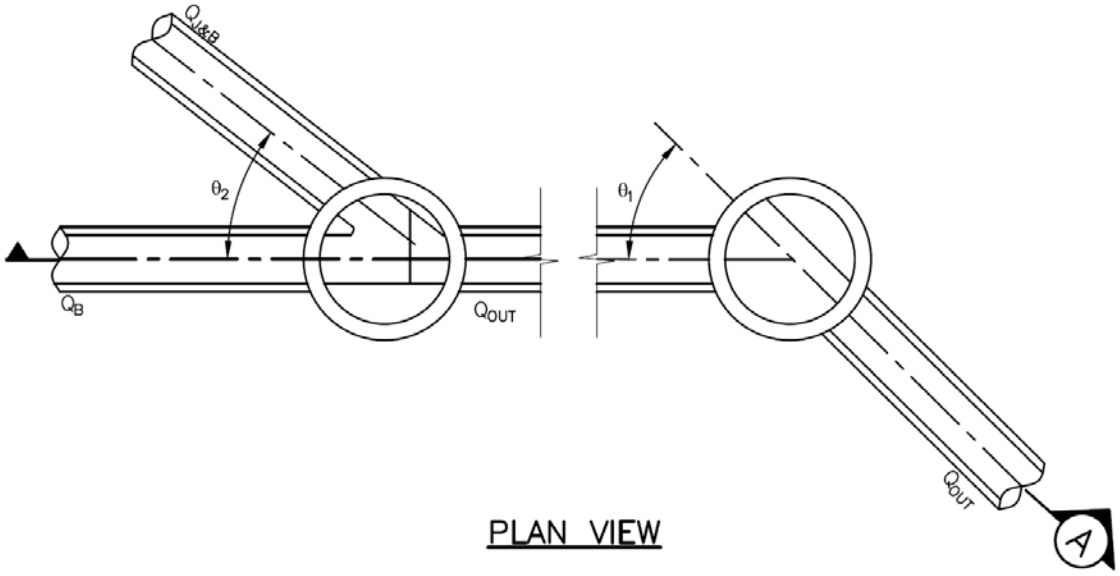
V_2 = pipe exit velocity (ft/s)

Y_2 = flow depth in feet at the pipe exit (ft)

Z_2 = invert elevation in feet at the pipe exit (ft)

E_1 = tailwater at Section 1 (ft)

Equation 7-51 states that the highest EGL value shall be considered as the downstream condition. If the manhole drop dictates the flow condition at Section 2, a discontinuity is introduced into the EGL.



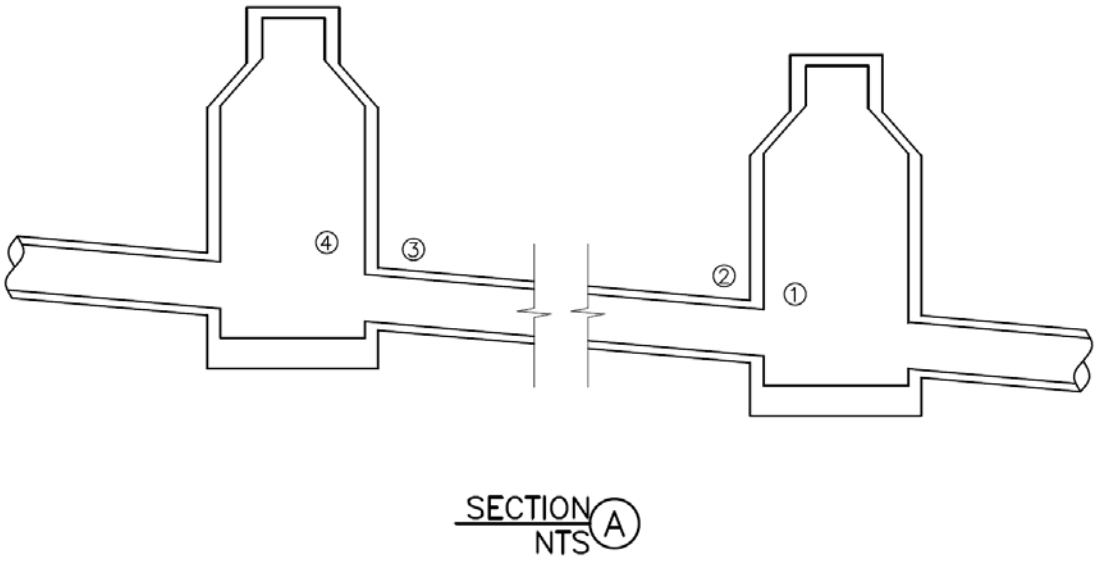


Figure 7-11. A pipe-manhole unit

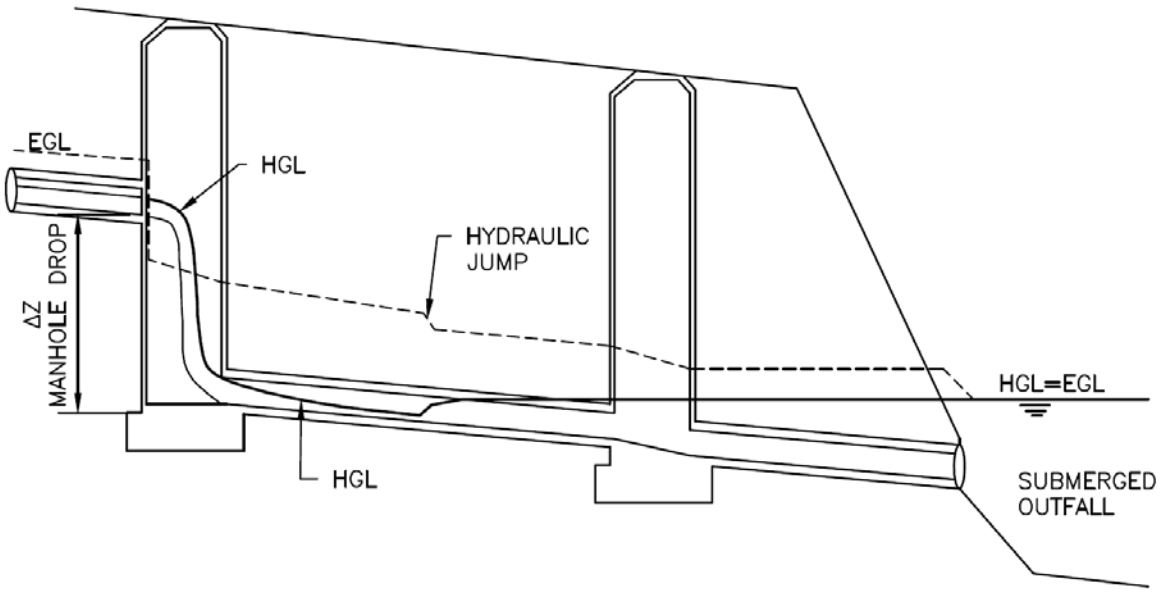


Figure 7-12. Hydraulic and energy grade lines

Losses in the Pipe, Section 2 to Section 3

The continuity of the EGL within the pipe depends on the friction losses through the pipe. The flow in the pipe can be one condition or a combination of open channel flow, full flow, or pressurized (surcharge) flow.

When a free surface exists through the pipe length, open channel hydraulics apply to the backwater surface profile computations. The friction losses through the pipe are the primary head losses for the type of water surface profile in the pipe. For instance, the pipe carrying a subcritical flow may have an M-1 water surface profile if the water depth at the downstream manhole is greater than normal depth in the pipe or an M-2 water surface profile if the water depth in the downstream manhole is lower than normal depth. Under an alternate condition, the pipe carrying a supercritical flow may have an S-2 water surface profile if the pipe entering the downstream manhole is not submerged; otherwise, a hydraulic jump is possible within the pipe.

When the downstream pipe soffit is submerged to a degree that the entire pipe is under the HGL, the head loss for this full flow condition is estimated by pressure flow hydraulics.

When the downstream pipe soffit is slightly submerged, the downstream end of the pipe is surcharged, but the upstream end of the pipe can have open channel flow. The head loss through a surcharge flow depends on the flow regime. For a subcritical flow, the head loss is the sum of the friction losses for the full flow condition and for the open channel flow condition. For a supercritical flow, the head loss may involve a hydraulic jump. To resolve which condition governs, culvert hydraulic principles can be used under both inlet and outlet control conditions and the governing condition is the one that produces the highest HGL at the upstream manhole.

Having identified the type of flow in the pipe, the computation of friction losses begins with the determination of friction slope. The friction loss and energy balance are calculated as:

$$h_f = LS_f \qquad \text{Equation 7-52}$$

$$E_3 = E_2 + \sum h_f \qquad \text{Equation 7-53}$$

Where:

h_f = friction loss (ft)

L = length of pipe (ft)

S_f = friction slope in the pipe (ft/ft)

E_3 = EGL at the upstream end of pipe (ft)

Losses at the Upstream Manhole, Section 3 to Section 4

Additional losses may be introduced at the pipe entrance. The general formula to estimate the entrance loss is:

$$h_E = K_E \frac{V^2}{2g} \qquad \text{Equation 7-54}$$

Where:

h_E = entrance loss (ft)

V = pipe-full velocity in the incoming pipe (ft/s)

K_E = entrance loss coefficient between 0.2 to 0.5

In the modeling of pipe flow, the pipe entrance coefficients can be assumed to be part of the bend loss coefficient.

The energy principle between Sections 3 and 4 is determined by:

$$E_4 = E_3 + h_E \qquad \text{Equation 7-55}$$

Where:

E_4 = EGL at Section 4 (ft)

Junction and Bend Losses at the Upstream Manhole, Section 4 to Section 1
The analysis from Section 4 of the downstream pipe-manhole unit to Section 1 of the upstream pipe-manhole unit consists only of junction losses through the manhole. To maintain the conservation of energy through the manhole, the outgoing energy plus the energy losses at the manhole have to equal the incoming energy. Often a manhole is installed for the purpose of maintenance, deflection of the pipe alignment, change of the pipe size, and as a junction for incoming laterals. Although there are different causes for junction losses, they are typically considered as a minor loss in the computation of the EGL. These junction losses in the pipe system are determined solely by the local configuration and geometry and not by the length of the flow path through the manhole.

Bend/Deflection Losses
The angle between the incoming pipe line and the centerline of the exiting main pipe line introduces a bend loss to the incoming pipe. Bend loss is estimated by:

$$h_b = K_b \frac{V^2}{2g} \qquad \text{Equation 7-56}$$

Where:

h_b = bend loss (ft)
V = full flow velocity in the incoming pipe (ft/s)
K_b = bend loss coefficient.

As shown in Figure 7-15 and Table 7-11, the value of K_b depends on the angle between the exiting pipe line and the existence of manhole bottom shaping. A shaped manhole bottom or a deflector guides the flow and reduces bend loss. Figure 7-16 illustrates four cross-section options for the shaping of a manhole bottom. Only sections "c. Half" and "d. Full" can be considered for the purpose of using the bend loss coefficient for the curve on Figure 7-15 labeled as "Bend at Manhole, Curved or Shaped."

Because a manhole may have multiple incoming pipes, Equation 7-56 should be applied to each incoming pipe based on its incoming angle, and then the energy principle between Sections 4 and 1 can be calculated as:

$$E_1 = E_4 + h_b \qquad \text{Equation 7-57}$$

Lateral Junction Losses

In addition to the bend loss, the lateral junction loss is also introduced because of the added turbulence and eddies from the lateral incoming flows. The lateral junction loss is estimated as:

$$h_j = \frac{V_o^2}{2g} - K_j \frac{V_i^2}{2g} \qquad \text{Equation 7-58}$$

Where:

h_j = lateral loss (ft)

V_o = full flow velocity in the outgoing pipe (ft/s)

K_j = lateral loss coefficient

V_i = full flow velocity in the incoming pipe (ft/s)

In modeling, a manhole can have multiple incoming pipes, one of which is the main (i.e., trunk) line, and one outgoing pipe. As shown in Table 7-11, the value of K_j is determined by the angle between the lateral incoming pipe line and the outgoing pipe line.

Table 7-11. Bend loss and lateral loss coefficients (FHWA 2009)

Angle in Degree	Bend Loss Coefficient for Curved Deflector in the Manhole	Bend Loss Coefficient for Non-shaping Manhole	Lateral Loss Coefficient on Main Line Pipe
Straight Through	0.05	0.05	Not Applicable
22.50	0.10	0.13	0.75
45.00	0.28	0.38	0.50
60.00	0.48	0.63	0.35
90.00	1.01	1.32	0.25

At a manhole, the engineer needs to identify the main incoming pipe line (the one that has the largest inflow rate) and determine the value of K_j for each lateral incoming pipe. To be conservative, the smallest K_j is recommended for Equation 7-58, and the lateral loss is to be added to the outfall of the incoming main line pipe as:

$$E_1 = E_4 + h_b + h_j \quad (h_j \text{ is applied to main pipe line only}) \qquad \text{Equation 7-59}$$

The difference between the EGL and the HGL is the flow velocity head. The HGL at a manhole is calculated by:

$$H_1 = E_1 - \frac{V_o^{\,2}}{2g} \qquad \text{Equation 7-60}$$

The energy loss between two manholes is defined as:

$$\Delta E = (E_1)_{upstream} - (E_1)_{downstream} \qquad \text{Equation 7-61}$$

where ΔE = energy loss between two manholes. ΔE includes the friction loss, junction loss, bend loss, and manhole drop.

Transitions

In addition to pipe-manhole unit losses, head losses in a storm pipe can occur due to a transition in the pipe itself, namely, gradual pipe expansion. Transition loss, h_{LE}, in feet, can be determined using:

$$h_{LE} = K_e\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) \qquad \text{Equation 7-62}$$

where K_e is the expansion coefficient and subscripts 1 and 2 refer to upstream and downstream of the transition, respectively. The value of the expansion coefficient, K_e, may be taken from Table 7-12 for free surface flow conditions in which the angle of cone refers to the angle between the sides of the tapering section (see Figure 7-17).

Table 7-12. Head loss expansion coefficients in non-pressure flow (FHWA 2009)

	Angle of Cone						
D_2/D_1	10°	20°	30°	40°	50°	60°	70°
1.5	0.17	0.40	1.06	1.21	1.14	1.07	1.00
3	0.17	0.40	.86	1.02	1.06	1.04	1.00

Head losses due to gradual pipe contraction, h_{LC}, in feet, are determined using:

$$h_{LC} = K_c\left(\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right) \qquad \text{Equation 7-63}$$

where K_c = contraction coefficient. Typically, K_c = 0.5 provides reasonable results.

The USDCM does not recommend pipe contractions for storm pipes.

Curved Pipes

Head losses due to curved pipes (sometimes called radius pipe), h_{Lr}, in feet, can be determined using:

$$h_{Lr} = K_r\frac{V^2}{2g} \qquad \text{Equation 7-64}$$

where K_r = curved pipe coefficient from Figure 7-15.

Losses at Storm Drain Exit

Head losses at storm drain outlets, h_{LO}, are determined using:

$$h_{LO} = \frac{V_o^2}{2g} - \frac{V_d^2}{2g} \qquad \text{Equation 7-65}$$

where V_o is the velocity in the outlet pipe (ft/s), and V_d is the velocity in the downstream channel (ft/s). When the storm drain discharges into a reservoir or as a free jet (no downstream tailwater), V_d = 0 and one full velocity head is lost at the exit.

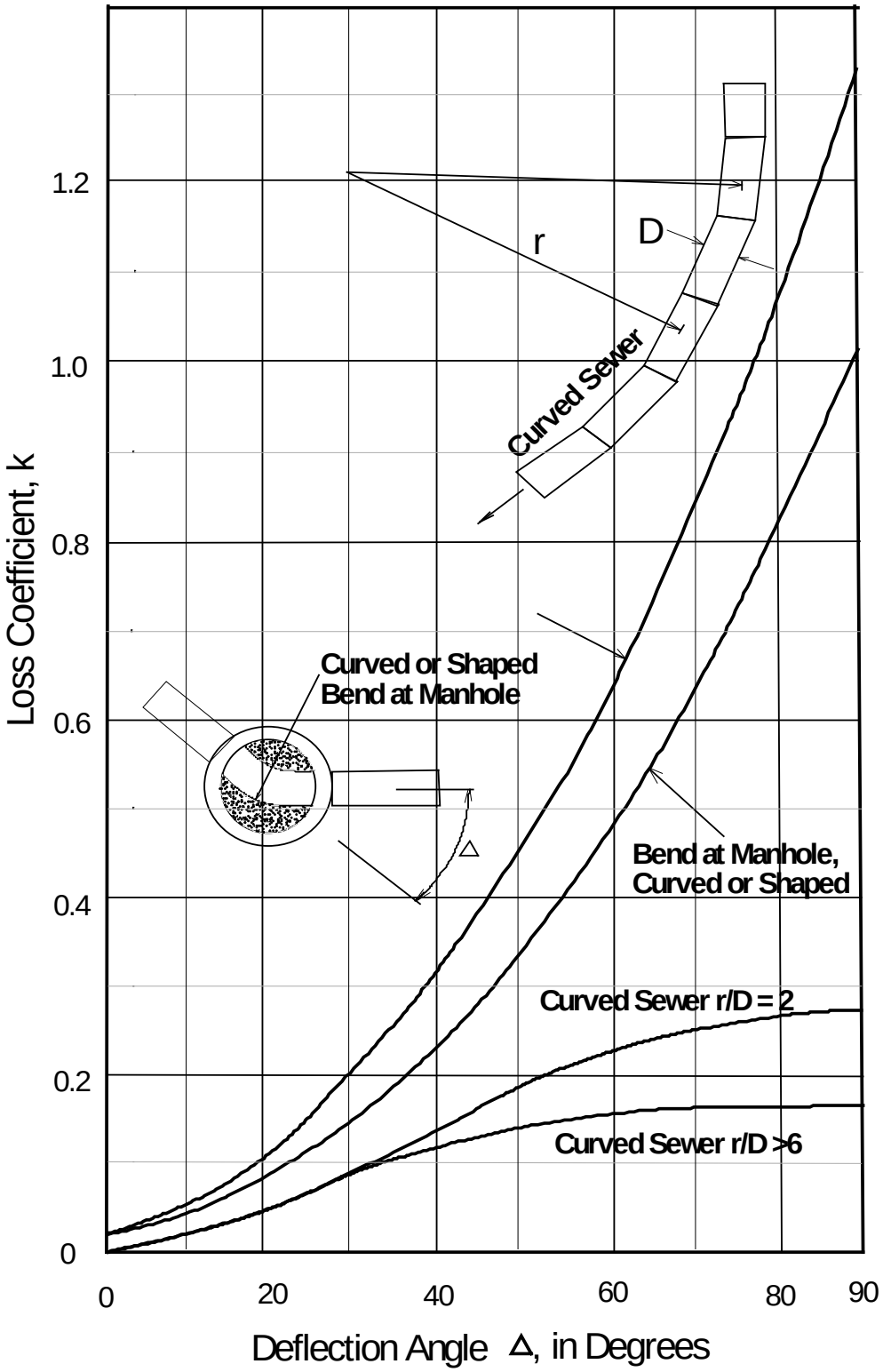


Figure 7-13. Bend loss coefficients

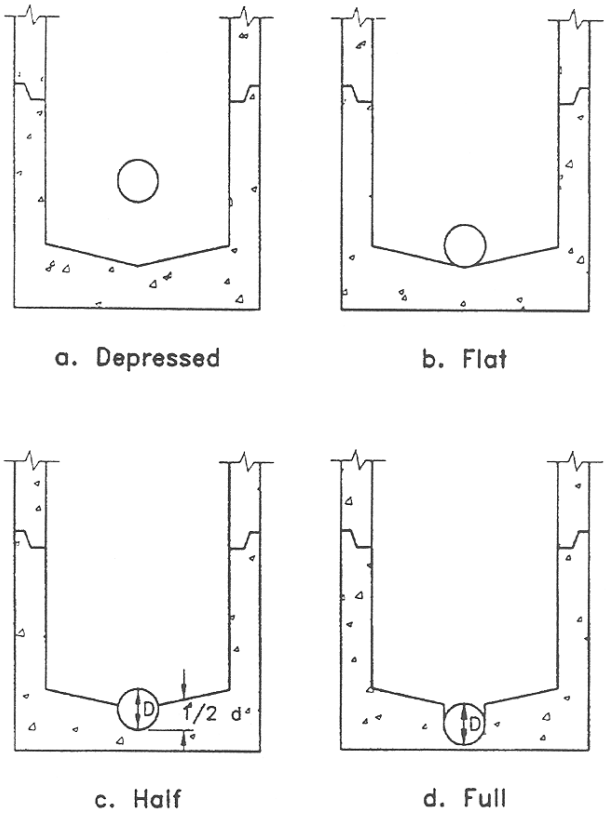


Figure 7-14. Manhole benching methods

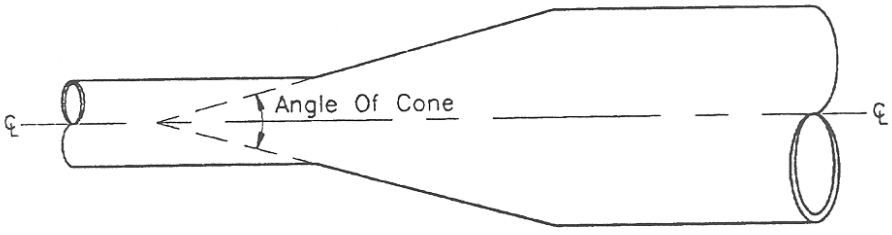


Figure 7-15. Angle of cone for pipe diameter changes

5.0 UD-Inlet Design Workbook

The UD-Inlet design workbook provides quick solutions for many of the street capacity and inlet performance computations described in this chapter. A brief summary of each worksheet of the workbook is provided below. Note that some of the symbols and nomenclature in the worksheets do not correspond exactly with the nomenclature of the text. The text and the worksheets are computationally equivalent. An example problem using UD-Inlet is provided in section 6.0 of this chapter.

- The *Q-Peak* tab calculates the peak discharge for the inlet tributary area based on the rational method for the minor and major storm events. Alternatively, the user can enter a known flow. Information from this tab is exported to the *Inlet Management* tab.
- The *Inlet Management* tab imports information from the *Q-Peak* tab and *Inlet [#]* tabs and can be used to connect inlets in series so that bypass flow from an upstream inlet is added to flow calculated for the next downstream inlet. This tab can also be used to modify design information imported from the *Q-Peak* tab.
- *Inlet [#]* tabs are created each time the user exports information from the *Q-Peak* tab to the *Inlet Management* tab. The *Inlet [#]* tabs calculate allowable half-street capacity based on allowable depth and allowable spread for the minor and major storm events. This is also where the user selects an inlet type and calculates the capacity of that inlet.
- The *Inlet Pictures* tab contains a library of photographs of the various types of inlets contained in the worksheet and referenced in this chapter.

6.0 Examples

6.1 Example—Triangular Gutter Capacity

A triangular gutter has a longitudinal slope of 1%, cross slope of 2%, and a curb depth of 6 inches. Determine the flow rate and flow depth if the spread is limited to 9 feet.

Using Equation 7-1 the flow rate is calculated as:

$$Q = \frac{0.56}{n} S_x^{5/3} S_o^{1/2} T^{8/3}$$

$$Q = \frac{0.56}{0.016}\left(0.02^{5/3}\right)\left(0.01^{1/2}\right)\left(9^{8/3}\right) = 1.81 \text{ cfs}$$

The flow depth can be found using Equation 7-2:

$$y = (9.0)(0.02) = 0.18 \text{ ft}$$

Note that the computed flow depth is less than the curb height of 6 inches (0.5 feet). If it was not, the spread and associated flow rate would need to be reduced.

6.2 Example—Composite Gutter Capacity

Determine the discharge in a composite gutter section if the allowable spread is 9 feet, the gutter width is 2 feet, and the vertical depth between gutter lip and gutter is 2.0 inches. The street's longitudinal slope is 1%, the cross slope is 2%, and the curb height is 6 inches.

First determine the gutter cross slope, S_w, using Equation 7-8:

$$S_w = S_x + \frac{a}{W}$$

$$S_w = 0.02 + \frac{\frac{2}{12} - 2(0.02)}{2} = 0.083 \text{ feet}$$

The flow in the street is found using Equation 7-1:

$$Q_x = \frac{0.56}{n} S_x^{5/3} S_o^{1/2} T^{8/3}$$

$$Q_x = \frac{0.56}{0.016} 0.02^{5/3} 0.01^{1/2} 7^{8/3} = 0.92 \text{ cfs}$$

From Equation 7-7 the ratio of gutter flow to total flow (Q_w/Q) is represented by E_o.

$$E_O = \frac{1}{1 + \frac{S_w / S_x}{\left[1 + \frac{S_w / S_x}{(T/W) - 1}\right]^{8/3} - 1}}$$

$$E_O = \frac{1}{1 + \frac{0.083/0.02}{\left[1 + \frac{0.083/0.02}{(9/2) - 1}\right]^{8/3} - 1}} = 0.63$$

Now the theoretical flow rate can be found using Equation 7-6:

$$Q = \frac{Q_x}{1 - E_o}$$

$$Q = \frac{0.92}{1 - 0.63} = 2.49 \text{ cfs}$$

Then by using Equation 7-9 the computed flow depth is:

$$y = a + TS_x$$

$$y = [0.1667 - 2(0.02)] + 9(0.02) = 0.31 \text{ feet}$$

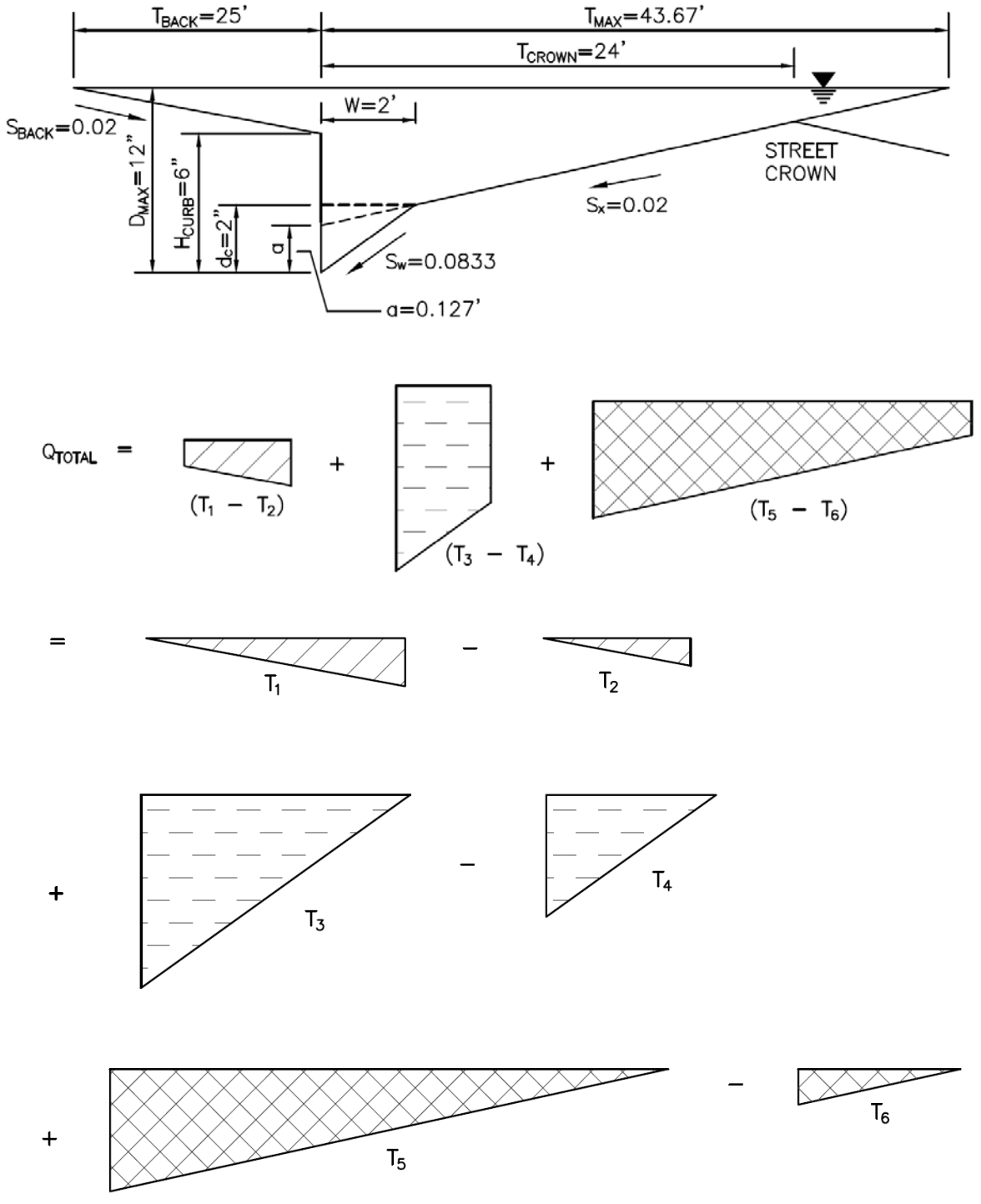
Note that the computed flow depth is less than the curb height of 6 inches.

6.3 Example—Composite Gutter Capacity – Major Storm Event

Determine the local street capacity of a composite gutter street section if the allowable depth is 12 inches. Assume there is ponding on the crown of the road and the encroachment has extended onto the 10-foot wide sidewalk behind the curb (sloping toward the curb at 2%). The street's longitudinal slope is 1% and the cross slope is 2%. The gutter width is 2 feet, the vertical distance between the gutter lip and flowline is 2 inches, and the height of the curb is 6 inches. The distance from the gutter flowline to the street crown is 24 feet. Use a Manning's coefficient (n) of 0.013 for concrete and 0.016 for asphalt. It should be noted that at a 12-inch depth, the sidewalk behind the curb would not contain the flow. This example assumes that flow is contained by a vertical wall at the back of the walk. From a standpoint of public safety, it is of great importance to ensure that flow is contained within the right-of-way for the full length of the project. For this reason, the allowable depth of flow is typically determined by the physical constraints behind the curb rather than maximum depth criteria.

The total flow can be found by dividing the cross section into six right triangles as shown below and calculating the flow through each section using Equation 7-1.

$$Q = \frac{0.56}{n} S_x^{5/3} S_o^{1/2} T^{8/3}$$



After flow in each of the 6 triangles has been determined, add and subtract the flow in each area as shown in the above figure.

$$Q = Q_{T1} - Q_{T2} + Q_{T3} - Q_{T4} + Q_{T5} - Q_{T6}$$

$$Q_{T1} = \frac{0.56}{0.013}\left(0.02^{5/3}\right)\left(0.01^{1/2}\right)\left(25^{8/3}\right) = 33.9 \text{ cfs}$$

$$Q_{T2} = \frac{0.56}{0.013}\left(0.02^{5/3}\right)\left(0.01^{1/2}\right)\left(15^{8/3}\right) = 8.86 \text{ cfs}$$

$$Q_{T3} = \frac{0.56}{0.013}\left(0.0833^{5/3}\right)\left(0.01^{1/2}\right)\left(12^{8/3}\right) = 51.7 \text{ cfs}$$

$$Q_{T4} = \frac{0.56}{0.013}\left(0.0833^{5/3}\right)\left(0.01^{1/2}\right)\left(10^{8/3}\right) = 31.8 \text{ cfs}$$

(Solve for T using equation 7-9)

$$Q_{T5} = \frac{0.56}{0.016}\left(0.02^{5/3}\right)\left(0.01^{1/2}\right)\left(41.7^{8/3}\right) = 107.8 \text{ cfs}$$

$$Q_{T6} = \frac{0.56}{0.016}\left(0.02^{5/3}\right)\left(0.01^{1/2}\right)\left(19.7^{8/3}\right) = 14.6 \text{ cfs}$$

Therefore by combining the above calculations the total flow can be calculated as:

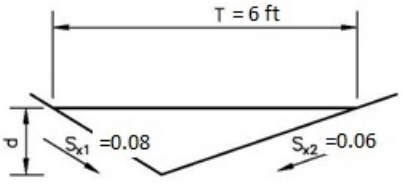
$$Q = Q_{T1} - Q_{T2} + Q_{T3} - Q_{T4} + Q_{T5} - Q_{T6} = 138 \text{ cfs}$$

Note: UD-Inlet.xls uses HEC-22 methodology to solve this problem and will provide a slightly different answer.

6.4 Example—V-Shaped Swale Capacity

Determine the maximum discharge and depth of flow in a V-shaped, roadside grass swale with side slopes of 8% and 6%, a longitudinal slope of 2% and a total width of 6 feet.

The adjusted slope, Sx, is determined using Equation 7-13:



$$S_x = \frac{S_{x1}S_{x2}}{S_{x1} + S_{x2}}$$

$$S_x = \frac{(0.08)(0.06)}{0.08 + 0.06} = 0.034$$

From Equation 7-1, the flow through the swale is computed:

$$Q = \frac{0.56}{n} S_x^{5/3} S_o^{1/2} T^{8/3}$$

$$Q = \frac{0.56}{0.03} 0.034^{5/3} 0.02^{1/2} 6^{8/3} = 1.12 \text{ cfs}$$

Using Equation 7-2 the flow depth is calculated as:

$$y = TS_x$$

$$y = 6(0.034) = 0.2 \text{ feet}$$

6.5 Example—V-Shaped Swale Design

Design a V-shaped swale to convey a flow of 1.8 cfs. The available swale top width is 8 feet, the longitudinal slope is 1%, and the Manning's roughness factor is 0.16. Determine the cross slopes and the depth of the swale.

Solving Equation 7-1 for S_x (i.e., average side slope) yields:

$$S_x = \left[\frac{Qn}{0.56 S_o^{1/2} T^{8/3}} \right]^{3/5}$$

$$S_x = \left[\frac{(1.8)0.016}{0.56(0.01)^{1/2} 8^{8/3}} \right]^{3/5} = 0.024 \text{ ft/ft}$$

Now Equation 7-13 is used to solve for the actual cross slope assuming $S_{x1} = S_{x2}$, Equation 7-13 can be rewritten and solved for Sx1 :

$$S = 2S_x = 2(0.024) = 0.048 \text{ ft/ft}$$

Then using Equation 7-2 yields a flow depth, y, of:

$$y = TS_x = (0.024)(8) = 0.19 \text{ feet}$$

The swale is 8-feet wide with right and left side slopes of 0.048 ft/ft and a flow depth of 0.19 feet.

6.6 Example—Grate Inlet Capacity

Determine the efficiency of a CDOT Type C Standard Grate (W = 2 feet and L = 2 feet) when placed in a composite gutter section with a 2-foot concrete gutter that has a 2-inch drop between the gutter lip and gutter flowline. The street cross slope is 2% and the longitudinal slope of 1%. The flow in the gutter is 2.5 cfs with a spread of 8.5 feet.

Using Equation 7-7, determine the ratio of gutter flow to total flow (Q_w/Q) (represented by E_o):

$$E_O = \frac{1}{1 + \frac{S_w / S_x}{\left[1 + \frac{S_w / S_x}{(T/W) - 1}\right]^{8/3} - 1}}$$

$$E_O = \frac{1}{1 + \frac{0.083/0.02}{\left[1 + \frac{0.083/0.02}{(8.5/2) - 1}\right]^{8/3} - 1}} = 0.66$$

Solve Equation 7-6 for Q_x to determine the flow in the section outside of the depressed gutter:

$$Q_x = Q(1 - E_o) = 2.5(1\text{-}0.66) = 0.85 \text{ cfs}$$

The flow in the dressed gutter section is determined by subtracting this value from the total flow:

$$Q_w = 2.5 - 0.85 = 1.65 \text{ cfs}$$

Next, find the flow area using Equation 7-10 and velocity using the continuity equation V = Q/A.

$$A = \frac{S_x T^2 + aW}{2}$$

$$A = \frac{0.02(8.5^2) + 0.127(2)}{2} = 0.85 \text{ ft}^2$$

$$V = \frac{Q}{A} = \frac{2.5}{0.85} = 2.94 \text{ fps}$$

The splash-over velocity is determined from Equation 7-20:

$$V_o = \alpha + \beta L_e - \gamma L_e^2 + \eta L_e^3$$

Where:

V_o = splash-over velocity (ft/sec)

L_e = effective length of grate inlet (ft)

α, β, γ, η = constants from Table 7-6

$$V_o = 2.22 + 4.03(2) - 0.65(2^2) + 0.06(2^3) = 8.16 \text{ fps}$$

From Equation 7-19, the ratio of the frontal flow intercepted by the inlet to total frontal flow, R_f, is determined by:

$$R_f = \frac{Q_{wi}}{Q_w} = 1.0 - 0.09(V - V_o) \text{ for } V \geq V_o \text{, otherwise } R_f = 1.0$$

$V \geq V_o$ in this example, therefore $R_f = 1.0$

Using Equation 7-21, the side-flow capture efficiency is calculated as:

$$R_x = \frac{1}{1 + \frac{0.15V^{1.8}}{S_x L^{2.3}}}$$

$$R_x = \frac{1}{1 + \frac{0.15(2.94)^{1.8}}{(0.02)(2)^{2.3}}} = 0.086$$

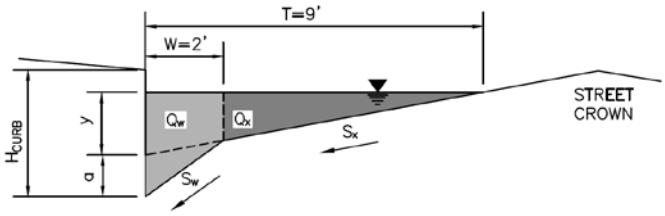
Finally, the overall capture efficiency, E, is calculated using Equation 7-22:

$$E = R_f (Q_w / Q) + R_x (Q_x / Q)$$

$$E = 1(1.64/2.5) + 0.086(0.86/2.5) = 0.69 \text{ (69\%)}$$

6.7 Example—Curb-Opening Inlet Capacity

Determine the amount of flow that will be captured by a 6-foot-long curb-opening inlet placed in the composite gutter described in Example Problem 6.2.



Equations 7-25 and 7-26 are used to determine the equivalent slope and the length of inlet required to capture 100% of the gutter flow.

First Equation 7-26 is used to calculate the equivalent cross slope, S_e.

$$S_e = S_x + \frac{(a + a_{local})}{W} E_o$$

$$S_e = 0.02 + \frac{(0.127 + 0)}{2}(0.63) = 0.060$$

The inlet length required to capture 100% of the gutter flow, LT, is found using Equation 7-25.

$$L_T = 0.38 Q^{0.51} S_L^{0.058} \left(\frac{1}{n S_e} \right)^{0.46}$$

$$L_T = 0.38(2.49)^{0.51}(0.01)^{0.058} \left(\frac{1}{0.016(0.06)} \right)^{0.46} = 11.32 \text{ feet}$$

Then, by Equation 7-23 the efficiency, E, of the curb inlet can be calculated.

$$E = 1 - \left[1 - \left(\frac{L}{L_T} \right) \right]^{1.8} \quad \text{for } L < L_T$$

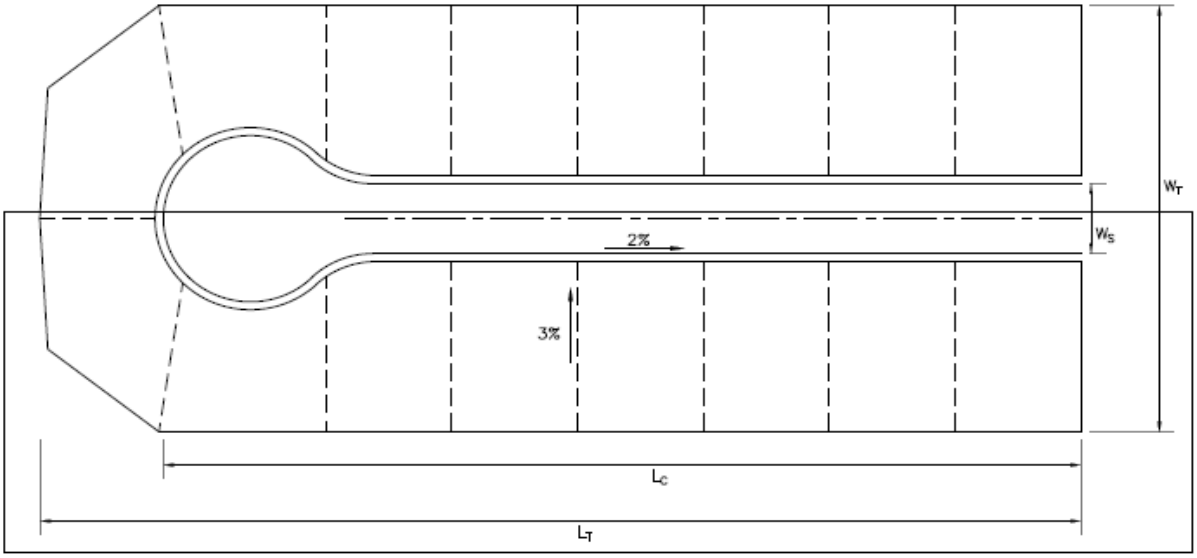
$$E = 1 - \left[1 - \left(\frac{6}{11.32} \right) \right]^{1.8} = 0.74 \ (74\%)$$

The flow intercepted by the curb-opening inlet is calculated as follows:

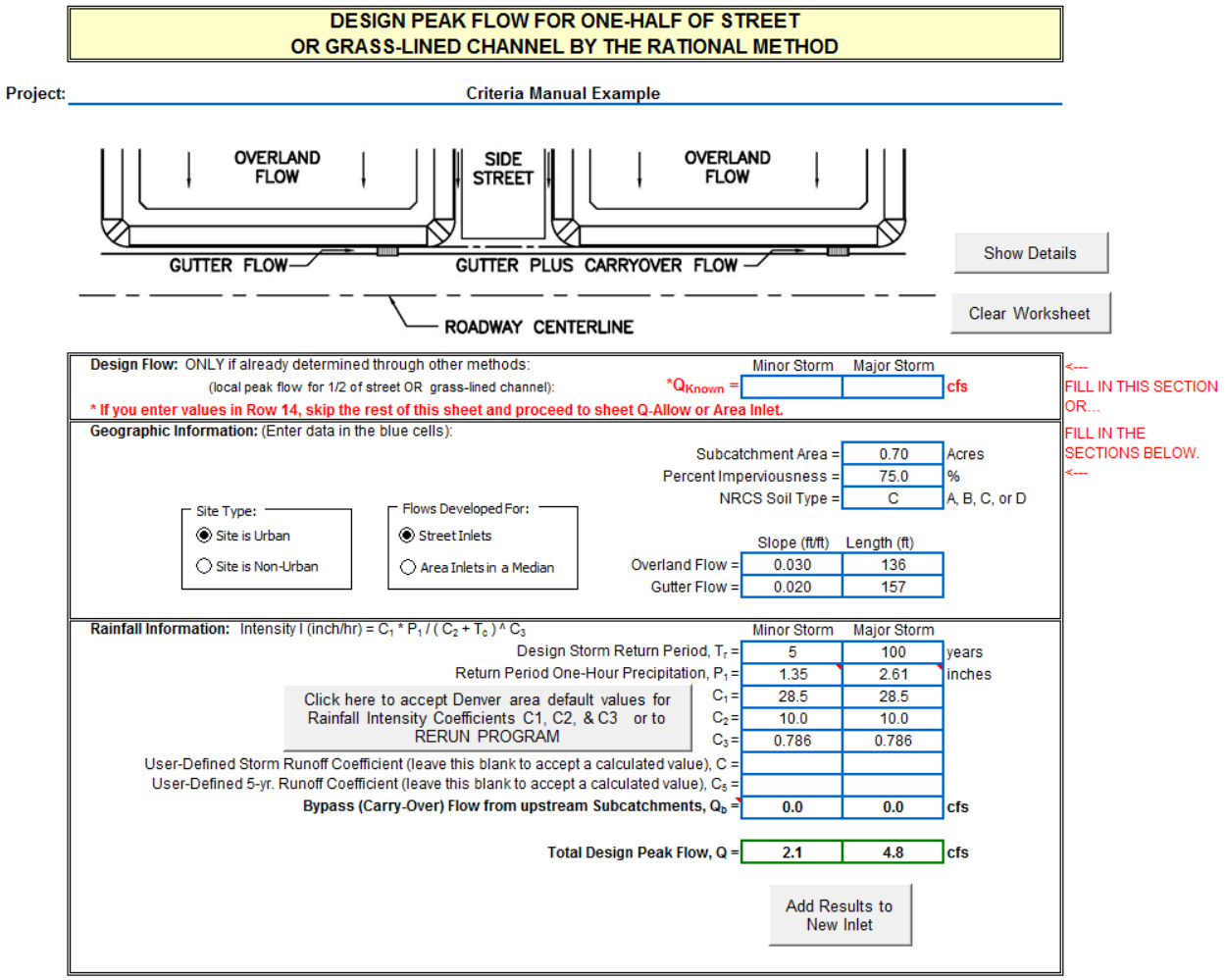
$$Q_i = EQ = (0.74)(2.49) = 1.84 \text{ cfs}$$

6.8 Example—Design of a Network of Inlets Using UD-Inlet

Determine the number of CDOT Type R curb inlets needed to maintain allowable street flow for the 5-yr and 100-year storm events for each side of the street as shown in the below figure. The area can be described as a 4.8-acre residential development in Denver with L_T = 711 ft, channel length L_C = 637 ft, W_T = 310 ft. and W_S = 30 ft. Each lot is 0.25 acres. The development has imperviousness I=75% and type C soil. The channel slope is 2% and the overland slope is 3%. All flows must be contained within the street and gutter section (i.e., no flow behind the curb). Additionally, the flow spread for the minor storm shall not exceed 9 ft.



The tributary area to be used is half of the total development (A = 2.4 acre). Based on the dimensions of the lot sizes, the overland flow length is 136 ft. Use the Q-Peak tab of the UD-Inlet workbook to calculate the 5-year and 100-year peak flow for the upper portion of the tributary area. This requires approximation of the location of the most upstream inlet and calculation of the area tributary to this inlet. The following screenshot shows the Q-Peak input and output for the upper 0.7 acres of the tributary area. Based on the geometry of the development, this corresponds to a channel flow length of 157 feet.



The *Q-Peak* inlet calculates the 5-year and 100-year peak flow based on the estimated sub-catchment area to the first inlet, percent imperviousness, soil type, appropriate time of concentration calculations, as well as location-specific rainfall information and runoff coefficients. For this problem, the 5-year flow is 2.1 cfs and the 100-year flow is 4.8 cfs. Alternatively, the user could enter known flows in this tab. Once the flows have been calculated, press the "Add Results to New Inlet" button. This adds a new inlet to the *Inlet Management* tab and opens a new tab for calculation of both the flow spread and depth in the street and the design of the receiving inlet.

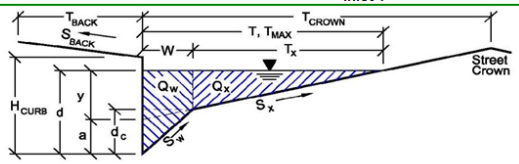
On the inlet tab, enter the geometry of half of the street section. Use the requirements stated in the problem statement for the allowable spread and depth of flow. This section indicates the maximum street flow for the minor and major storm events based on allowable spread and depth criteria. If the allowable street flow is less than the flow calculated on the *Q-Peak* tab, reduce the area and associated channel length on the *Q-Peak* tab. For this example, neither flow depth nor flow spread exceed criteria. See the screenshot below.

ALLOWABLE CAPACITY FOR ONE-HALF OF STREET (Minor & Major Storm)

(Based on Regulated Criteria for Maximum Allowable Flow Depth and Spread)

Project: Enter Your Project Name Here

Inlet ID: Inlet 1



Show Details

Clear Worksheet

Gutter Geometry (Enter data in the blue cells)			
Maximum Allowable Width for Spread Behind Curb	T_{BACK} =	4.0	ft
Side Slope Behind Curb (leave blank for no conveyance credit behind curb)	S_{BACK} =	0.020	ft/ft
Manning's Roughness Behind Curb (typically between 0.012 and 0.020)	n_{BACK} =	0.012	
Height of Curb at Gutter Flow Line	H_{CURB} =	6.00	inches
Distance from Curb Face to Street Crown	T_{CROWN} =	15.0	ft
Gutter Width	W =	2.00	ft
Street Transverse Slope	S_X =	0.020	ft/ft
Gutter Cross Slope (typically 2 inches over 24 inches or 0.083 ft/ft)	S_W =	0.083	ft/ft
Street Longitudinal Slope - Enter 0 for sump condition	S_O =	0.020	ft/ft
Manning's Roughness for Street Section (typically between 0.012 and 0.020)	n_{STREET} =	0.016	

		Minor Storm	Major Storm	
Max. Allowable Spread for Minor & Major Storm	T_{MAX} =	9.0	15.0	ft
Max. Allowable Depth at Gutter Flowline for Minor & Major Storm	d_{MAX} =	6.0	6.0	inches
Allow Flow Depth at Street Crown (leave blank for no)		☐	☐	check = yes

Optional: Set d-MAX to Limit V*d Product

		Minor Storm	Major Storm	
MINOR STORM Allowable Capacity is based on Spread Criterion				
MAJOR STORM Allowable Capacity is based on Spread Criterion	Q_{allow} =	3.5	11.3	cfs

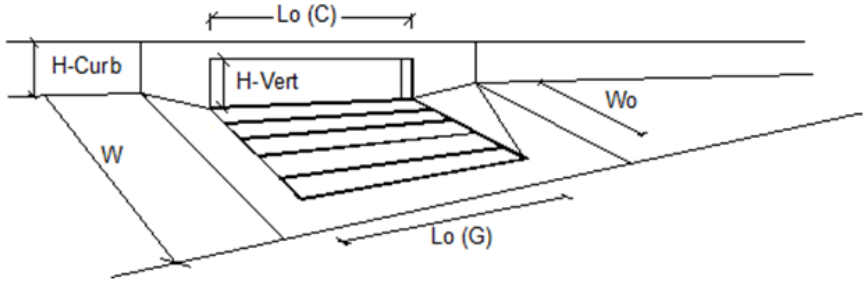
Minor storm max. allowable capacity GOOD - greater than the design flow given on sheet 'Inlet Management'

Major storm max. allowable capacity GOOD - greater than the design flow given on sheet 'Inlet Management'

Bypass UDFCD Safety Factor

The screenshot below shows the inlet design specifications. Notice that there is bypass flow for both storms. These flows will be accounted for at the next (downstream) inlet. The length of the inlet or number of units can be increased to reduce bypass flow.

INLET ON A CONTINUOUS GRADE



Show Details

Reset Defaults

Clear Worksheet

Design Information (Input)		MINOR	MAJOR	
Type of Inlet	Type =	CDOT Type R Curb Opening		
Local Depression (additional to continuous gutter depression 'a')	a_{LOCAL} =	3.0	3.0	inches
Total Number of Units in the Inlet (Grate or Curb Opening)	No =	1	1	
Length of a Single Unit Inlet (Grate or Curb Opening)	L_o =	5.00	5.00	ft
Width of a Unit Grate (cannot be greater than W, Gutter Width)	W_o =	N/A	N/A	ft
Clogging Factor for a Single Unit Grate (typical min. value = 0.5)	C_f-G =	N/A	N/A	
Clogging Factor for a Single Unit Curb Opening (typical min. value = 0.1)	C_f-C =	0.10	0.10	

Street Hydraulics: OK - Q < maximum allowable from sheet 'Q-Allow'		MINOR	MAJOR	
Total Inlet Interception Capacity	**Q =**	**1.79**	**2.79**	**cfs**
Total Inlet Carry-Over Flow (flow bypassing inlet)	**Q_b =**	**0.3**	**2.0**	**cfs**
Capture Percentage = Q_a/Q_o =	**C% =**	**86**	**58**	**%**

To add the next downstream inlet (Inlet 2), return to the *Q-Peak* tab and enter the same information for the next (downstream) tributary area as was required for Inlet 1. This information is automatically moved to the *Inlet management* tab when a new inlet is added. Prior to designing this inlet, ensure that bypass flows are added on the *Inlet management* tab. To do this, use the drop-down menu in the "Receive Bypass Flow from" row and select Inlet 1. The *Inlet Management* tab can also be used to adjust the subcatchment area and corresponding channel length to make adjustments as needed during design while maintaining a network of inlets that update when these changes are made. Changes made on the individual inlet tabs will also update on the *Inlet Management* tab. A screenshot of the *Inlet Management* tab is shown below.

Inlet Management

Worksheet Protected

	Delete	Delete	Delete
INLET NAME	Inlet 1	Inlet 2	Inlet 3
Inlet Application (Street or Area)	STREET	STREET	STREET
Hydraulic Condition	On Grade	On Grade	On Grade
Inlet Type	CDOT Type R Curb Opening	CDOT Type R Curb Opening	CDOT Type R Curb Opening

USER-DEFINED INPUT Show Input Details

Receive Bypass Flow from:		Inlet 1	Inlet 2
Minor Q_{Known} (cfs)			
Major Q_{Known} (cfs)			
Minor Bypass Flow, Q_b (cfs)	0.0	0.3	0.5
Major Bypass Flow, Q_b (cfs)	0.0	2.0	4.2
Watershed Characteristics			
Subcatchment Area (acres)	0.7	0.85	0.85
Percent Impervious	75	75	75
NRCS Soil Type	C	C	C
Watershed Profile			
Overland Slope (ft/ft)	0.03	0.03	0.03
Overland Length (ft)	136	136	136
Channel Slope (ft/ft)	0.02	0.02	0.02
Channel Length (ft)	157	240	240
Minor Storm Rainfall Input			
Design Storm Return Period, T_r (years)	5	5	5
One-Hour Precipitation, P_1 (inches)	1.35	1.35	1.35
Major Storm Rainfall Input			
Design Storm Return Period, T_r (years)	100	100	100
One-Hour Precipitation, P_1 (inches)	2.61	2.61	2.61

CALCULATED OUTPUT Show Output Details

Minor Total Design Peak Flow, Q	**2.1**	**2.8**	**2.9**
Major Total Design Peak Flow, Q	**4.8**	**7.7**	**9.9**

The screenshot above shows that the selected tributary area of this development will require 3 CDOT Type R Curb inlets. This will ensure that the majority of the flows don't exceed the allowable depth or spread stated in the problem. The 4.8-acre development will require a total of six inlets, three on each side of the street.

7.0 References

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Chapter 8
Open Channels

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1.0 Introduction

This chapter focuses on the preservation, enhancement, and restoration of stream corridors as well as the design of constructed channels and swales using natural concepts. Guidance is provided for the hydraulic evaluation of open channels and the design of measures to improve the stability and health of stream systems. These measures include maintaining or establishing an effective planimetric channel form, cross sectional shape, and longitudinal slope; implementing grade control and bank protection; and establishing and maintaining a favorable mix of riparian vegetation. See the *Hydraulic Structures* chapter for various types of structures with an open channels and the *Stream Access and Recreational Channels* chapter for criteria related to the design of shared use paths adjacent to streams and criteria for responsible design of recreational channels including boatable channels. This chapter is organized as follows:

Section 2.0 – Natural Stream Corridors. This section highlights the many functions and benefits of natural stream corridors then describes some of the threats to these natural systems that can be imposed by urbanization. Historically, urban impacts have included realigning or straightening streams, narrowing the width of natural floodplains, and even replacing surface streams with underground conduits. Increases in runoff as a result of urbanization have contributed to degradation, aggregation, loss of vegetation and habitat, and impaired water quality. This section introduces the concept of preserving natural stream corridors and implementing techniques to restore stream functions. See the *Planning* chapter for techniques for implementing preservation.

Section 3.0 – Preserving Natural Stream Corridors. This section recommends several key actions that are necessary at the outset of development to preserve natural stream corridors. Preservation includes providing ample room for the floodplain, reducing increases in urban runoff, and addressing problems proactively. These actions can reduce impacts and provide for future stream management at a lower cost and smaller footprint compared to constrained floodplains where elevated discharges must be conveyed in narrow corridors.

Section 4.0 –Stream Restoration Principles. Eight principles of stream restoration are discussed to provide design guidance for developers, engineers, ecologists, and others involved in the protection of stream resources. The principles are valid for a variety of stream conditions, whether the corridor has been preserved as described in Section 3.0 or constrained and impacted through urbanization. Special design considerations are recommended for constrained urban stream reaches where velocities and shear stress imposed by elevated peak discharges are greater and infrastructure tends to be in close proximity to the stream.

Section 5.0 – Naturalized Channels. Sometimes streams need to be created where adequate channel conveyances do not exist. This section applies the principles of Section 4.0 to the design of naturalized channels. When designed with natural features, these channels can become established in a form that may be indistinguishable from natural streams.

Section 6.0 – Swales. As an alternative to storm drains, it is often desirable to create small surface channels, or swales, to convey runoff from small drainage areas. This section provides guidance for the design of grass and rock (soil riprap or void-filled riprap) swales.

Section 7.0 – Hydraulic Analysis. This section provides guidance on the hydraulic analysis of natural and constructed stream systems, emphasizing the use of HEC-RAS for hydraulic modeling.

Section 8.0 – Rock and Boulders. The use of soil riprap, void-filled riprap, and boulders in stream restoration and constructed channels is addressed in this section.

2.0 Natural Stream Corridors

Natural stream corridors, as illustrated in Figure 8-1, often contain a primarily non-vegetated bankfull channel that may flow continuously or ephemerally within adjacent vegetated floodplain terraces (also called benches or overbanks) and higher outer banks. An appropriately sized single-thread channel with floodplain terraces creates favorable conditions at baseflows, producing greater depth, lower temperatures, and better aquatic habitat. The spilling of flows out of the bankfull channel onto wider floodplain terraces provides important interaction between water, soil, and vegetation. As floodwaters spread out onto the floodplain terraces, energy is dissipated, riparian vegetation receives water, and sediment can be conveyed through the system.

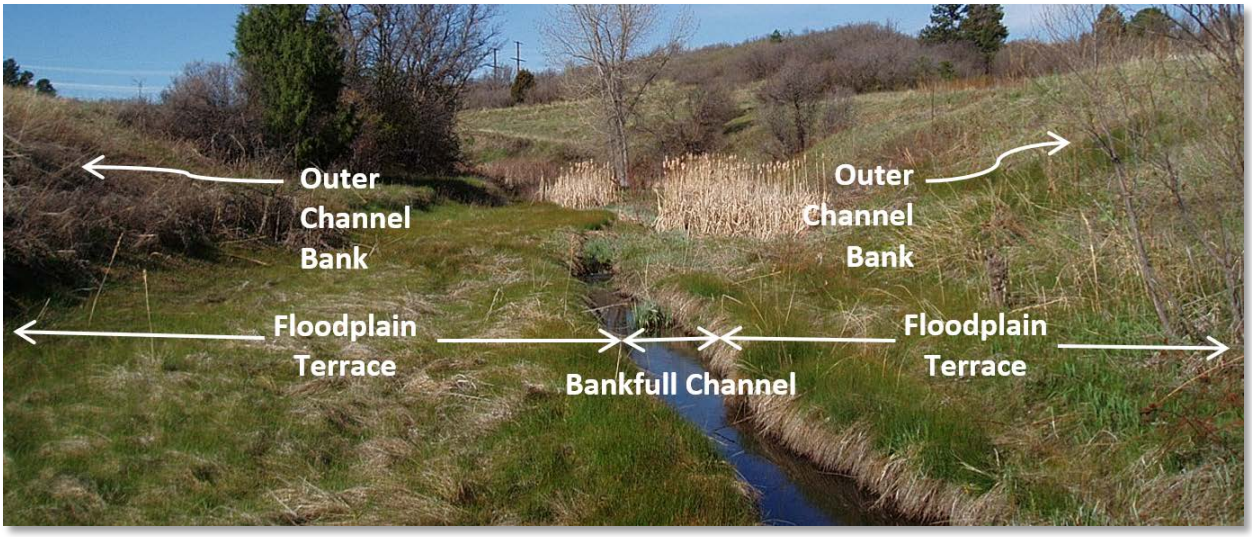


Figure 8-1. Natural channel cross section illustrating floodplain terraces

Natural channels take other forms besides the appearance of the cross section in Figure 8-1. They may be influenced by a relatively high sediment load and have a wide, sandy bankfull channel as illustrated in Figure 8-2. Or they may be vegetated across the entire channel bottom, either with wetland species if the channel is normally wet or transitional or upland species if it is normally dry. Figure 8-3 shows a dry, vegetated stream common to upland areas. These channels also function best when high flows are allowed to spread out over a wider floodplain. Natural steam channels are dynamic and change over time in response to hydrology, watershed conditions, and other factors. Large floods can result in rapid channel evolution/avulsion. When the floodplain is preserved, these natural changes have space to occur with lower potential for damage than channels that are constrained.

During high flow events, the water level rises and spreads to a width and depth associated with a specific return period. Local, State, and Federal floodplain criteria are most commonly associated with the 100-year event. In some cases, the 500-year event is mapped and human development is limited with respect to this criterion. The overall width of the stream corridor should be planned and designed to convey these large flood events that can and will occur.

Figure 8-2. Example sand-bed stream

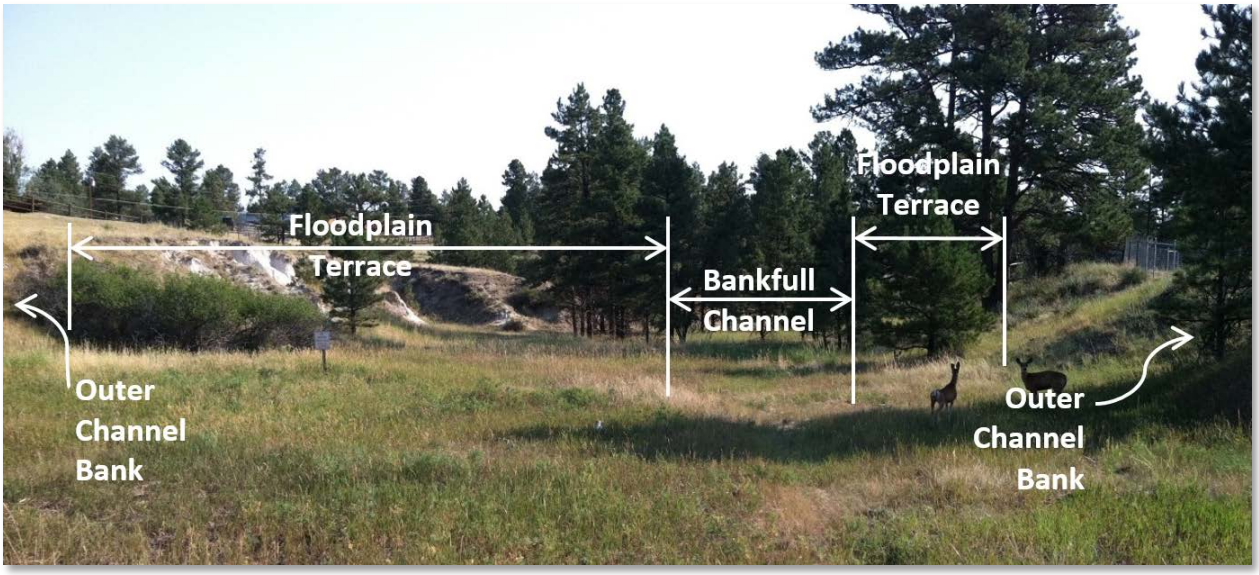


Figure 8-3. Example upland channel

2.1 Functions and benefits of Natural Streams

Healthy streams and floodplains provide a number of important functions and benefits. These are summarized below and illustrated in Figure 8-4.

1. Stable conveyance of baseflows and storm runoff.

2. Support of riparian vegetation.

3. Creation of habitat for wildlife and aquatic species.

4. Appropriate management of energy during a wide range of flows.

5. Promotion of infiltration, groundwater recharge, and exchange of surface and subsurface water in the hyporheic zone located under and adjacent to the low-flow channel (this exchange has been shown to be an important beneficial biological process).

6. Enhancement of water quality through reduced erosion and through vegetative filtering and soil-water interactions.

7. Provision of corridors for trails and open space.

8. Enhancement of property values and quality of life.

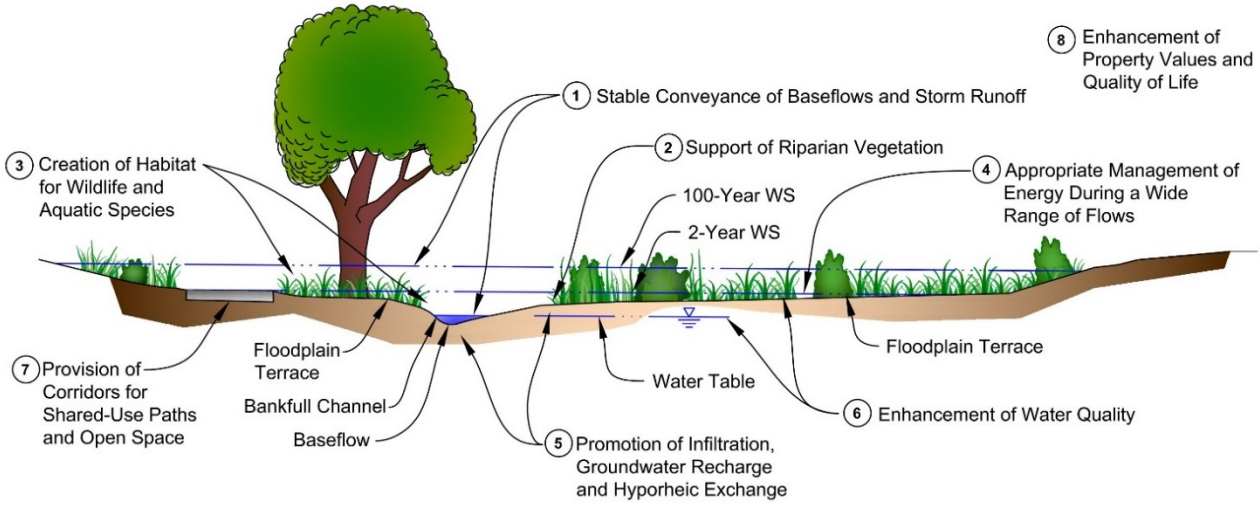


Figure 8-4. Functions and benefits of natural stream corridors (Source: Arapahoe County)

2.2 Natural Stream Corridors Prior to Urbanization

Natural stream systems are dynamic, responding to changes in flow, vegetation, geometry, and sediment supply. In the absence of urbanization, these stream systems are generally free to undergo dynamic change with little negative impact. A free, open, natural stream system is characterized by:

- Space to move and adjust,
- Capacity to convey floods,
- Natural flow regime of water and sediment,
- Channel form adapted to its flow regime, and
- Riparian vegetation established to suit the natural hydrology and soils of the corridor.

Such streams, although subject to aggradation, degradation, and other channel adjustments, are generally able to sustain themselves over the long term.

2.3 Urban Stream Corridors

2.3.1 Impacts and Constraints

In developing urban environments, the driving variables of flow, sediment movement, geometry, and vegetation can undergo significant and rapid changes, exaggerating and accelerating the kind of adjustments the stream makes; as a result, streams in urban environments face threats that can degrade the functions and benefits highlighted in Section 2.1.

In addition, urbanization often places homes, roadways, and infrastructure in close proximity to streams and their floodplains, exposing them to risk of damage from channel movement, bed and bank erosion, and inundation with runoff and mud and debris during flood events. The encroachment of development on stream corridors can limit the allowable width and depth of floodplains, increase velocities and erosive power of flood flows, and impose constraints on the type of improvements necessary to improve channel stability.

2.3.2 Stream Degradation

Urbanization typically increases the frequency, duration, volume, and peak flow rate of stormwater runoff. Based on a review of Colorado Front Range hydrologic analyses, average annual runoff volumes and peak discharges in urban areas can increase by an order of magnitude or more compared to predevelopment conditions. The largest increases in volume and peak discharge occur in the more frequent events that comprise the critical stream-forming flows. In addition, by re-surfacing the ground with pavement and landscaping and installing water quality and flood storage facilities, urbanization can decrease the supply of watershed sediment below pre-development conditions.

Photograph 8-1. Extreme degradation in an unstable channel. (Source: Arapahoe County)

As a result of increased runoff and reduced sediment loading, urban streams tend to degrade and incise toward a flatter slope as the channels seek a new condition of equilibrium to transport that water and sediment. An extreme example of degradation is shown in Photo 8-1. Degradation produces a number of negative impacts to riparian environments and adjacent properties. These are illustrated in Figure 8-5 and described below.

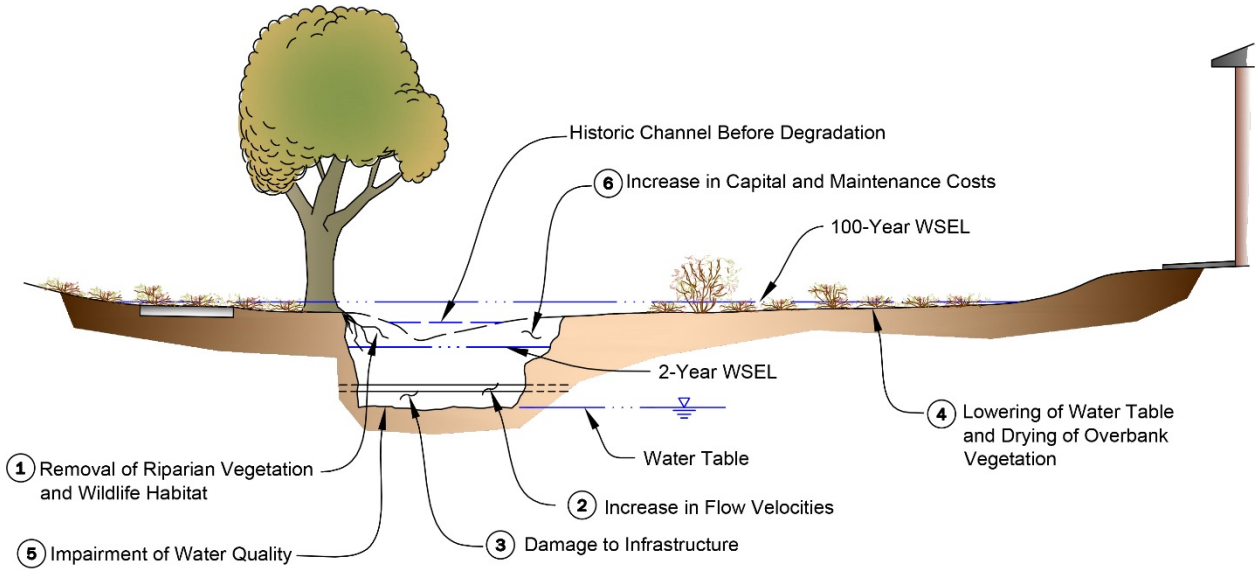


Figure 8-5. Impacts of stream degradation (Source: Arapahoe County)

1. **Removal of Riparian Vegetation and Wildlife Habitat.** Erosion typically strips natural vegetation from the bed and banks of streams. This disrupts habitat for aquatic and terrestrial species and leaves the stream exposed to further erosion damage.

2. **Increase in Flow Velocities.** An incised channel concentrates runoff in a narrow, deep section and increases flow velocities and shear stresses. Increased velocities continue to erode the channel.

3. **Damage to Infrastructure.** Channel erosion can threaten utility lines, bridge abutments, and other infrastructure. Utility pipelines that were originally constructed several feet below the bed of a creek can become exposed as the bed lowers. Damage to the utility lines can result as the force of water and debris come to bear against the line. Channel degradation can expose the foundations of bridge abutments and piers, leading to increased risk of undermining and scour failure during flood events. Erosion and lateral movement of channel banks can cause significant damage to properties adjacent to streams, especially if structures are located in close proximity to the banks.

4. **Lowering of Water Table and Drying of Terrace Vegetation.** In many cases, lowering of the channel thalweg and baseflow elevation leads to a corresponding lowering of the local water table and less frequent flows on the floodplain terraces. Besides the loss of water storage, lowering the water table can "dry-out" the terraces and can effect a transition from wetland and riparian species to weedy and upland species, harming the ecology of floodplain terrace areas. It should be noted that raising the degraded channel up again will raise groundwater levels closer to the surface and may impact properties adjoining the floodplain.

5. **Impairment of Water Quality.** The sediment associated with the erosion of an incised channel can lead to water quality impairment in downstream receiving waters. One mile of channel incision 5-feet deep and 15-feet wide produces almost 15,000-cubic yards of sediment that could be deposited in downstream lakes and stream reaches. Along the Front Range of Colorado, these sediments typically contain naturally occurring phosphorus, a nutrient that can lead to accelerated eutrophication of lakes and reservoirs. Also, channel incision impairs the "cleansing" function that natural floodplain terraces can provide through settling, vegetative filtering, wetland treatment processes, and infiltration.

6. **Increase in Capital and Maintenance Costs.** Typical stabilization projects to repair eroded streams require significant capital and maintenance investment; the more erosion, generally the higher the cost.

Although degraded channels may eventually erode and widen to create new floodplain terraces at a lower elevation following a process called the *channel evolution model* (CEM), this would damage infrastructure and impact water quality in the process. Channel evolution is complex, and a number of different CEMs have been developed by fluvial geomorphologists to conceptually describe how streams typical of the Colorado Front Range evolve (Watson 2002). Instead, stream restoration is encouraged. As discussed in Section 2.2, stream restoration is greatly facilitated if adequate stream corridors are maintained.

3.0 Preserving Natural Stream Corridors

The opportunity to preserve natural stream corridors typically comes only at the outset of planning in a watershed. Preserving natural stream corridors not only preserves valuable habitat and vegetation; it can also reduce impacts and provide for future stream management at a lower cost and smaller footprint compared to constrained floodplains where elevated discharges must be conveyed in narrow corridors.

3.1 Preserve Natural Streams and Riparian Vegetation

As described in Section 2.1, existing natural stream corridors are an important resource offering flood conveyance, desirable riparian vegetation, habitat, landforms, passive recreation, and the potential for water quality filtering and infiltration. Natural stream corridors should be preserved –not filled in, re-graded, re-aligned, or placed in a conduit. Photograph 8-2 shows how development boundaries have been established to preserve a natural stream corridor.

Photograph 8-2. Preserving an existing stream corridor within a developing area.

New construction along streams can produce negative short term effects such as vegetation disturbance, proliferation of weeds, susceptibility to damage during high runoff events, and nutrient leaching associated with runoff coming into contact with freshly disturbed soils. Therefore, it is desirable to preserve as much of a natural stream corridor as possible. If measures are necessary to improve the capacity or stability of a stream reach, it is recommended that these improvements be implemented as "surgically" as possible, preserving valuable land forms, vegetation, and habitat. Photograph 8-3, taken immediately after construction of stream improvements, shows an example of preserving pockets of existing riparian vegetation. Photograph 8-4, taken two years later, illustrates how the overall recovery time of a reach of stream after construction is accelerated by preserving pockets of existing vegetation.

Photograph 8-3. Preserved vegetation during and shortly after construction.

Photograph 8-4. Same channel as left, 2 years after construction.

3.2 Provide Ample Space for Stream and Floodplain

Streams and their floodplains require space to remain fully functional. Ample space needs to be provided both horizontally and vertically.

Horizontal space is necessary to allow the stream to naturally flex and adjust as it seeks dynamic equilibrium. An ample corridor width is necessary to enable high flows to spread out over the floodplain. As is discussed in Section 4.3, relative roughness increases and flow velocity and erosive force decreases as the wetted channel width increases for a given flood discharge. Therefore, wide floodplains are generally more stable than narrow floodplains for a given flow rate.

Ample corridor widths generally allow softer stream improvements more reliant on cross section shaping and vegetation, as indicated in Photograph 8-5. When the available horizontal space is constrained, as shown in Photograph 8-6, channel conveyance and stabilization improvements are always more challenging and costly.

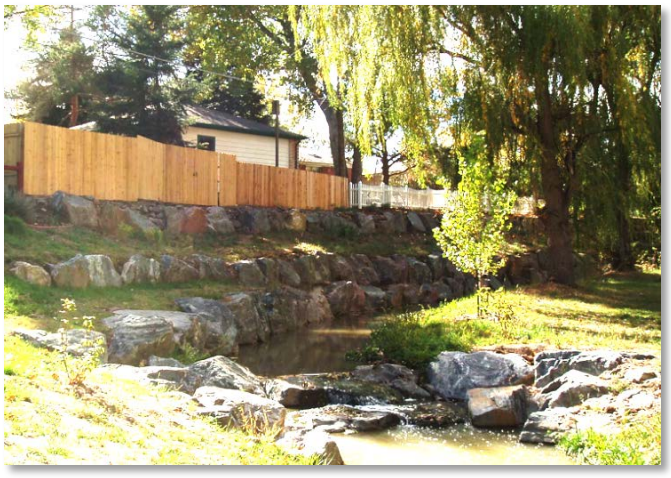
Photograph 8-5. Ample space generally allows softer stream improvements more reliant on cross section shaping and vegetation.

Vertical space is necessary to allow floodplain elevations to rise over time. Floodplain elevations can rise over time due to the following:

- Increased baseflows and runoff from development can promote increased growth of wetland and riparian vegetation, making streams hydraulically rougher and leading to greater flow depths.

- Stream restoration work usually has the goal of raising the bed of incised channels to levels that existed prior to degradation. This effort, plus modifying channel slopes to flatter or more stable grades, can increase water surface elevations above mapped or regulatory floodplains modeled based on the degraded condition.

- Upstream bank erosion or watershed erosion over time can lead to sediment deposition and channel aggradation in downstream channel reaches that may have wider sections, flatter slopes, or increased channel vegetation–raising streambed and floodplain elevations.



Photograph 8-6. Channel improvements tend to be more structural and costly when space is limited.

The most important reason for providing ample space for streams is recognizing the tremendous power of floods to convey and deposit rock, mud, and debris and carve new channel alignments irrespective of property or infrastructure. The Front Range floods of September 2013 showed that impacts are often felt beyond the limits of regulatory floodplains. As an example, Figure 8-6 indicates that the area impacted by the 2013 flood (indicated by blue shading) in this reach of Fourmile Canyon Creek in Boulder is larger than the area of the regulatory 100-year floodplain (indicated by red outline), even though the 2013 event was estimated to have a peak discharge less than the 100-year flow rate.

Therefore, providing ample space for streams in the following ways is strongly recommended to reduce risk to people and property.

Figure 8-6. Fourmile Canyon Creek, September 2013 flood impacts and floodplain

Avoid Floodplain Filling and Encourage Stream Preservation Zones. Building structures adjacent to floodplains carries risk; filling existing floodplains and building structures closer to flooding sources increases that risk, especially when the filling creates higher flood velocities. Some communities have adopted stream preservation zones that limit filling and new development within stream corridors that may be wider than the 100-year floodplain. This is prudent given the power and unpredictable nature of floods. Support for this policy can often be seen in aerial imagery as shown in Figure 8-7. The historic meander belt width, indicating channel movement over time, can be many times wider than regulatory floodplains.

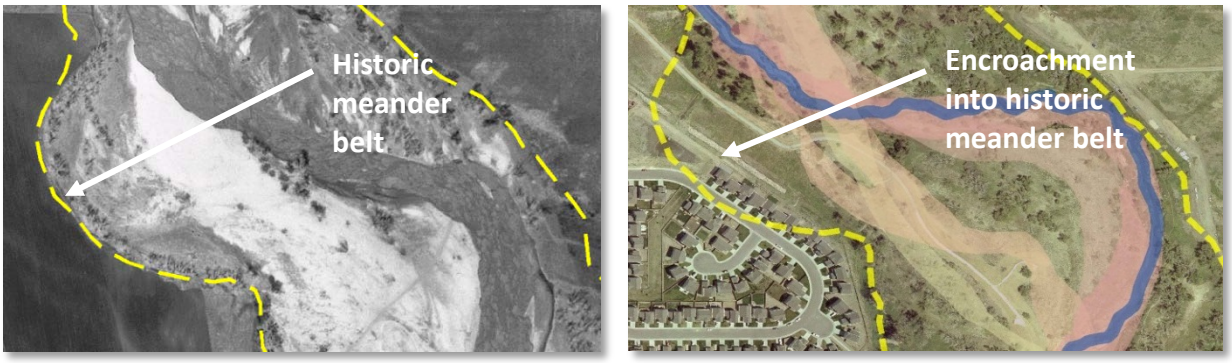


Figure 8-7. Importance of stream preservation zones

Provide Ample Freeboard. Freeboard is the vertical distance above a referenced floodplain water surface to a specific elevation associated with constructed infrastructure, typically the lowest elevation of a building site adjacent to a floodplain, the lowest habitable floor of a structure, or the low chord of a bridge spanning a stream. It is critical to recognize that higher water surface elevations can and will occur as a result of increased channel vegetation and roughness, aggradation, raising degraded inverts, and flood debris. Urban Drainage and Flood Control District (UDFCD) recommends providing 18 inches or more of freeboard for new development projects to account for these changes, as these changes cannot be considered when determining the regulatory floodplain. Bridges often have higher freeboard requirements to account for debris. Where risk or damage associated with flooding is high, or there is high potential for sediment, rocks, and debris in runoff, the designer should elect to incorporate additional freeboard.

3.3 Manage Increased Urban Runoff

Stream degradation is often associated with the increased peak discharge, volume, and frequency of urban runoff, especially during small (occurring multiple times each year) to moderate (occurring once every several years) flood events. Employing runoff reduction techniques (e.g., minimizing directly connected impervious areas) as well as implementing full spectrum detention to reduce urban runoff peak flows and volumes can mitigate the impacts of urbanization. These two strategies represent Steps 1 and 2 of the Four Step Process as described in Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM).

Runoff reduction can be accomplished through a variety of techniques, including the following, each of which is described in Volume 3:

- Minimizing directly connected impervious area,
- Grass buffers and swales,
- Permeable pavements,
- Bioretention/rain gardens, and
- Sand filters.

Full spectrum detention, if implemented in significant portions of a watershed, holds the potential for controlling peak discharges to levels similar to pre-development conditions over a wide range of storms from small, frequent events to large, rare events. If portions of a watershed have been developed without full spectrum detention, or without any detention at all, local governments may be able to explore opportunities to retrofit full spectrum detention facilities to reduce the impacts of elevated urban runoff.

Master plan modeling has shown that retrofitting regional full spectrum detention in a watershed can more than pay for itself in reduced stream stabilization costs (Cottonwood Creek Outfall Systems Plan, 2012 and Happy Canyon Major Drainageway Plan, 2014). Full spectrum detention is described in detail in the *Storage* Chapter of Volume 2.

It is generally good practice to locate regional detention facilities on smaller tributaries with low sediment loading rather than in streams having significant upstream watershed area and sediment load. This reduces the likelihood that the detention facilities will quickly fill with sediment from the natural stream system and release flows with reduced sediment load that may initiate a cycle of degradation in the reach downstream.

However, siting a regional detention facility on a larger stream where the sediment load is low, the upstream and downstream reaches have low erosion potential, and where regional water quality is a specific objective may be beneficial. Several of these large online regional detention facilities have been constructed on streams leading into Cherry Creek Reservoir in Denver as part of an overall plan to protect water quality in the reservoir.

3.4 Monitor and Proactively Address Channel Instability

The restoration process is intended to be proactive, best started prior to the onset of significant development and resulting stream erosion in the watershed. Addressing problems when they are small rather than waiting until severe degradation occurs reduces disturbance to existing vegetation and habitat resources, protects water quality, and reduces the extent and cost of stabilization improvements. The objective of a proactive stream stabilization approach is to implement improvements at the appropriate pace, in the appropriate locations, and of the appropriate type to stay ahead of problems.

A proactive approach to address channel instability requires a commitment to undertake regular surveys of stream systems, identify early signs of degradation, aggradation, earmark funding, secure easements, and undertake design and construction of improvements at a relatively early stage in the erosion process. A proactive approach generally allows a set of improvements that is relatively modest, soft, oriented toward reinforcing potential weak points, and intended to work in conjunction with the portions of the existing stream system that are generally stable on their own. This reduces the extensive disturbance, re-grading, and structural measures that are often necessary to address severe erosion after it has already taken place. Proactive measures can be financially challenging as these need to be constructed prior to development; however, the alternative of waiting until the channel degrades is more costly.

Photograph 8-8. Proactive stabilization at McMurdo Gulch, constructed with little disturbance to the existing channel.

4.0 Stream Restoration Principles

This section introduces the concept of stream restoration. In general, stream restoration is aimed at re-establishing the natural and beneficial functions of a stream corridor depicted in Figure 8-4. Although a degraded channel similar to the condition shown in Figure 8-5 and Photograph 8-7 could be left in a narrow, deep configuration and perhaps protected with heavy rock lining, stabilizing the invert in its lowered condition would potentially perpetuate a low water table, dried out terrace vegetation, high flood velocities, and reduced water quality filtering and infiltration in the terraces. It would be ideal, and often less expensive, to raise the invert to re-connect the channel with its floodplain, as shown in Photograph 8-8. It is better to promote healthy floodplain terrace conditions that can handle periodic flood flows, controlling increased runoff from development than to "force" a degraded channel into a stabilized condition using extensive structural measures.

Photograph 8-7. Degraded channel (before restoration).

Photograph 8-8. Same channel as photo 8-7 after restoration.

Eight principles for stream restoration are discussed in the following subsections. The principles are valid for a variety of stream conditions, whether the corridor has been preserved and protected as described in Section 3.0 or constrained and impacted through urbanization. Special design considerations are recommended for constrained urban stream reaches where velocities and shear stress imposed by elevated peak discharges are greater and infrastructure tends to be in close proximity to the stream. Stream restoration measures tend to be more structural and costly in constrained corridors where maintaining or increasing flood capacity is typically the highest priority.

The principles are not a "cookbook" or "one size fits all" set of design steps, but rather principles to be applied to channel reaches with the experience, judgment and collaboration of a multi-disciplinary design team. Consider the following expertise when developing the design team: surface and subsurface hydrology, hydraulics, geomorphology, plant ecology, terrestrial and aquatic biology, environmental permitting, landscape architecture, geotechnical, and water rights.

What does *Restoration* mean?

Stream restoration is the process of assisting the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replacing lost, damaged, or compromised elements of the natural system (Bledsoe, 2013).

Restoration is the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource (Corps of Engineers, 2011).

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society of Ecological Restoration, 2004).

Restoration refers to actions that result in the re-establishment of ecological processes, function, and biotic/abiotic linkages, that lead to a persistent, resilient ecosystem that is integrated within its landscape (Society of Wetland Scientists, 1998)

From the definitions above, the idea is communicated that restoration is a matter of *assisting* ecosystems that are in a *degraded* condition to re-establish *healthy processes and functions*. Although other terms, such as reclamation, rehabilitation, and stabilization, may be used to describe activities improving the structure and health of stream corridors, especially in urban or disturbed environments, the term "stream restoration" will be used in this chapter.

4.1 Understand Existing Stream and Watershed Conditions

Before any design work on a stream reach takes place, it is imperative to understand the existing conditions associated with the stream and its watershed. Review the current master plan including upstream and downstream reaches and major tributaries flowing into the reach. The master plan also provides information on existing and future development, allowing for an understanding of potential impacts due to anticipated growth. Understanding development plans and planning/zoning documents is an important component to understanding watershed conditions. Comprehensive field reconnaissance should also be performed. The following types of information should be observed on a reach by reach basis:

- Planform geometry, such as the information illustrated in Figure 8-8. Further discussion regarding channel sinuosity can be found in Section 4.4.
- Cross-section geometry, especially width and depth of the main channel below adjacent terraces, relative elevations and widths of terraces, heights and slopes of channel banks.
- Bankfull width and depth and the channel entrenchment ratio as defined in Section 4.3.
- Stream bed conditions, including bed material type and particle size, riffle characteristics, pools, steps, rock outcrops, presence of baseflows, and indications of the amount of sediment transport.
- Longitudinal slope of channel and valley along their respective centerline alignments.
- Vegetation characteristics along the channel, in floodplain terraces, at knickpoints, and channel banks.
- Signs of instability (e.g., headcuts, bed degradation/ aggradation, bank erosion, constricted channel sections) and stability (e.g., lack of erosion, favorable cross sectional geometry, dense vegetation).
- Existing facilities that modify hydrology and hydraulics such as dams, wastewater treatment plants, ponds, detention facilities, storm drain outfalls, or grade control structures.

- Horizontal distance from stream and elevation above stream of any structures or development parcels adjacent to stream as well as total unencumbered width of floodplain.
- Locations of infrastructure such as roadway crossings and utilities.

Figure 8-8. Planform geometry of a meandering river system

A reference reach (a stream reach with similar hydrology and watershed characteristics that displays characteristics of a stability without artificial means) can be used as a template for design of a stream restoration project. Although suitable reference reaches rarely exist for urban streams, when a reference reach can be identified in a relatively undisturbed and healthy portion of the stream or a similar stream, characteristics of a the reach can often serve as a guide for creating similar characteristics in an impaired reach.

Additional information regarding field data to collect for assessment is provided in *A View of the River* (Leopold 1994). Existing conditions should be documented with field notes, photos, and quantitative comparisons of measurable parameters.

Any available historic aerial photography should be carefully reviewed and compared to current channel conditions, noting changes that have occurred over time, and especially after large flood events. Interviews with nearby residents are another means of gathering information on the history of streams.

Available information on regulatory flow rates and floodplains and gage data should be obtained and reviewed, along with master plans and any prior stream stabilization. It is important to assess how much flows have increased from predevelopment conditions to current levels and how much further they may increase with future development–for large floods like the 100-year event and also for more frequently occurring floods such as the 2-year event. This comparison will help to quantify the increased velocities and shear stresses imposed on the stream over a range of flow rates and will help to guide the design of stabilization measures.

Assess not only the stream but also the watershed. Evaluate current aerial photography of the watershed to understand the locations and densities of existing developments. Obtain planning documents and development plans that show projected land use to estimate the extents, representative imperviousness, and anticipated timing of development projects in the watershed. The larger the development, higher the average imperviousness, and quicker the anticipated build-out, the more the potential impact on downstream channels. Review information on soils, imperviousness, hydrology, hydraulics, detention facilities, and improvement recommendations in any existing master plans conducted for the watershed.

By understanding channel behavior historically, currently, and projected into the future, the designer will have the foundation needed to develop strategies for improving the stability of the stream.

Stream Restoration Principle 1: Understand Existing Stream and Watershed Conditions

Representative Design Tasks and Deliverables

1. Document results of field observations and background research on project reach, applicable reference reaches, and watershed.
2. Compile representative photos along reach.
3. Compare future development design flows for return periods ranging from 2-year to 100-year to existing and, if available, pre-development conditions to assess the relative increase in stresses imposed on the project reach.
4. Summarize findings as they apply to the design of improvements in project reach.

4.2 Apply Fluvial Geomorphology Principles to Manage Sediment Balance

A drainage system within a watershed involves flowing water, described by the term *fluvial*. *Geomorphology* is the study of landforms and the processes that influence the shape and dynamics of landforms. The flow of water and the associated movement of sediment that forms and shapes streams are processes that are identified as *fluvial geomorphology*. Surface form characteristics of stream channels behave in a dynamic and complex manner dependent on watershed factors such as geology, soils, ground cover, land use, topography, and hydrologic conditions. These same watershed factors contribute to the sediment eroded from the watershed and from the stream bed and banks and supplied to the channel. The sediments eroded, moved by the flowing water, and deposited in turn influence channel hydraulic characteristics.

4.2.1 Aggradation, Degradation, and Equilibrium

An alluvial channel is usually considered stable and in equilibrium if it has adjusted its width, depth, slope, and other factors so that the channel neither aggrades nor degrades, resulting in no significant change in channel cross section over time. This is a dynamic equilibrium in which the sediment supply from upstream is generally equal to, or in balance with, the sediment transport capacity of the channel for the full range of flows. Under watershed conditions with normal hydrologic variations affecting runoff and sediment inflow, this balance shifts and some adjustments in channel characteristics are inevitable.

An illustration, shown as Figure 8-9 (from USFISRWG 1998 [originally from Lane 195 5a]), provides a visual depiction of a stable channel balance based on the relationship proposed by (Lane 1955a) for the equilibrium concept whereby:

$$Q_w S \propto Q_s D_{50} \qquad \text{Equation 8-1}$$

Where:

Q_w = water discharge

S = channel slope

Q_s = bed material load

D_{50} = mean particle size of bed material

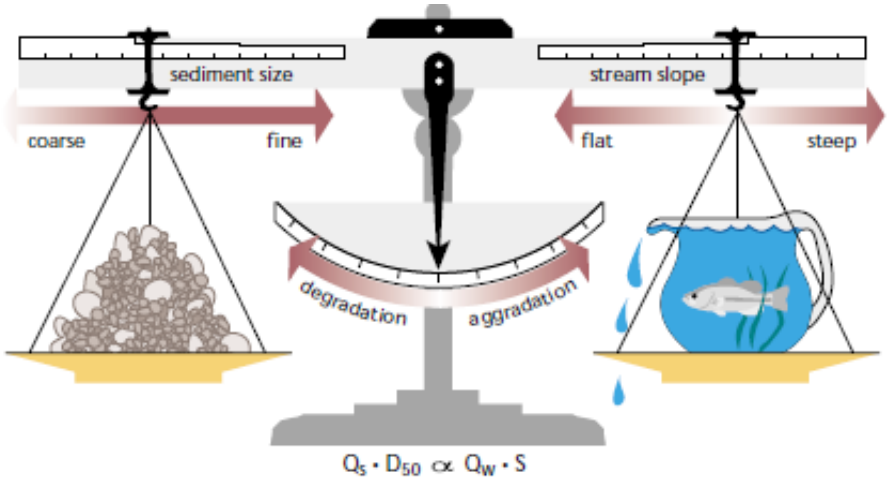


Figure 8-9. Lane's diagram

For a stable channel, these four parameters are balanced, and, when one or more of the parameters changes, the others adjust over time to restore the state of equilibrium. For example, a typical response to increased flow associated with urbanization is an increase in bed material load through erosion of the channel and a corresponding reduction in slope. This describes channel degradation that is prevalent in urban streams. Preserving natural stream corridors and reducing urban runoff as described in Section 3.0 will reduce the magnitude and progression of stream erosion and associated deposition; however, degradation and aggradation will still occur to some extent in preserved stream corridors. Degradation and aggradation tends to be more pronounced in urban streams.

Photograph 8-9. Degradation in a channel.

The presence of channel degradation (erosion) or aggradation (sedimentation) is readily identified in the field. Degradation is evidenced by lowered channel inverts, high eroded channel banks, flatter longitudinal slopes, and other impacts illustrated in Figure 8-5 and Photograph 8-9. On the other hand, aggradation appears as mud, sand, or coarser sediment accumulated on the bed or floodplain terraces of a stream, burial of lower stalks of herbaceous or woody vegetation (see Photograph 8-10), steeper longitudinal slopes, and often a relatively shallow and sometimes wide sandy active channel. Aggradation and degradation processes may differ between the active channel and adjacent terraces. Sediment deposition can occur on densely vegetated terraces at the same time that degradation occurs in the active channel.

Photograph 8-10. Signs of aggradation include fresh, sandy deposition and the burial of plant stems.

Evidence of aggradation and degradation over time can be documented by comparing current survey information of the stream invert to any prior survey or mapping information or bed elevations that may be indicated in past floodplain or master plan profiles, considering any datum differences. For large streams, bridge maintenance records often record streambed elevations over time and original bridge design plans may indicate streambed elevations at the time the bridge was constructed. Plotting the current streambed profile against prior information is a good way of illustrating degradation and aggradation.

It is not unusual to find aggrading reaches downstream of severely degrading reaches as the high sediment load generated by the degrading reach finds a lower-energy reach and drops out. The clearer water downstream of the aggrading reach often begins another reach of degradation and the conditions can repeat in alternating cycles along the length of a stream. Although the aggrading reaches downstream of degrading reaches may appear stable, their stability may be dependent on the abnormally high erosion rates upstream; if the degrading reaches are stabilized, reaches that were formerly aggrading or in a quasi-stable condition may begin to degrade.

It is the designer's responsibility to understand aggradational and degradational conditions along a stream and develop improvement plans that intend to appropriately manage the sediment balance.

4.2.2 Dynamic Equilibrium and Threshold Principles in Stream Restoration

In its purest form, a dynamic *equilibrium* approach to stream restoration seeks to re-establish a horizontal and vertical configuration of a stream–encompassing cross section shape, longitudinal slope, sinuosity, meander pattern, bed material, and terrace vegetation that will convey inflowing sediment and sustain itself in dynamic equilibrium over a range of flow conditions without the use of hard structures. This is not to say that there will not be degradation and/or aggradation from event to event; however, over the long-term the degradation and aggradation are balanced. Equilibrium approaches have been successfully implemented by experienced practitioners to restore the health of natural stream systems, especially in montane and non-urban environments. The dynamic equilibrium approach can be very challenging in a continuously-urbanizing watershed with non-cohesive soils.

A *threshold* approach, in contrast, relies on rock or hard structures for grade control or bank protection that are sized to remain in place for a given range of design flow rates. As long as the design hydraulic threshold is not exceeded, the structures are designed to remain in place. Threshold techniques can be applied to the vegetative cover in floodplain terrace areas as long as shear stresses imposed by the design flow do not exceed the resistive stress strength of the vegetation and soil. Threshold approaches have also been successfully implemented to restore impaired stream systems, especially in the urban environment.

Pure equilibrium approaches are most feasible when the following factors exist:

1. Open, unconstrained stream corridors (to allow dynamic adjustments and enable flows to spread over floodplain to dissipate energy), with gentle valley slopes.

2. Natural hydrology relatively unaffected by urban impacts (to reduce imbalances caused by flow regime).

3. Significant sediment supply (the "building material" necessary to form the stream).

4. Relatively consistent, predictable sediment supply for given flow range (to sustain the stream form over time).

5. Cobble or gravel-bed streams (compared to sand-bed streams, are better able to resist erosion, maintain steeper slopes, promote armoring, and help form natural riffles to assist with grade control).

Factors 1 and 2 are characteristic of protected natural stream corridors as described in Section 3.0; therefore, equilibrium approaches are most feasible in protected corridors that also demonstrate one or more of the other three factors. The more a

Stream Restoration Principle 2: Apply Fluvial Geomorphology Principles to Manage Sediment Balance

Representative Design Tasks and Deliverables

1. Plot current streambed profile of project reach and upstream and downstream reaches against available information showing prior streambed elevations to estimate relative aggradation and degradation.
2. Document geomorphic assessment of stream addressing sediment supply, evidence of degradation and aggradation, predictions of future trends, and any quantitative analyses of sediment supply and equilibrium.
3. Indicate how findings of geomorphic assessment are to be applied to the design of stream restoration improvements in the project reach.

stream is constrained and impacted by urbanization, the more challenging it is to implement a pure equilibrium approach to stream restoration. As mentioned, successful implementation of a pure equilibrium approach requires a high level of understanding and experience in fluvial geomorphology principles.

A number of references have been published on the subject (Rosgen, 1996, USACE (Copeland et al), 2001, USACE (Soar and Thorne) 2001). Threshold approaches have been more often used for stream restoration in urban environments. Threshold approaches are somewhat more predictable and can be used when conditions favorable to equilibrium approaches (identified above) do not exist. Threshold approaches can be designed in several ways. In its most extensive form, it can consist of lining the entire stream width and length with rock sized to not move in the design event. More often, the threshold structures are comprised of vegetated bank protection and regularly spaced grade control structures constructed of sculpted concrete, grouted or loose boulders, and/or riprap.

In effect, most stream restoration projects in the urban environment use a hybrid approach. Threshold principles are employed for grade control structures and equilibrium principles can be used in the soft stream reaches between drop structures.

4.2.3 Support the Stream's Natural Capacity to Sustain Itself

Sustainability

The goal is not to "build" natural habitat and fully completed streams, but to assist in creating the conditions where the system can strengthen and maintain itself.

If the fluvial geomorphology principles discussed above are understood, the restoration process itself can be oriented toward creating a healthy channel configuration and thus assisting the stream system in sustaining its functions primarily on its own. Natural stream systems can act like living entities, responding and adapting to try to maintain balance. The flow of water and sediment, the establishment of riparian vegetation, and the biologic processes in streams and floodplains all have the potential to sustain themselves within a dynamic envelope over a long period of time. In a word, streams systems have a capacity for *resilience*.

The key is to protect streams from major impacts, such as severe channel incision with potential to degrade the system to a point that it cannot recover on its own, and to allow the stream enough space for some degree of natural response. The floods of September 2013 provided multiple examples where streams that had been straightened or narrowed either found their historic alignment or created a new alignment all together. Floods usually serve to remind us that streams are difficult to control if their space requirements are not understood.

The restoration approach is successful if the passage of time results in the stream system getting stronger and healthier through the working of natural stream processes, rather than weakening and degrading over time. The goal is not to "build" natural habitat and fully completed streams, but to assist in creating the conditions where the system can strengthen and maintain itself.

4.3 Establish Effective Cross-Sectional Shape

One of the most fundamental principles in stream restoration is establishing an effective cross-sectional shape. This section describes the importance of a favorable cross-section shape to maintaining the function of a floodplain, discusses "bankfull" channel sizing, and illustrates how cross-section shape influences flow velocities and shear stresses.

4.3.1 Maintaining Floodplain Function

A primary design task is to preserve or establish a floodplain cross section that maintains the natural function of a floodplain–a section with a bankfull channel that is appropriately sized to allow flood flows to spread out over vegetated floodplain terraces for stable conveyance, vegetative filtering, infiltration, and energy dissipation. The bankfull channel should be shallow enough to maintain a connection to the floodplain. In some reaches, deeper areas for aquatic life should also be considered. Severely degraded, incised channels do not allow that connection.

Figure 8-10 illustrates the influence of cross-sectional shape. The figure consists of three cross sections carrying the same flow rate with varying flow characteristics. The first section represents a degraded, incised channel whose flow area fills the incised channel just below the point where it would spill into the adjacent floodplain. The second section is the same as the first except that the active channel was filled to hydraulically reconnect the floodplain. It has a depth of 1.5 feet below the floodplain terraces. The third section has the same size active channel as the second, but a wider and shallower floodplain terrace.

The sections show a color-coded velocity distribution of each section. Average flow velocity in the active channel and terraces in feet per second are indicated, showing how velocity decreases as the section gets wider and shallower. Therefore, unless excessive sedimentation is expected, establishing stream configurations with relatively shallow bankfull channels and wide floodplain terraces are encouraged, since they are inherently less erosive than deeper, narrower sections. The size of the bankfull section is the most critical aspect of the cross-section in maintaining floodplain function and should be sized appropriately considering all geomorphic principles provided in this chapter.

Connecting the Floodplain

The bankfull channel should be shallow enough to maintain a connection to the floodplain and provide occasional flooding of the riparian vegetation.

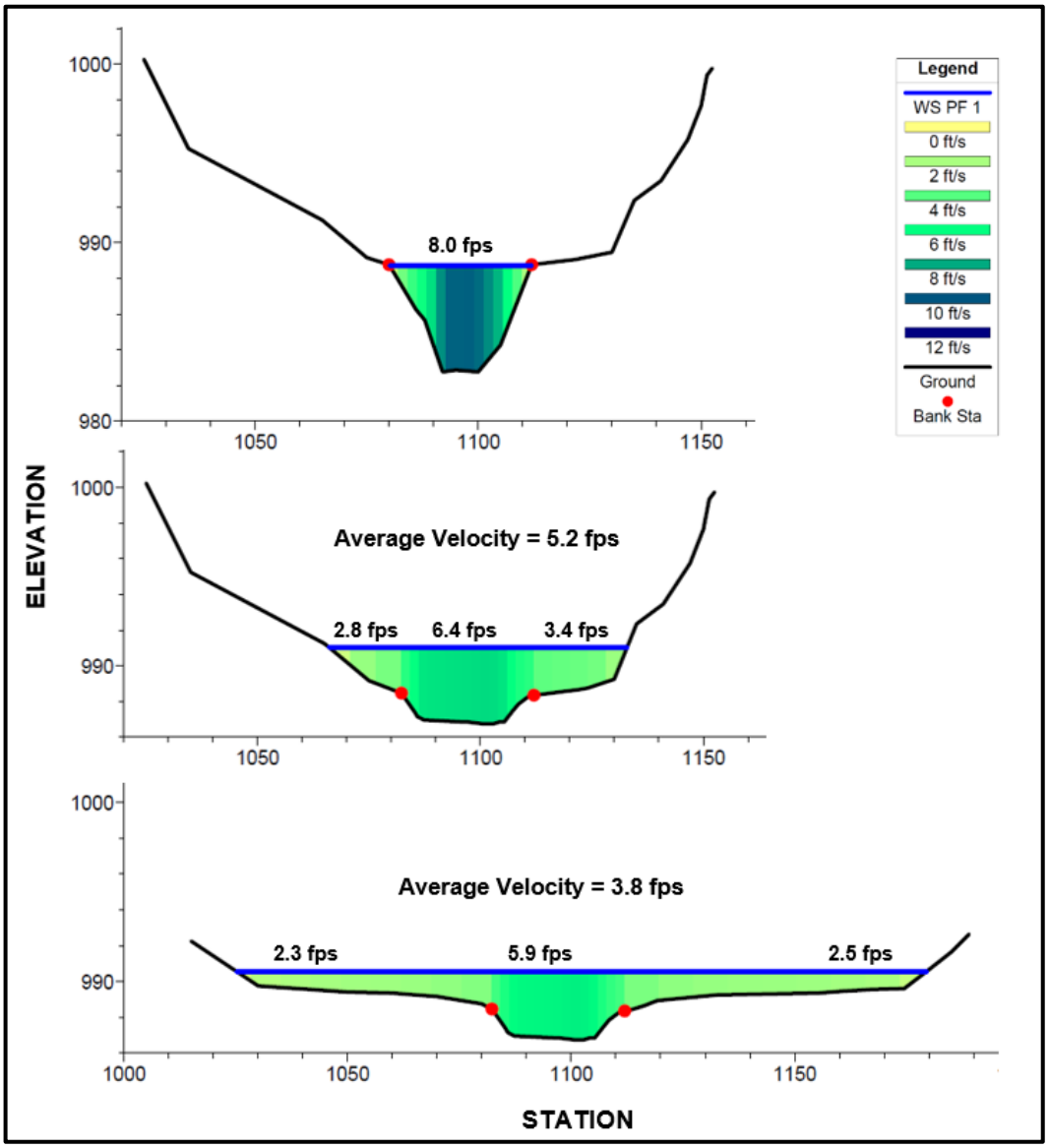


Figure 8-10. Impact of channel geometry on velocity

4.3.2 Sizing of Bankfull Channel

Bankfull channels were introduced in Section 2.0 and indicated in Figures 8-1 through 8-4. Based on geomorphic principles, appropriate sizing of the bankfull channel can be related to a particular discharge, termed "bankfull discharge." Bankfull discharge is defined as the discharge where flow is just about to spill out into its floodplain terraces. Bankfull discharge is further illustrated in Figure 8-11. This section provides several approaches to approximate the appropriate bankfull discharge and in turn, determine the appropriate sizing for the bankfull channel.

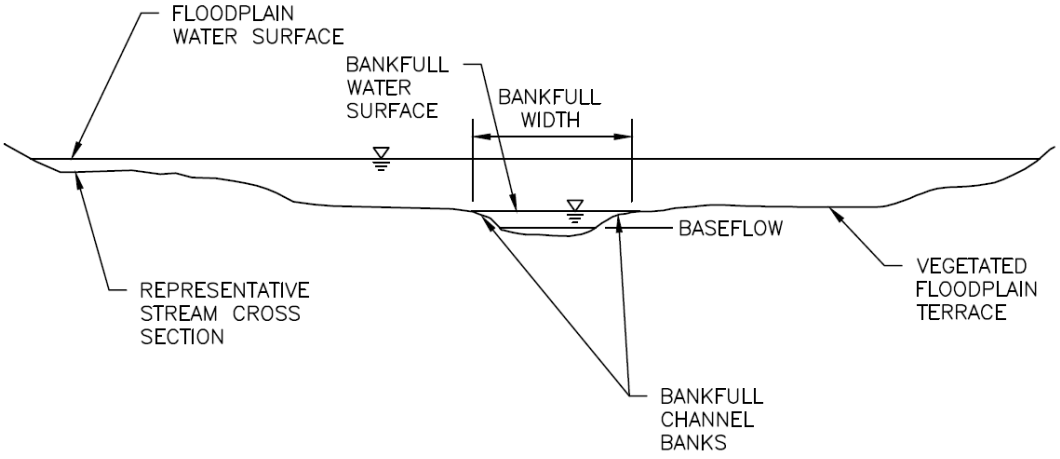


Figure 8-11. Channel cross section with bankfull discharge illustration

Based on reference reach. If stable, the width and depth of the bankfull channel of a reference reach is a good starting place to estimate bankfull channel dimensions in the design reach, assuming the reference reach has not already been altered by past channelization projects. The associated bankfull discharge may be estimated based on bankfull capacity of stable alluvial reference reaches upstream or downstream of the design reach. The process involves observing the depth at which flows just spread out into adjacent floodplain terraces and then estimating the capacity of the bankfull channel at that depth based on the actual slope, roughness, and cross sectional area.

Based on return period. Bankfull channels are not formed based on a single return period event, however; bankfull discharge in stable natural channels has sometimes been observed to be between the 1.5- to 2-year event (Leopold 1994). In urban settings where other methods for sizing the bankfull channel may not be practical, UDFCD recommends using a bankfull discharge value equal to the developed 1.5 to 2-year flow when sizing the bankfull channel. Determination of the 1.5 to 2-year flow should be based on gage records, when available, although the resulting flow estimates will represent the development conditions existing during the period of record and may need to be adjusted upward to account for higher projections of future imperviousness. If the 1.5 to 2-year flow is based on the results of a hydrologic model, caution should be applied since variables such as floodplain infiltration can reduce observed stream flows and result in overly inflated modeled flows for frequent events, especially in large watersheds.

Based on effective discharge. Effective discharge is defined as the discharge that transports the largest percentage of the sediment load over a period of many years. It is used synonymously with "channel-forming" or "dominant" discharge, a theoretical discharge that, if maintained indefinitely, would produce the same channel

References for Determining Bankfull Discharge

The following link directs readers to a video providing guidance for field identification of bankfull stage in the western U.S.:

http://www.stream.fs.fed.us/publications/bankfull_west.html

Chapter 5 of *Applied River Morphology* (Rosgen, 1996) describes bankfull discharge, stage, and field determination of bankfull conditions.

Leopold, 1994 also provides guidance on determining bankfull depth in the field.

geometry as the natural long-term hydrograph. Quantitative analyses to determine effective discharge are fairly complex and depend on good data and proper application of assumptions and methods. Effective discharge analyses are documented in *Hydraulic Design of Stream Restoration Projects* (USACE 2001) and other geomorphology references. Using the effective discharge to size the bankfull channel implies an assumption that an appropriately sized bankfull channel could be based on the effective discharge, (i.e., the bankfull discharge and effective discharge are assumed to be equal).

Regardless of how the bankfull discharge is estimated, geomorphic relationships make it possible to use this value to help determine appropriate sizing of the bankfull channel width and depth. The width for natural alluvial streams has been related to bankfull discharge according to the following equation (Leopold 1994):

$$w = aQ^{0.5} \qquad \text{Equation 8-2}$$

Where:

w = bankfull width of channel (top width when conveying bankfull discharge)
Q = bankfull discharge
a = 2.7 (wide bankfull channel)
2.1 (average bankfull channel width)
1.5 (narrow bankfull channel)

Although this relationship applies to natural alluvial steam systems, it may serve as an approximation for streams in an urban environment, especially if corroborated with reference reach dimensions in streams not already altered by past channelization projects.

In addition, the width/depth ratio, defined below, is a useful parameter that can be key to understanding the distribution of energy within the channel and the ability of the channel to move sediment (Rosgen 1996).

$$\frac{\text{Width}}{\text{Depth}} = \frac{\text{W}}{\text{D}} = \frac{\text{bankfull channel width}}{\text{mean depth of the bankfull channel}} \qquad \text{Equation 8-3}$$

Based on the relationship between bankfull width and bankfull discharge described by Equation 8-2, it is possible to estimate bankfull width based on bankfull discharge and then select a bankfull channel depth based on the area of conveyance needed to contain the bankfull discharge.

This exercise translates into width to depth ratios generally in the range of 6 to 16. Typical bankfull channel depths range from about one to three feet, where the later would be typical for bankfull channels that are a minimum of 18 feet wide. This typical width to depth ratio range of 6 to 16 appears to be generally representative of healthy streams within the UDFCD area. Streams in semi-arid areas tend to have a high width to depth ratio.

4.3.3 Addressing Incised Channels

Degraded streams that are too deep may require filling of incised channels, excavating floodplain terraces adjacent to the bankfull channel, or some combination of the two. Usually, filling a degraded channel is the option that results in the least disturbance to existing floodplain vegetation.

It is sometimes difficult to raise the invert of a degraded channel due to costs associated with importing fill material (if it cannot be generated onsite) or existing infrastructure such as storm sewer outfalls located near the bottom of the incised channel. It may be necessary to remove the downstream end of low storm sewer outfalls and reconstruct them at a higher elevation. Raising the invert will also cause a rise in

a critical floodplain elevation if the regulatory floodplain was based on the degraded channel condition (as discussed in Section 3.2, it is recommended that floodplains be determined for restored, not degraded channel conditions). There may be a need for compensatory excavation in another portion of the floodplain to offset any rise in the floodplain caused by filling in the eroded active channel.

4.3.4 Floodplain Terraces

As discussed above, the existence of floodplain terraces immediately above and adjacent to the bankfull channel help to spread and dissipate the energy associated with high flows. Floodplain terraces may exist on one or both sides of the bankfull channel.

It is desirable that floodplain terraces adjacent to the bankfull channel be relatively wide, flat, well-vegetated, and not excessively steep with respect to longitudinal slope. Terraces with these characteristics assist with reducing flow velocities and provide adequate capacity for larger storm events. Generally speaking, the wider the floodplain terraces, the lower the flow depths for a given return period event, the greater the relative roughness, and the lower the velocities of flow, as shown in Figure 8-10.

A useful parameter for quantifying the width of the floodplain terraces in streams not already altered by past channelization projects is entrenchment ratio, which should be similar to those of stable upstream or downstream reference reaches, ideally in the range of about three or greater. The entrenchment ratio, defined below, provides a measure related to the distribution of shear stress and the potential for erosion within the channel section (Rosgen 1996):

$$\text{Entrenchment Ratio} = \frac{\text{flood prone channel width}}{\text{bankfull channel width}} \qquad \text{Equation 8-4}$$

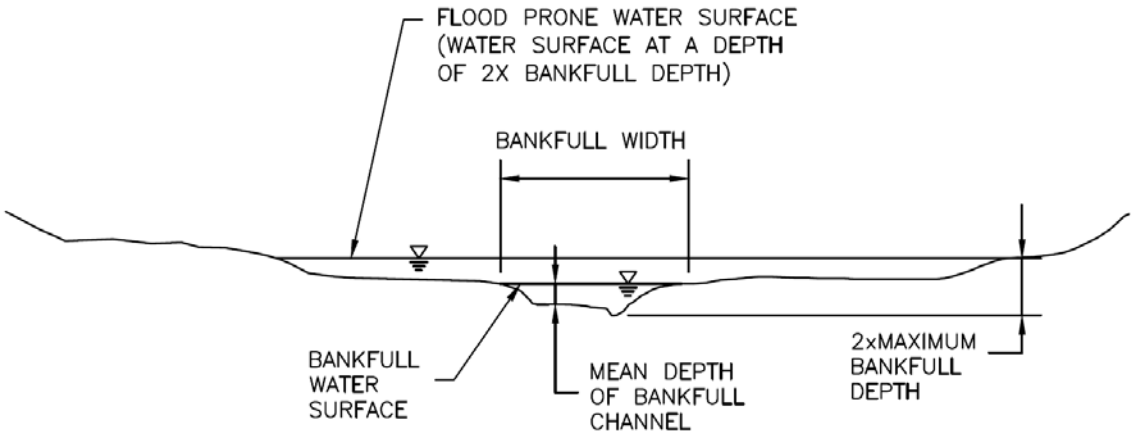
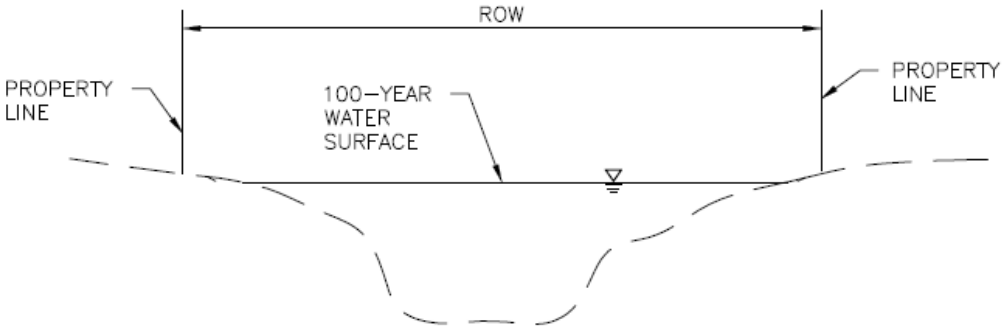


Figure 8-12. Channel cross section with bankfull and flood prone water surfaces (Rosgen 1996)

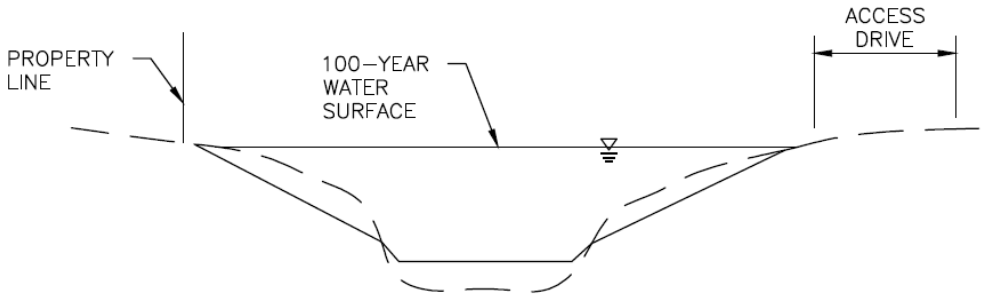
Channels in a degrading condition may not have true floodplain terraces evident; the former floodplain terraces may take the form of abandoned terraces situated well above the active channel invert such that they no longer receive spills when flows just exceed the actual bankfull discharge. Stream restoration efforts should seek to reestablish a connection to the channel's prior functioning floodplain terraces, or undertake grading measures, if feasible, to create new floodplain terraces adjacent to an appropriately sized bankfull channel. Desirable entrenchment ratios would be similar to those of stable upstream or downstream reference reaches, ideally in the range of about three or greater.

Some stream restoration projects are undertaken in constrained urban channels where natural floodplains have been filled and corridor widths are unnaturally narrow. In these cases, it would still be advantageous

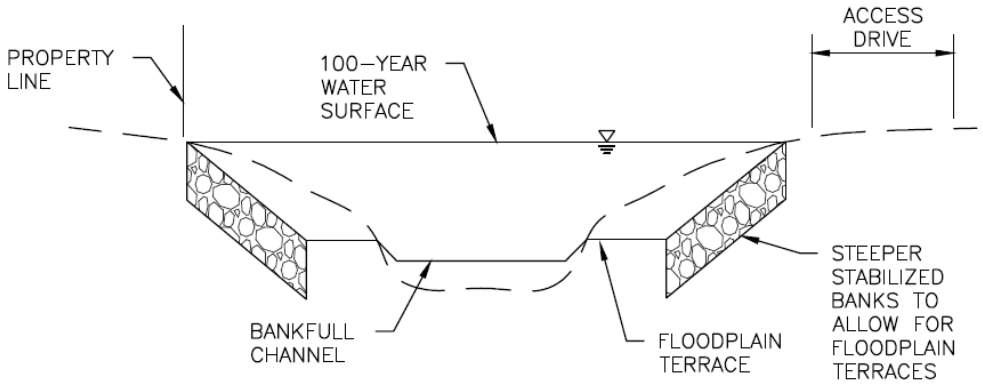
to create a bankfull channel with an appropriate width and depth (and width/depth ratio) flanked by adjacent floodplain terraces with a reasonable entrenchment ratio. If a narrow corridor compromises channel shape, it may be better to steepen the outside banks than to reduce or eliminate a stream's floodplain terrace. This is depicted by the proposed improvements illustrated in Figure 8-13; when opening up the existing narrow channel in the limited right-of-way shown in *Existing Section*, it may be preferable to create a shape similar to that in *Proposed Section with Floodplain Terraces* rather than that in *Proposed Section without Floodplain Terrace*.



EXISTING SECTION



DISFAVORED SECTION WITHOUT FLOODPLAIN TERRACES



PREFERRED SECTION WITH FLOODPLAIN TERRACES

Figure 8-13. Creating floodplain terrace in narrow corridor

Sometimes, constrictions in stream corridors lead to locally high velocities. The constrictions may be part of the natural landform or resulting from floodplain filling taking place in the past. Opportunities to pull back banks and open up constricted areas by excavating, reshaping, and revegetating should be pursued. Hydraulics should be checked as described in Section 8.0.

The cross section geometry for all streams should allow for maintenance access. See the *Stream Access and Recreational Channels* chapter for these criteria.

Stream Restoration Principle 3: Establish Effective Cross-Sectional Shape

Representative Design Tasks and Deliverables

1. Document approaches used to size width, depth, shape, and capacity of bankfull channel.
2. Summarize range of proposed entrenchment ratios in project reach and identify steps to be taken to create or maintain floodplain terraces.
3. Confirm that no filling is to take place in floodplain (however, if fill is proposed, document proposed grading limits and hydraulic impacts per Section 4.8).
4. Document minimum freeboard provided to adjacent property elevations.
5. Provide design drawings showing proposed layout of appropriately sized bankfull channel and floodplain terraces in profile and cross section.

4.4 Maintain Natural Planform Geometry

Natural streams offer variety and complexity in form; they are seldom straight and uniform. Outer banks move in and out and bank heights, slopes, and widths vary. Bankfull channels exhibit a degree of meandering and sinuosity, moving right and left across a section in an alternating manner. The shape of the bankfull channel varies as well, tending to widen slightly in bends; side slopes tend to steepen at the outside of bends and flatten as point bars form on the inside of bends. Increasing sinuosity decreases longitudinal slope. Pools can form in the channel bottom at the apex of bends.

Based on typical geometry associated with sand bed streams, meander wavelength (as illustrated in Figure 8-8) may be on the order of 10 to 14 times the bankfull width of the bankfull channel (Leopold 1994). Sinuosity of a channel is defined by the following equation:

$$\text{Sinuosity} = \frac{\text{bankfull channel length}}{\text{valley length}} \qquad \text{Equation 8-5}$$

Where the bankfull channel length is measured along the actual channel length and the valley length is measured along the valley.

Refer to Figure 8-8 for graphical representation of the above variables. Sinuosity is often in the range of 1.1 to 1.3 for Front Range streams.

As shown in Figure 8-14, meandering stream forms, especially if there is a presence of gravels or cobbles in the stream bed, may take on a riffle-pool form. In this case, riffles are typically located at the cross-over points between meander bends and pools occur at the outside of the meander bends.

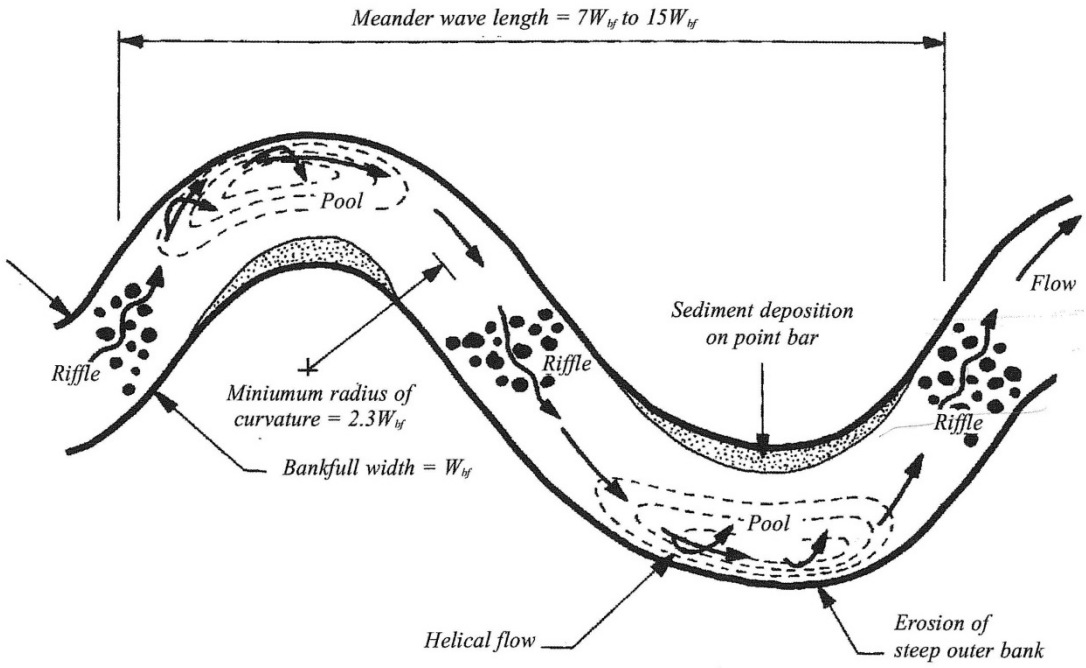


Figure 8-14. Riffle-pool stream form

(Source: Newbury & Gaboury 1993)

If the historic alignment of a natural channel has been altered or disturbed, historic aerial photography may provide useful guides for restoration of the planform geometry. For streams not already altered by past channelization projects and watershed alterations, observations of reference reaches in healthy upstream or downstream reaches or similar stream systems may provide guidance for parameters such as meander amplitude and meander radius.

Figure 8-15 illustrates the planimetric alignment of a reach of Cottonwood Creek upstream of Cherry Creek Reservoir that was reclaimed with a relatively high degree of meandering (with a sinuosity of 1.9) within broad floodplain terraces and an unconstrained right-of-way.

Stream Restoration Principle 4: Maintain Natural Planform Geometry

Representative Design Tasks and Deliverables

1. Document background observations on sinuosity, floodplain width, and meander patterns in study reach or reference reaches and describe basis of proposed stream alignment and planform geometry.
2. Provide design drawings showing plan view of proposed stream restoration improvements.

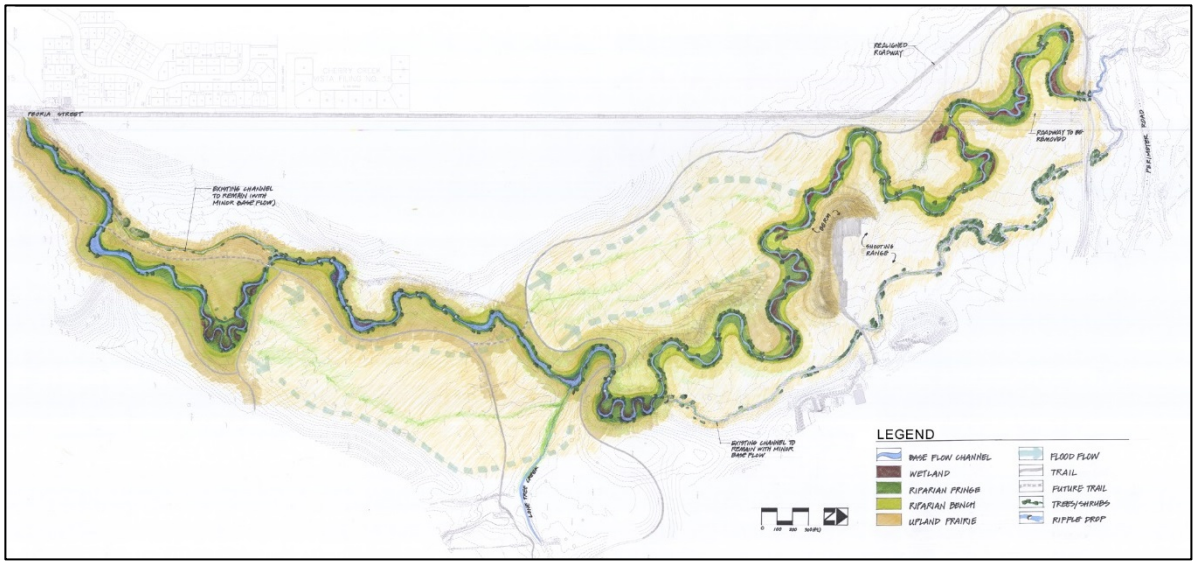


Figure 8-15. Example of meandering single-thread channel form (Courtesy: Wenk and Associates)

4.5 Develop Grade Control Strategy to Manage Longitudinal Slope

As discussed in Section 2.3, a typical stream response to increased urban runoff is to trend toward flatter longitudinal slopes, which, if left unmanaged, leads to degradation and channel incision. A primary management approach to limit degradation is the installation of grade control structures along the length of a stream; the structures hold grade so if the stream wants to flatten its equilibrium slope, incision is limited.

Grade control structures do not create the equilibrium slope of a stream; the stream does. Even a channel filled or constructed at a specific slope will cut or fill within a range of its equilibrium slope. Sometimes a period of high sediment load, which could occur during a large runoff event or result from upstream erosion, will lead to a temporary steepening of the slope, which may reduce during prolonged periods of lower sediment load.

The placement of grade control structures is related to three primary considerations, equilibrium slope, cross sectional capacity, and drop structure height:

Equilibrium slope. Equilibrium slope influences the cumulative drop height needed for a specific stream reach. The estimated equilibrium slope is the flattest slope anticipated in a stream reach over the long term. The actual slope of a stream may vary over time. It is possible that an open channel may exhibit a steeper slope than the estimated equilibrium slope for periods of time, especially if a stream is subject to a high sediment load. At other times slopes may flatten in response to lower sediment loads. Plan to construct check structures with the assumption that these buried structures will eventually become drop structures and, based on the minimum estimated equilibrium slope, will not be undermined. If the channel maintains a steeper slope, or temporarily steepens in response to high sediment loading conditions, this may lead to a partial burying of grade control structures, but without negative effect. The term "grade control structure" generally refers to structures intended to reduce the channel slope and control the elevation of the channel invert (i.e., check structures and drop structures). See the *Hydraulic Structures* chapter for more information.

If the long-term equilibrium slope of the bankfull channel is less than the longitudinal slope of the adjacent terraces, grade control structures are required with the intent of achieving the appropriate slope

between the structures. The location of grade control structures can be determined by extending the estimated equilibrium slope from the crest elevation of a downstream grade control structure to the downstream invert of the next grade control structure upstream. Several approaches are available to estimate long-term equilibrium slope:

1. In streams not already altered by past channelization projects, equilibrium slope can be estimated using a reference reach approach. This is a qualitative fluvial geomorphology method that correlates equilibrium slopes from similar streams that have undergone changes (aggradation or degradation) in slope in response to urban development. Reference reaches have similar geomorphic characteristics as the project reach such as watershed size, watershed imperviousness, soil type, bed material, sediment loading, etc. In addition, the reference reach must be in equilibrium conditions and not unduly influenced by unstable upstream conditions (i.e., high sediment loads from eroding upstream channels or tributaries). Reference reach evaluations require familiarity and experience in geomorphology and river mechanics.

2. Sediment equilibrium analyses can be undertaken to estimate a longitudinal gradient that will provide for a balance between the expected inflow of water and sediment to a reach and the ability of the reach to convey that water and sediment without significant long-term aggradation or degradation. Like the reference reach approach, sediment equilibrium analyses require familiarity and experience in geomorphology and river mechanics.

3. Equilibrium slope may have been estimated in an UDFCD master plan.

4. A conservative low estimate of equilibrium slope for many urban stream systems within UDFCD boundaries is between zero and 0.2 percent. Sandy channel reaches subject to perennial flows in watersheds with significant urbanization and very low sediment load have been observed in the field at a near zero percent slope. Grade control structures laid out based on a zero or near-zero percent slope may at times of higher flow, higher sediment loading, and slightly steeper slope have their vertical drop height reduced on a temporary basis, but generally without negative effect as long as the sediment load and level of aggradation is not excessive.

Once a minimum equilibrium slope has been estimated, the overall drop structure height for a reach is the product of the reach length and the difference between the equilibrium slope and the actual slope or the floodplain terrace slope.

Cross sectional capacity. Drop structures are designed to span across the bankfull channel and some portion of the floodplain and are intended to tie into both floodplain terraces of the channel. In some streams, the grade control structures are designed to extend across the full width of the channel from outside bank to outside bank; these drop structures fully convey the capacity of the channel, which could include the 100-year event. This is depicted in Figure 8-16.

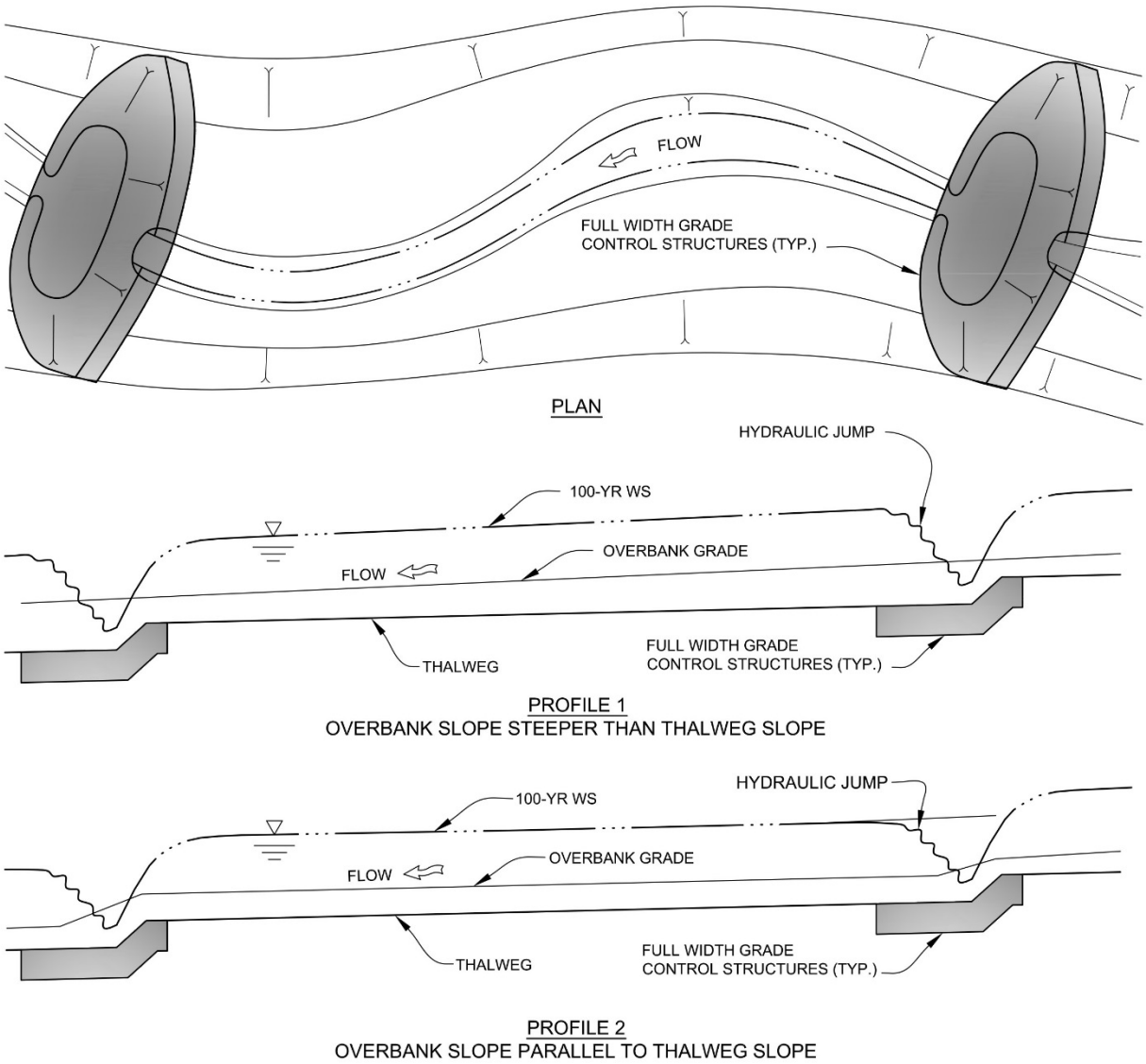


Figure 8-16. Full width grade control structures

Two longitudinal profiles are shown in Figure 8-16. The first assumes that the bankfull channel invert develops a long-term equilibrium slope that is flatter than the adjacent floodplain terraces; in this case the depth of the bankfull channel varies and is typically at a minimum just upstream of a grade control structure and a maximum just below the next drop structure upstream.

The second profile shows the slope of the floodplain terraces parallel to the invert of the bankfull channel. This case could occur when there is a natural drop in grade across the whole width of the channel, or when a design includes re-grading the terraces and a constant bankfull channel depth is maintained. In each profile, hydraulic jumps are shown to occur at the full-width grade control structures.

In other streams, especially in the larger ones, grade control structures may be designed to tie into the intermediate channel banks of the floodplain terraces that may have a capacity less than the 100 year peak flow. This concept is depicted in Figure 8-17. The grade control structures may have a capacity of a 20-year, 2-year, or just a bankfull channel event.

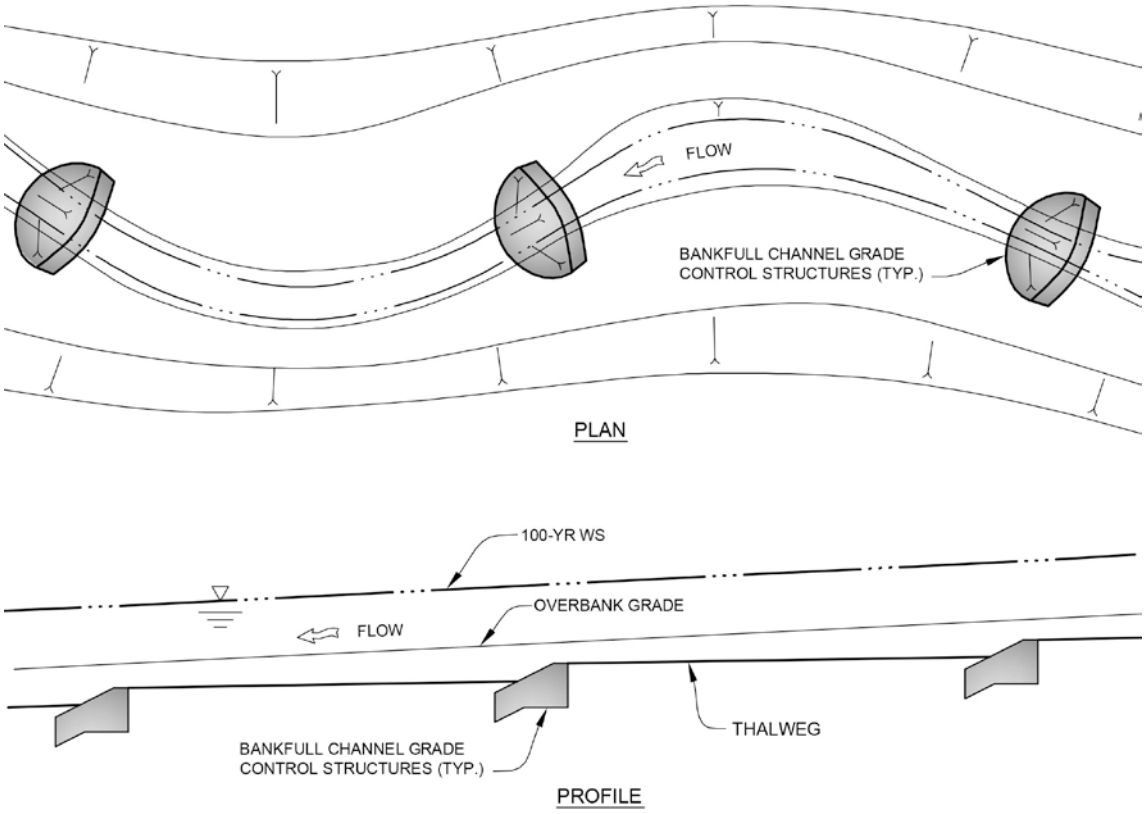


Figure 8-17. Bankfull channel grade control structures

Drop structures with capacities less than the 100-year event must be thoroughly analyzed to verify acceptable performance and stability during the 100-year event within the drop structure itself and in the adjacent terrace areas that will experience flow during the 100-year event. Often, the cutoff wall or sheet piling for a drop structure with a capacity less than the 100-year event will be extended substantially beyond the limits of the drop structure, sometimes to the limits of the 100-year floodplain.

Like the first profile of Figure 8-16, the longitudinal profile for bankfull drop structures reflects a bankfull channel longitudinal slope that is flatter than the longitudinal slope of the adjacent floodplain terraces. The depth of the bankfull channel varies and is typically at a minimum just upstream of a grade control structure and a maximum just below a drop structure; however, since drop structure spacing is typically more frequent for bankfull channel drop structures than full-width drop structures, the variation in channel depth is typically less. Bankfull channel drop structures are generally designed to drown out during large, infrequent floods such as the 100-year event and thus hydraulic jumps are not shown.

Drop structure height. In general, more frequently spaced low-height drop structures work best for flows smaller than the 100-year event. The most appropriate height should be verified through hydraulic analyses but may be less than a foot in height up to two feet. These small drop structures create less energy to dissipate, are better for fish passage integration, and can frequently be shown to drown out at higher flows, as shown in the profile of Figure 8-17. Figure 8-14 provides an example of how low-height drop structures can be incorporated into stream restoration design; it shows how drop structures in natural sand or cobble streams can consist of rock riffles located at crossovers between meander bends.

Stream Restoration Principle 5: Develop Grade Control Strategy to Manage Longitudinal Slope

Representative Design Tasks and Deliverables

1. Document estimate of long-term equilibrium slope used for drop structure spacing and its basis.
2. Describe rationale for selection of bankfull channel grade control structures or full-width structures, design capacity, heights of drops, and types of drops.
3. Confirm if fish passage is applicable and provided.
4. Document hydraulic design of grade control structures (refer to Sections 4.8, 7.0, and Hydraulic Structures chapter).
5. Provide design drawings showing grade control structures in plan, profile, section, and details.

4.6 Address Bank Stability

Existing steep, unstable banks at the edges of the bankfull channel or at outer channel banks should be addressed. Consider the following methods in the order that they are presented:

- Vegetation measures.
- Bioengineering measures that strategically combine vegetation with various means of reinforcements such as coir blankets, willows in various configurations, turf reinforcement mats (TRMs), or soil- or void-filled riprap.
- Structural measures such as riprap and boulders.

4.6.1 Bioengineering Techniques

Over the course of decades, the practice of stream restoration within UDFCD has evolved from the use of structural measures to an approach that first considers vegetation, then bioengineering techniques prior to hard structural measures. UDFCD promotes the integration of bioengineering techniques into stream restoration design when the use of these measures is consistent with the policies concerning flow carrying capacity, stability, and maintenance.

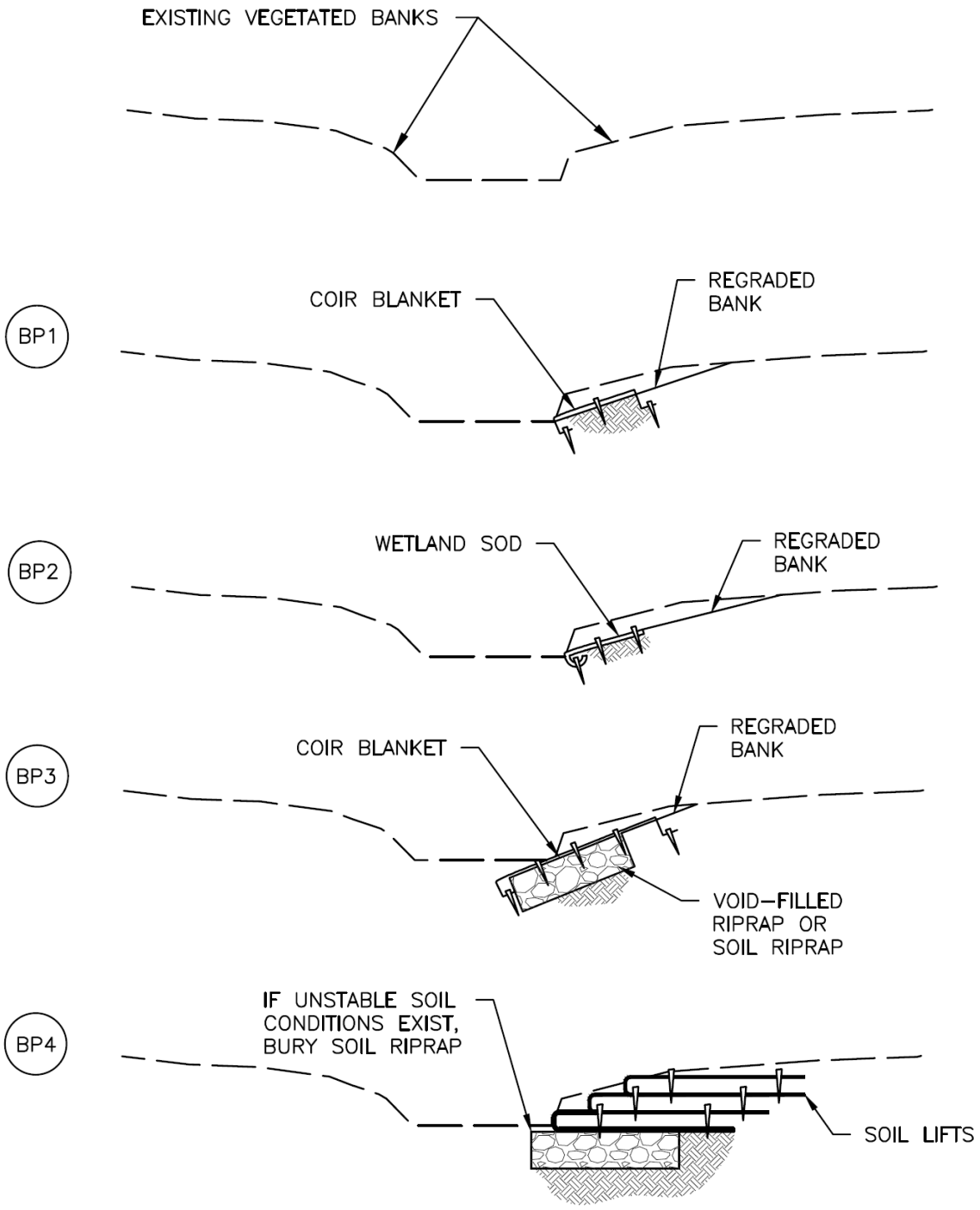
Compared to structural measures alone, vegetation and bioengineering appear more natural in character, enhance habitat, increase roughness to reduce velocities, may be of lower cost, and can create a living system that becomes stronger with time. On the other hand, care is necessary to select methods and vegetation suited to the hydrology of the stream, increased roughness of mature vegetation reduces flood conveyance capacity, and during the early years of establishment the risk of damage from large flood events may be greater than if more extensive structural measures are used. Many bioengineered stream restoration efforts have failed because the designer underestimated the stream power during large runoff events, or the likelihood of such events occurring during the vulnerable first several years of the newly established vegetation.

The advantages and risks of bioengineering techniques need to be taken into account by designers when selecting bank protection measures. As mentioned in Section 4.1, observing and understanding existing bank conditions, flow characteristics, causes of existing erosion, the potential for future erosion, and the proximity of infrastructure or property that could be impacted are necessary to design appropriate bank protection.

4.6.2 Bank Protection Approaches

Figure 8-18 shows several example approaches for protecting unstable banks along the bankfull channel. Photographs 8-11 through 8-16 illustrate a number of bioengineering approaches.

Because bank erosion may be more pronounced on the outside of bends, treatments may differ between the outside and inside. Treatments shown in Figure 8-18 generally apply to the outside bank. However, depending on stream conditions, any of these bank treatments may be implemented on the inside bank as well.



NOTES:
1. BANK PROTECTION TREATMENTS ARE SHOWN APPLIED TO RIGHT BANKS, BUT ARE APPLICABLE TO TO EITHER BANK.
2. TREATMENT SHOWN ARE FOR SCHEMATIC PURPOSES ONLY. THE DESIGNER IS RESPONSIBLE FOR FINAL DESIGN OF ALL TREATMENT INCLUDING STAKING PATTERNS, ROCK SIZING, ETC.

Figure 8-18. Example low-flow channel bank protection treatments

Photograph 8-11. Bioengineering techniques for channel stabilization immediately following construction.

Photograph 8-12. Same view as photo 8-11, one year after construction.

Photograph 8-13. Coir blanket used to protect the outside banks of a low-flow channel immediately following construction.

Photograph 8-14. (Same view as photo 8-13) Dense established vegetation.

Photograph 8-15. Soil lifts used to stabilize banks of low-flow channel. Photo taken immediately after construction.

Photograph 8-16. (Same view as photo 8-15 taken one year following construction.)

Severe bank erosion can occur when a low-flow channel migrates into a high outer bank, undermining the toe of the bank and causing a steep eroded face. Figures 8-19A and 8-19B show a number of examples for stabilizing and protecting this type of bank erosion. Like Figure 8-18, the bank protection approaches shown on the right side typically represent the outside bank.

Photograph 8-17. Void-filled riprap used to stabilize the low-flow channel.

Designers must weigh the imposed shear stresses during floods of various magnitudes and locations to the resistive shear of the vegetation and soil. Methodology for assessing shear resistance of vegetation is discussed in Section 4.7. UDFCD recommends using purely vegetative treatments when the vegetation can provide adequate protection for the bank. In areas where immediate protection is required, this approach may include the use of wetland sod. Biooengineered solutions such as soil lifts (see Figure 8-20), can be used to offer a higher level of protection in the initial years after construction, allow steeper construction, and also help establish vegetation. The material used for typical soil lift construction consists of a combination of coconut fabric and coir. In some locations more "permanent" turf reinforcement mats can be used within a soil lift to withstand shear stress in excess of vegetation alone.

The use of soil-filled and void-filled riprap for bank protection should undergo hydraulic design using the methods described in Section 8.0. Rock and boulders can be used when vegetative and bioengineered practices won't provide adequate bank protection. UDFCD experience has shown that bank treatments relying on boulders tend to be more susceptible to scour and undermining; therefore, the use of boulders should be limited to entrenched channel conditions and tight radii where vegetative methods are viewed as less viable. Grouted boulders require adequate foundation and proper backfill. See Figure 8-36 for a detail. As shown in Figure 8-19A and 8-19B, boulder bank protection over six feet high requires structural analysis to demonstrate that the design is stable against overturning.

Stream Restoration Principle 6: Address Bank Stability

Representative Design Tasks and Deliverables

1. Describe rationale for selection of bank protection measures, considering vegetative, bioengineering, or structural approaches. Determine whether the stream's hydraulic response to extreme events makes it suitable for bioengineering and vegetative approaches. This includes consideration of shear stress during floods of various magnitudes.
2. Provide design drawings showing bank protection layouts in plan and section.
3. Provide supporting hydraulic calculations for selected bank protection.

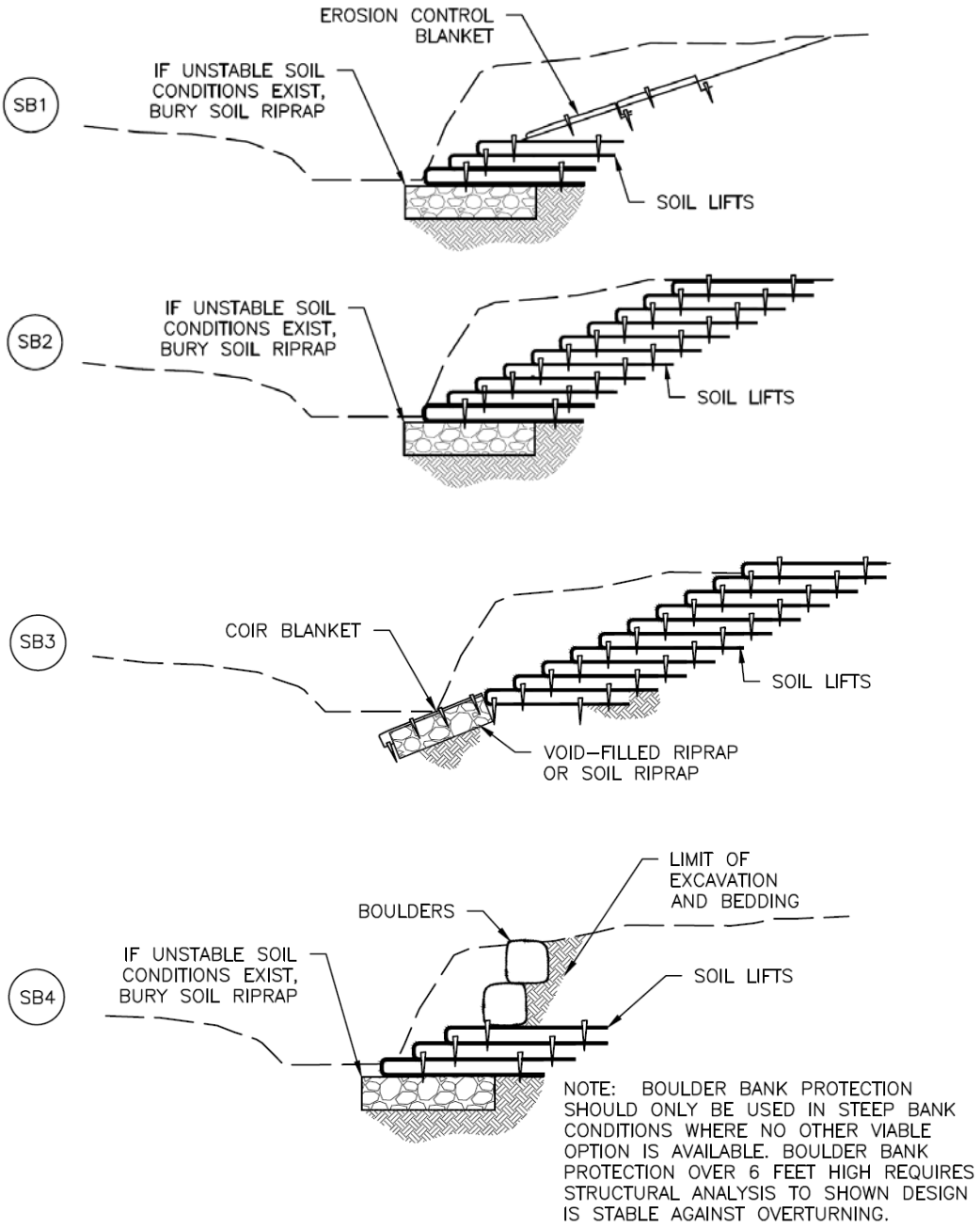


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Figure 8-19A. Example bank protection treatments for steep eroded banks

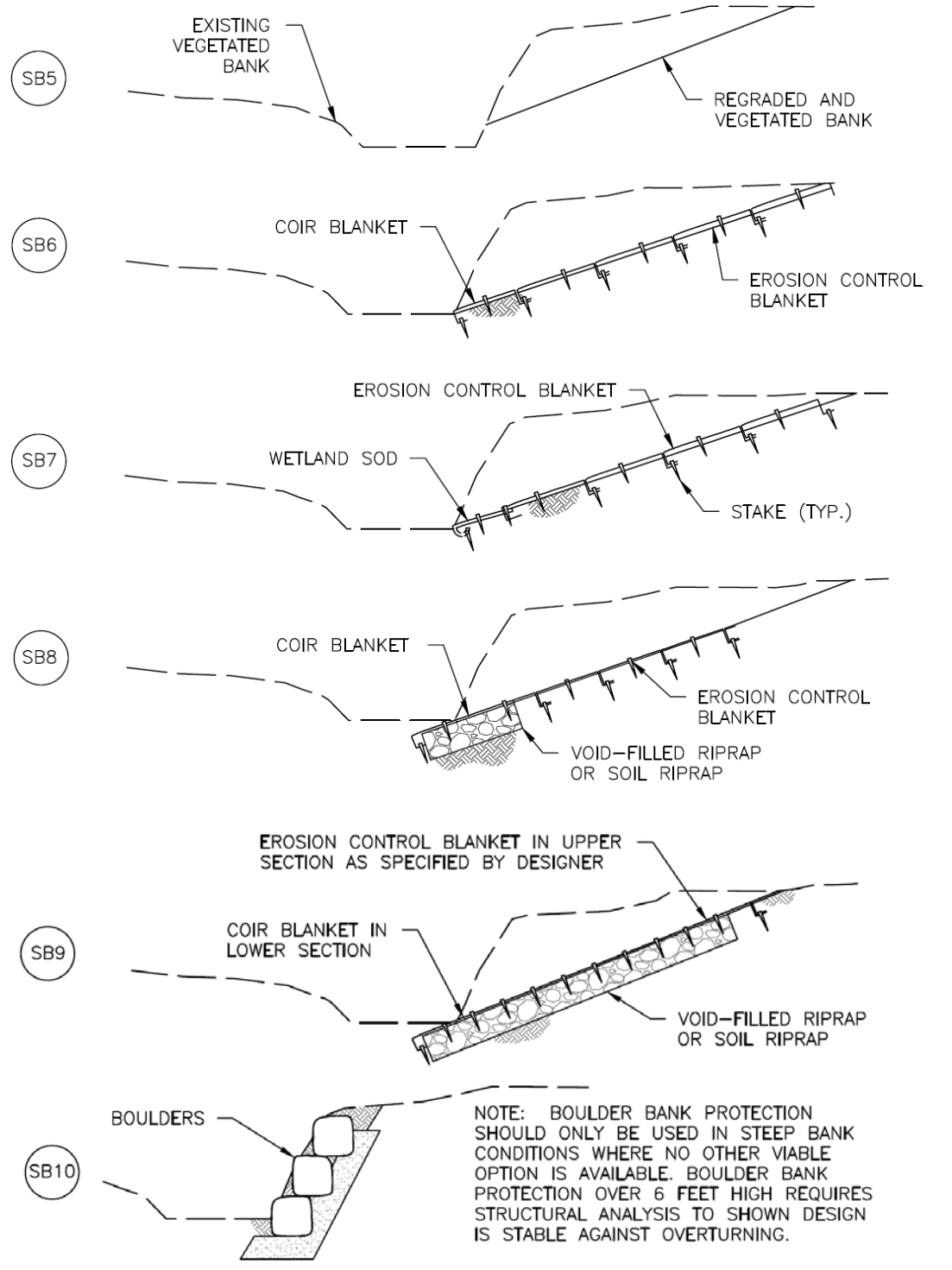

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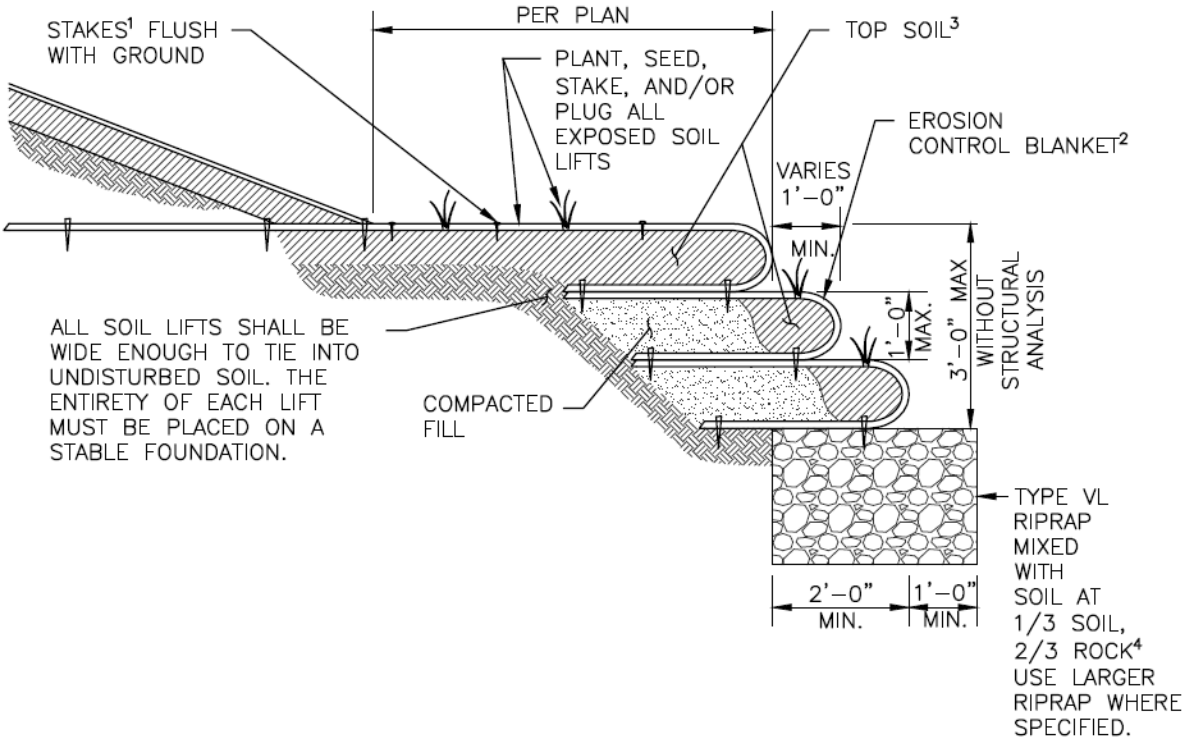
Figure 8-19B. Example bank protection treatments for steep eroded banks



1. SEE FIGURE 13-5 IN REVEGETATION CHAPTER.
2. SPECIFY MATERIALS BASED ON HYDRAULIC CONDITIONS. MINIMIZE SEAMS, SPECIFYING MATERIAL WITH A WIDTH WIDE ENOUGH TO PLACE FABRIC PARALLEL TO FLOW. ALL FABRIC SHOULD BE PLACED TIGHT TO SOIL.
3. SEE REVEGETATION CHAPTER.
4. RIPRAP MAY NOT BE REQUIRED IN ALL LOCATIONS. THIS MAY BE ELIMINATED WHERE HYDRAULIC CONDITIONS DO NOT WARRANT RIPRAP AND THE ENGINEER DETERMINES SUBGRADE TO BE STABLE.

Figure 8-20. Sample soil lift section

4.7 Enhance Streambank and Floodplain Vegetation

As described in Section 4.6 in relation to bioengineering approaches, it is desirable to re-establish or supplement vegetation in stream corridors, especially along the banks of the low-flow channel and on the adjacent floodplain terraces to build up a sturdy, durable cover to help retard flood flows, resist erosion, and enhance habitat. Establishing a relatively shallow bankfull channel as described in Section 4.3 can help maintain a shallow water table favorable for terrace vegetation.

Deep-rooted riparian grasses such as Prairie Cordgrass, sedges, rushes, and other herbaceous species can provide excellent shear resistance to protect streambanks and floodplain terraces. Willows possess an amazing ability to root and thrive in streamside environments and are an important element in bioengineered bank protection; however, it is desirable to create a diverse mix of herbaceous species, woody shrubs, and trees within the floodplain and to avoid establishing a dominant monoculture of willows. Willows can also create a very dense stand of vegetation that may ultimately impact flood conveyance.
Analysis of the stability of grass lined channels should be completed using the stability procedures documented in the Agricultural Research Service (ARS) *Agricultural Handbook Number 667* (hereinafter referred to as *Handbook #667*). Developed in 1987, Handbook *#667* includes comprehensive methods for evaluating shear stress on grass and the underlying soil based upon grass height, density and soil type.

U.S. Army Corp. of Engineers, through its Ecosystem Management and Restoration Research Program (EMRRP), also provides a good resource for evaluating shear stress for a number of different channel lining methods in *Stability Thresholds for Stream Restoration Materials* (Fischenich 2001). Another resource for shear stresses of various vegetation and bioengineering methods is Table TS14I–4 in Technical Supplement 14I, *Streambank Soil Bioengineering* (USDA 2007).

The soil compaction effects of heavy equipment engaged in stream restoration work must be mitigated to help revegetation efforts. Compacted ground must be thoroughly deep-tilled and topsoil previously stripped and stockpiled needs to be replaced and fine-graded in disturbed areas prior to seeding and planting. If inadequate existing topsoil is available, topsoil meeting specified agronomic characteristics should be imported.

Bioengineering Tips

1. When using blankets or mats parallel to the channel, avoid grade breaks in the middle of the blanket or mat run. Consider using soil wraps at these locations to provide better channel definition.
2. Ensure blankets and mats meet manufacturers' shear stress and velocity limits under critical flows in an unvegetated state. Use a safety factor as these tests are not typically performed for extended durations. (Fischenich 2001)
3. In areas subject to flow, blankets must be installed to hold the seed and soil in place. Placing seed and then straw and staking coir fabric over the straw is commonly used to achieve this. See the *Revegetation* chapter for a detail.
4. Consider using larger wooden stakes at toes and in trenches while using biodegradable stakes through the middle and upper sections of blankets and mats. This reduces obstacles for maintenance operations and recreational users.
5. Consider the area where the bank meets the channel bottom carefully. Reinforcement with wetland sod, willow logs, etc. can help ensure success.

Because of the challenges involved in getting vegetation established in areas disturbed by construction as well as the importance of early establishment to the function of a stream, follow-up activities must be planned over a several-year period to nurture vegetation efforts. Activities such as weed control, supplemental watering, reseeding, and replanting need to be planned, budgeted, and executed diligently to help disturbed areas fully recover and be protected with a healthy, varied mix of riparian vegetation. Streams that are constrained in terms of flood capacity require periodic maintenance activities to thin floodplain vegetation and reduce roughness.

Chapter 12, *Revegetation*, provides detailed guidance regarding revegetation efforts in stream corridors.

Stream Restoration Principle 7: Enhance Streambank and Floodplain Vegetation

Representative Design Tasks and Deliverables

1. Identify areas of existing riparian vegetation that will be preserved and fenced off during construction.
2. Document approach and rationale for revegetation, identifying general seed mixes and types of plantings. Confirm that hydrology is suitable for vegetation selected.
3. Provide design drawings showing a detailed vegetation plan, including seed mix and planting details and specifications for loosening compacting disturbed soils and establishing adequate topsoil.

4.8 Evaluate Stream Hydraulics of over a Range of Flows

Detailed hydraulic modeling of stream corridors with proposed restoration improvements is required to assess flow depths, velocities, Froude number, imposed shear stress and other relevant parameters. The hydraulic analysis should consider a range of flows including the bankfull discharge, 2-year, 10-year, 100-year, and perhaps other intermediate and larger flows.

Section 7.0 provides guidance for conducting hydraulic modeling. The hydraulic modeling provides important information to guide the design of stream restoration improvements. It is recommended that hydraulics be evaluated for three conditions:

1. Baseline conditions reflecting estimated historic, unconstrained channel configuration, vegetation, and pre-development flow rates, if such conditions can be estimated.
2. Existing channel conditions based on estimated future development flow rates.
3. Proposed conditions representing the designed stream restoration improvements.

In each case, hydraulic parameters should be summarized for average flow conditions in the channel as well as independently in the main channel and terraces. The following hydraulic summaries are recommended:

- Longitudinal profiles showing bed invert, any grade control structures, and water surface profiles for a range of return periods.
- Longitudinal summaries of flow velocities and shear stress for the main channel and left and right terraces referenced to the same stationing as the profile information above.
- Cross section distributions of velocity and shear stress at representative locations along a design reach.

Section 7 provides guidance and examples of this hydraulic information. The overall goal is to use the information to assess in what ways and to what extent existing channel and hydraulic conditions depart from baseline conditions and to identify proposed stream improvements that create or restore healthy stream form, hydraulic conditions, and sediment equilibrium.

It is important to test the sensitivity of varied channel roughness – low roughness estimates for velocity and shear considerations and high roughness estimates for water surface determinations. Additional guidance on roughness estimates is provided in Section 7.0. Based on anticipated species and densities of vegetation and the in situ soil characteristics, it is necessary to confirm that imposed shear stress is less than shear resistance of soil/vegetation for the intended design event. Section 4.7 describes resources available to support these evaluations. In addition, rock sizing procedures are described in Section 8.0. The hydraulic analysis effort is normally iterative, requiring refinements to the design to obtain desired hydraulic conditions.

Table 8-1 summarizes desirable geometric and hydraulic design parameters for naturalized channels. This table should be used as a guide for determining the stability of a channel. The designer's experience and judgment are also an important aspect of determining channel stability. Although recommendations for maximum tractive force (or shear stress) are provided, the designer may elect to assess the resistive shear stress provided by terrace vegetation and soils and determine design limits specific to the project.

Since the subject of this Section 4 is restoring natural streams, it may be that the maximum prudent values for the hydraulic parameters shown in Table 8-1 are exceeded in the 100-year event even after the recommendations of subsections 4.1 through 4.8 are followed, including avoiding filling the floodplain, establishing a shallow bankfull channel with adjacent vegetated terraces, opening up constrictions, implementing grade control structures, and enhancing vegetation. The goal would be to come as close as

possible for as much of the reach as possible to the maximum prudent values for the hydraulic parameters in the 100 year event. The designer should determine the return period where these parameters would be achieved and, with the owner and local jurisdiction, determine if the associated risks are acceptable.

On the other hand, if the recommendation to avoid floodplain filling is not followed and fill is proposed, this should only happen in floodplains where the maximum prudent values for the hydraulic parameters shown in Table 8-1 are not exceeded in the 100-year event.

Table 8-1. Maximum prudent values for natural channel hydraulic parameters

Design Parameter	Non-Cohesive Soils or Poor Vegetation	Cohesive Soils and Vegetation
Maximum flow velocity (average of section)	5 ft/s	7 ft/s
Maximum Froude number	0.6	0.8
Maximum tractive force (average of section)	0.60 lb/sf	1.0 lb/sf
Maximum depth outside bankfull channel	5 ft	5 ft

Stream Restoration Principle 8: Evaluate Hydraulics of Streams over a Range of Flows

Representative Design Tasks and Deliverables

1. Document hydraulic analyses of the project reach following the guidance of Section 7.0.
   2. Describe how hydraulic performance of the project reach compares to maximum prudent values for the hydraulic parameters shown in Table 8-1 for several return periods (including 2-, 10-, and 100-year events at a minimum). Describe any locations in the reach where these parameters are exceeded and discuss efforts made to improve hydraulics.
3. Confirm that hydraulic parameters of Table 8-1 are satisfied in for the100-year event in all locations where fill is proposed in the floodplain.

5.0 Naturalized Channels

Natural channels may not be well-defined in upland tributary areas and it may be necessary to construct new channels "from scratch." By applying principles from Section 4, new surface channels can be created that emulate natural streams and, over time, may take on the appearance and functions of natural streams with supporting vegetation and biota. The criteria and techniques presented in this section may also be used on some existing stream reaches where existing urban constraints are limiting.

Remember Permitting Requirements

The environmental permitting process benefits greatly from early and close coordination with the US Army Corps of Engineers. Environmental firms experienced in 404 permitting not only make the process efficient and successful but provide valuable expertise on restoration projects. The stream restoration principles described in this chapter represent good practice and are consistent with the intent of the 404 permit system to protect waters of the US. In addition, Endangered Species Act (ESA) requirements must be addressed for Conditional Letters of Map Revisions

These projects also frequently require Federal Emergency Management Agency (FEMA) map changes. See the *Flood Risk Management* chapter for guidance.

Naturalized channels do not have concrete trickle channels and are generally not intended to be vegetated with irrigated sod; rather, native grasses and riparian species are recommended. Vegetation at the edges of the low-flow channel and in the adjacent floodplain terraces is generally not intended to be mowed to a low height. Current criteria in this manual do not address bare rock riprap-lined channels or concrete-lined channels, since these are not recommended as typical channel treatments. Design guidelines for these types of channels can be found in other manuals.

The eight stream restoration principles from Section 4 apply directly to the design and construction of naturalized channels. These are summarized below; the designer is encouraged to review the applicable information in the corresponding Sections 4.1 through 4.8.

5.1 Understand Existing Stream and Watershed Conditions

For naturalized channels, the goal of this principle is to locate candidate reference reaches that have desirable geometric, hydraulic, and vegetative characteristics that can be used as a guide for the design of the project reach. Ideally, reference reaches would serve about the same upstream area and convey similar flow rates; however, desirable reference reaches serving larger or smaller areas may be able to be scaled to match the design flows of the naturalized channel. In many cases however, no applicable reference reach will exist, in which case the bankfull channel sizing methods described in Section 4.3.2 should be applied.

Researching design flows and understanding characteristics of the watershed upstream of the naturalized channel involves the same types of information and yields the same benefits as described for natural streams in Section 4.1. As a first step, every effort should be made to apply runoff reduction methods in upstream watershed areas. The more runoff reduction upstream, the lower the range of flow rates, velocities, and shear stresses, the less structural the stream improvements need to be and the higher the water quality of runoff. The relative increase in flows from pre-development conditions to future build-out are to be evaluated as part of understanding the existing stream and watershed conditions for the naturalized channel.

5.2 Apply Fluvial Geomorphology Principles to Manage Sediment Balance

While sediment loading may not be a design consideration for naturalized channels draining small watersheds, it is still advisable to consider sediment movement and fluvial channel characteristics. A relatively small upstream drainage area combined with a low sediment load may translate into a channel that can support vegetation across the bottom of the bankfull channel. This type of channel may resist bed degradation better than an unvegetated channel bottom and therefore be able to maintain a slightly steeper longitudinal slope, driven less by a need to control baseflow erosion and more by the desired overall channel hydraulics in the design storm.

5.3 Establish Effective Cross-Sectional Shape

Creating a properly sized bankfull channel with adjacent vegetated floodplain terraces is a critical element in the design of naturalized channels. Sizing of the bankfull channel as described in Section 4.3.2 can be applied to these channels; however, Table 8-2 provides minimum dimensions for bankfull channels and floodplain terraces in naturalized channels. Figure 8-21 defines the geometry addressed in Table 8-2 for a naturalized channel.

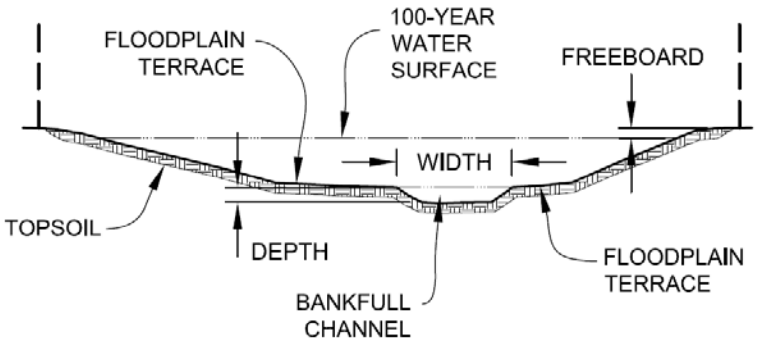


Figure 8-21. Typical naturalized channel geometry

The bankfull channel in naturalized channels should be sized to convey at least 70% of the future development 2-year flow or 10% of the future development 100-year flow, whichever is greater. In addition to the minimum dimensions shown in Table 8-2, a maintenance access path with a minimum per the geometry listed in Table 9-3 of the *Stream Access and Recreational Channels* chapter.

Table 8-2. Minimum dimensions for naturalized channels[1]

Bankfull Channel Depth, ft	Minimum Bankfull Channel Width, ft	Minimum Floodplain Terrace Width (average each side), ft
0.5	6	6
1.0	10	8
1.5	14	10
2.0	18	12
2.5	24	16
3.0	30	20

[1] Values are based on a desired entrenchment ratio between 3 and 4. Based on several scenarios modeled in HEC-RAS, the values in this table, when paired with the criteria in Table 8-3, produce generally favorable hydraulics.

As in natural streams, channel vegetation and roughness will increase over time and long-term sediment deposition could raise the bed of the channel. Therefore, conservatively high roughness values should be used for assessing flow depths (per Section 7.0) and a freeboard of 18 inches or more should be considered.

5.4 Maintain Natural Planform Geometry

The planform of naturalized channels can be created to emulate features of natural reference reaches. As was discussed in Section 4.4, natural streams offer variety and complexity in form; they are seldom straight and uniform. Outer banks move in and out and bank heights, slopes, and widths vary. Bankfull channels exhibit a degree of meandering and sinuosity, moving right and left across a section in an alternating manner. The shape of the low-flow channel varies, tending to widen slightly in bends and narrow in riffles between bends; side slopes tend to steepen at the outside of bends and flatten as point bars form on the inside of bends. All of these characteristics can be reflected in naturalized channels.

Care should be taken to avoid sharp bends in the channel. A radius of curvature at least two times the channel top width is recommended, although ratios of three or four times top width are preferable.

5.5 Develop Grade Control Strategy to Manage Longitudinal Slope

If the grading adjacent to a channel can be made to match the design slope of the channel, the need for drop structures may be eliminated. If the adjacent grade is steeper than the design slope, grade control in the channel will be necessary. For small channels, grade control structures will most often extend across the full channel section and the grade of the floodplain terraces will typically be configured to match the design slope of the bankfull channel invert. Section 4.4 should be referred to for design guidance regarding the height and spacing of drop structures.

5.6 Address Bank Stability

Constructed naturalized channels will not typically have extensive bank erosion problems to address; however, bank protection for low-flow channel banks or outer banks may be incorporated into the design, particularly on the outside of bends. Bank protection measures can be determined based on the options identified in Section 4.6. Bioengineering applications for bank protection may be considered for naturalized channels given acceptable hydraulic response (e.g., stream power) to extreme events.

5.7 Enhance Streambank and Floodplain Vegetation

The naturalized channel should be seeded and planted with herbaceous and woody species appropriate for anticipated hydrologic conditions in zones adjacent to the bankfull channel as described in Section 4.7 and the *Revegetation* chapter of this manual. It is critical that the soil compaction effects of heavy equipment be mitigated to help revegetation efforts. Compacted ground must be thoroughly deep-tilled, amended and topsoil previously stripped and stockpiled needs to be replaced and fine-graded in the channel prior to seeding and planting.

In addition, a post-construction maintenance phase should be planned for watering, weed control, and supplemental seeding/planting to ensure vegetation establishment.

Topsoil

Topsoil is a valuable resource. Where present, remember to strip, stockpile and use this material. Because of the importance of favorable soil characteristics for plant health, naturalized channel projects may call for 12 inches of topsoil for the full width of the channel. See the Revegetation chapter for additional recommendations.

5.8 Evaluate Stream Hydraulics over a Range of Flows

Conduct detailed hydraulic modeling of naturalized channels, applying low roughness estimates for velocity and shear considerations and high roughness estimates for water surface determinations, as described in Section 7.0. Confirm that imposed shear stress is less than the shear resistance of soil/vegetation for the intended design event and refine the design to obtain the hydraulic conditions identified in Table 8-3, below. Note that the parameters listed in this table assume cohesive soils and vegetation; however, it is recommended that these values be satisfied for roughness conditions that will exist immediately after construction.

Table 8-3. Design parameters for naturalized channels

Design Parameter	Design Value
Maximum 100-year depth outside of bankfull channel	5 ft
Roughness values	Per Table 8-5
Maximum 5-year velocity, main channel (within bankfull channel width) (ft/s)	5 ft/s
Maximum 100-year velocity, main channel (within bankfull channel width) (ft/s)	7 ft/s
Froude No., 5-year, main channel (within bankfull channel width)	0.7
Froude No., 100-year, main channel (within bankfull channel width)	0.8
Maximum shear stress, 100-year, main channel (within bankfull channel width)	1.2 lb/sf
Minimum bankfull capacity of bankfull channel (based on future development conditions)	70% of 2-year discharge or 10% of 100-yr discharge, whichever is greater[1]
Minimum bankfull channel geometry	Per Table 8-2
Minimum bankfull channel width/depth ratio (Equation 8-3)	9
Minimum entrenchment ratio (Equation 8-4)	3
Maximum longitudinal slope of low flow channel (assuming unlined, unvegetated low flow channel)	0.2 percent
Bankfull channel sinuosity (Equation 8-5)	1.1 to 1.3
Maximum overbank side slope	4(H):1(V)
Maximum bankfull side slope	2.5(H):1(V)
Minimum radius of curvature	2.5 times top width

[1]Roughly equivalent to a 1.5-year event based on extrapolation of regional data.

6.0 Swales

The functions and benefits of natural streams can be extended further upstream in the watershed by conveying runoff on the surface in vegetated channels and swales rather than in underground storm drains. Besides the aesthetic and habitat value of surface channels, stormwater quality can be enhanced by promoting beneficial interaction between water, soil, and vegetation. Conveyance in storm drains produces no such interaction or water quality enhancement.

Guidance is provided in this subsection for the design of swales, draining areas from less than an acre up to about 10 impervious acres (e.g., 20 acres at 50% imperviousness). A series of design charts are provided to guide the designer in determining stable conditions in vegetated or void-filled riprap swales of varying cross sections based on design flow rate and slope. The charts show flow rates as high as 100 cfs (stable at relatively flat slopes) and slopes as steep as 10 percent (stable at relatively low flows). It should be noted that the design criteria in this section differs from those in *Volume 3* of this manual. Volume 3 criteria are intended to provide a higher level of water quality treatment. These criteria are intended for stable conveyance more so than water quality benefits.

6.1 Design Criteria for Swales

Design criteria are described for grass and rock (soil riprap or void-filled riprap) swales. Where indicated by Figures 8-22 through 8-25, grass swales meeting these criteria are preferred, but when conditions require, swales lined with soil riprap or void-filled riprap are advisable.

In order to maximize the use of grass swales, and increase the likelihood that the swale will remain functional and stable over time, two key design principles should be considered.

1. **Adopt shallow swale section with flat bottom.** Swale cross sections that allow runoff to spread out (shallow, flat bottom with gentle side slopes) promote lower velocities and shear stresses than triangular (or "V" shaped) swales. This is also good for water quality. In general, the wider the bottom width of the swale, the more stable it will be, although concentrated flow paths may still form. It is generally recommended that swales be of a trapezoidal shape with a bottom width of 2 feet or more and with side slopes that are 5:1 or flatter.

2. **Establish dense turf-forming grass in suitable soils**. The single most important factor in creating stable grass swales is to establish a dense stand of turf-forming grass in the bottom and side slopes of the swale. This requires good soils or amendments and proper soil preparation and planting. Irrigation may also be necessary. See the *Revegetation* chapter for more information.

6.1.1 Stability Charts

Swale stability based on slope, flow rate, swale geometry, and grass or rock lining are shown graphically in Figures 8-22 through 8-25. Design guidance is provided in the stability charts for design discharges up to 100 cfs and for longitudinal slopes up to 10 percent. Although these figures go up to 100 cfs, it may be appropriate to design a more naturalized channel section for flow rates greater than 30 to 40 cfs. This is largely dependent on site-specific considerations. As already mentioned, steep swales are most feasible for small discharges while swales carrying large discharges are most feasible at flatter slopes. If the chart is indicating that riprap greater than Type H (see Figure 8-34) is required, a swale for those hydraulic conditions is not recommended. Typically, if Type H riprap is required, consider other options such as widening the swale or flattening the slope.

The use of Figures 8-22 through 8-25 for swale stability analysis requires that the geometric parameters indicated at the top of each chart apply and the requirements of Section 6.2 for grass swales and Section 6.3 for soil riprap or void-filled riprap are met.

Table 8-4 below summarizes the appropriate stability chart to reference based upon the swale geometry.

Table 8-4. Summary of swale properties for stability chart reference

Bottom Width	Side slope	Stability Chart
2 - 4 feet	between 5:1 and 10:1	Figure 8-22
2 - 4 feet	10:1 or flatter	Figure 8-23
greater than 4 feet	between 5:1 and 10:1	Figure 8-24
greater than 4 feet	10:1 or flatter	Figure 8-25

For swales outside the range of application of Figures 8-22 through 8-25, specific analysis of the

proposed swale parameters may be required. See Section 6.2 for additional guidance on determining the stability of grass swales. Analysis for riprap-lined swales should be completed using the methodologies discussed in Section 6.3.

6.2 Grass Swales

6.2.1 Soil and Vegetation Properties

The single most important factor governing the stability of grass swales is the quality of vegetation. Refer to the *Revegetation* chapter of this manual for proper site preparation including soil testing, topsoil, amendments, and recommendations for addressing soil compaction. The *Revegetation* chapter also provides recommended seed mixes. Turf-forming grasses that include a variety of species work best.

In addition to seeding, it is recommended that grass plugs of the dominant species in the seed mix be planted to provide some immediate vegetative cover and improve overall establishment. Place drier species on the side slopes. Placing sod is also an option for grass swales.

Discussion regarding the use of Handbook #667 for stability analysis of grass channels can be found in Section 4.7.

6.2.2 Construction

It is imperative that the construction drawings and specifications address seedbed preparation; installation of seed, blankets, and plugs; temporary irrigation; weed control; and follow-up reseeding and maintenance. Specific construction recommendations, including for submittals and inspections, can be found in the *Revegetation* chapter. Good temporary erosion controls are critical during establishment of vegetation.

6.3 Soil Riprap and Void-Filled Riprap Swales

For swales that require riprap lining, use a soil riprap for void-filled riprap mix. Additional information is provided in Section 8.0. Use Figures 8-22 through 8-25 for final design only when the appropriate geometric parameters are met. Table 8-4 summarizes the appropriate stability chart based on swale geometry.

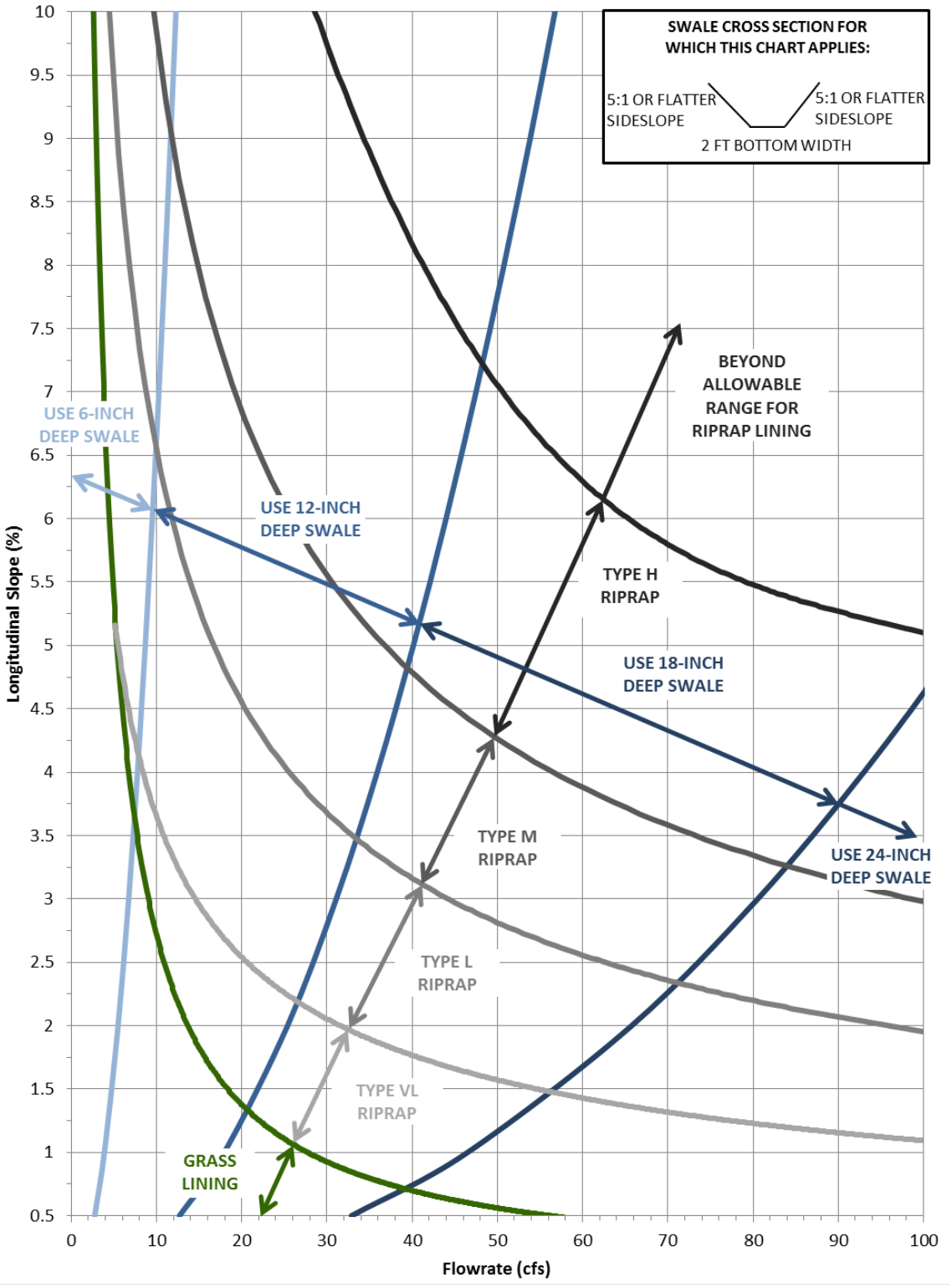


Figure 8-22. Swale stability chart; 2- to 4-foot bottom width and side slopes between 5:1 and 10:1 (Note: Riprap classifications refer to gradation for riprap used in soil riprap or void-filled riprap. See Figure 8-34 for gradations.) (Source: Muller Engineering Company)

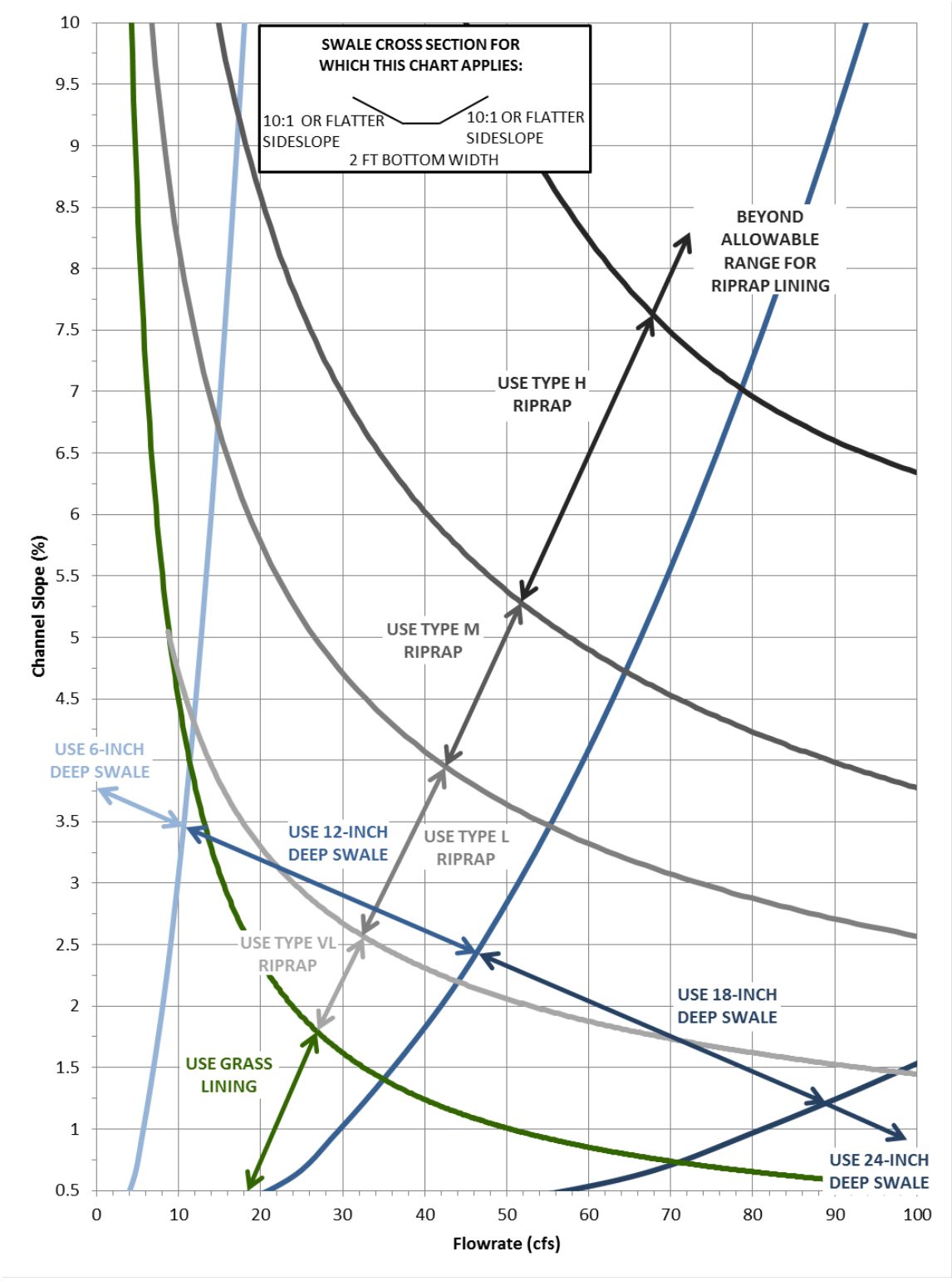


Figure 8-23. Swale stability chart: 2- to 4-foot bottom width and 10:1 (or flatter) side slopes
(Note: Riprap classifications refer to gradation for riprap used in soil riprap or void-filled riprap. See Figure 8-34 for gradations.) (Source: Muller Engineering Company)

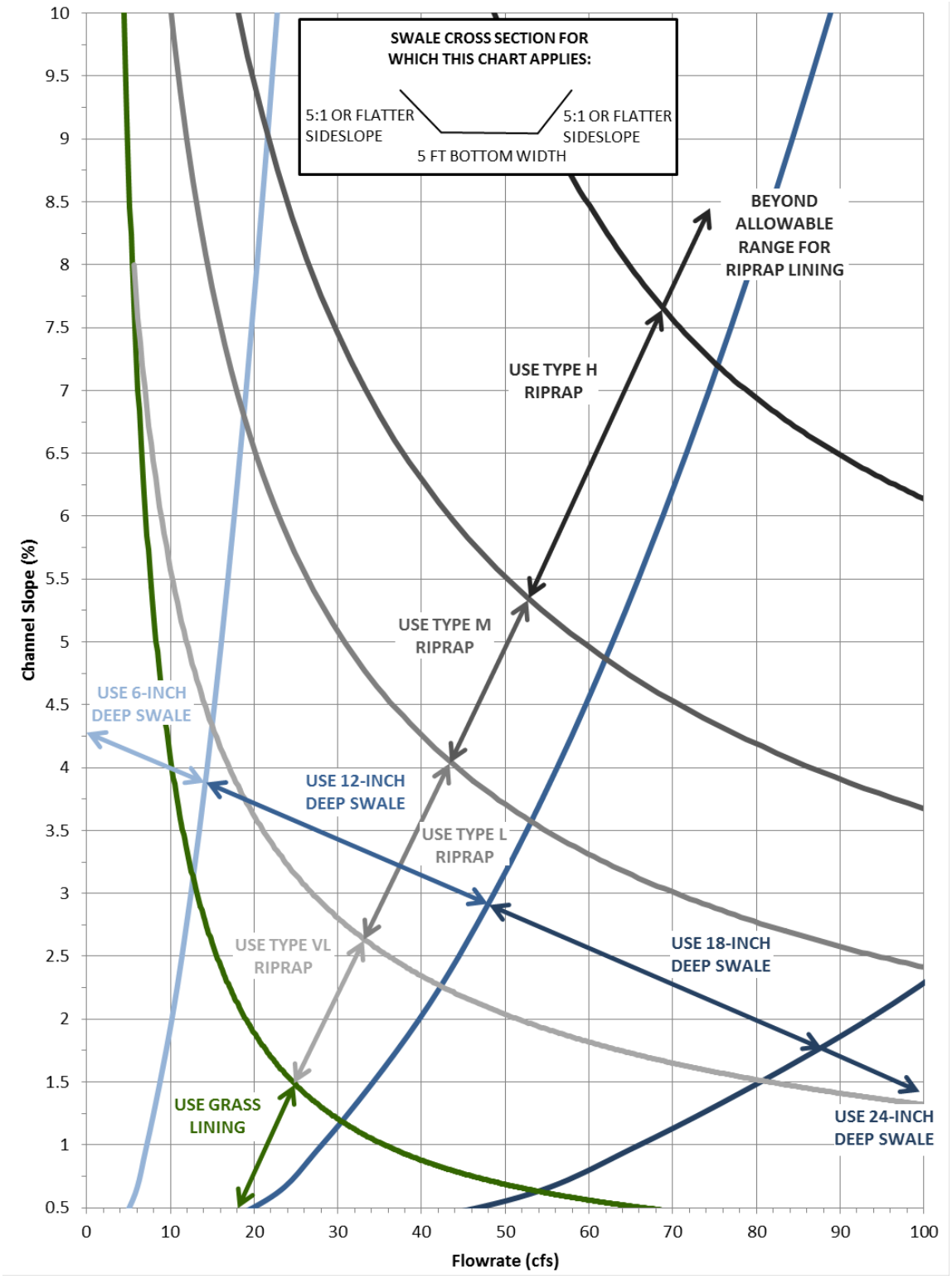


Figure 8-24. Swale stability chart: greater than 4-foot bottom width and side slopes between 5:1 and 10:1

(Note: Riprap classifications refer to gradation for riprap used in soil riprap or void-filled riprap. See Figure 8-34 for gradations.) (Source: Muller Engineering Company)

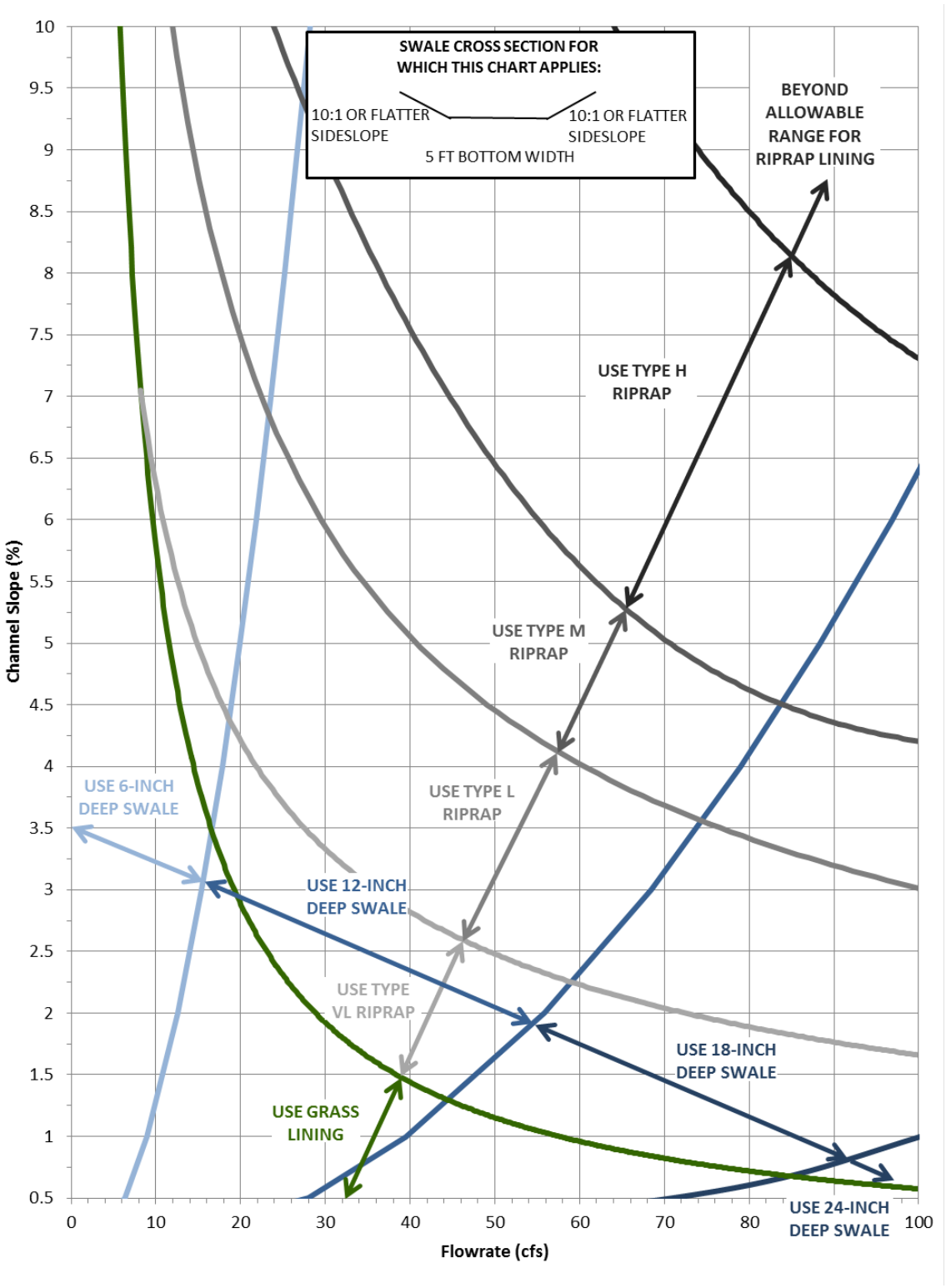


Figure 8-25. Swale stability chart: greater than 4-foot bottom width and 10:1 (or flatter) side slopes (Note: Riprap classifications refer to gradation for riprap used in soil riprap or void-filled riprap. See Figure 8-34 for gradations.) (Source: Muller Engineering Company)

7.0 Hydraulic Analysis

Evaluating channel and floodplain hydraulics is a key component of any stream project. Hydraulic modeling provides insight into flow properties including water surface elevation, depth, velocity, shear stress, and Froude Number. Understanding these flow properties is necessary to assess risks associated with structure flooding and channel erosion and can help guide the design of stream capacity and stabilization improvements.

7.1 Preliminary Channel Analysis

For detailed hydraulic analysis, hydraulic modeling software is recommended (i.e., HEC-RAS). There may be times when a preliminary or "quick" analysis is needed to evaluate channel properties in uniform steady flow conditions. For these cases, Manning's Equation should be used. Manning's Equation describes the relationship between channel geometry, slope, roughness and discharge for uniform flow conditions and is expressed as:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \qquad \text{Equation 8-6}$$

Where:

Q = discharge (cfs)

n = roughness coefficient (see Section 7.2.3)

A = area of channel cross section (ft^2)

R = hydraulic radius = A/P (ft)

P = wetted perimeter (ft)

S = friction slope (ft/ft) (approximated by channel invert slope for normal depth calculations)

Manning's Equation can also be expressed in terms of velocity by employing the continuity equation, $Q = VA$, as a substitution in Equation 8-6, where V is velocity (ft/sec).

For wide channels of uniform depth, where the width, b, is at least 25 times the depth, the hydraulic radius can be assumed to be equal to the depth, y, expressed in feet, and, therefore:

$$Q = \frac{1.49}{n} by^{5/3} S^{1/2} \qquad \text{Equation 8-7}$$

The solution of Equation 8-6 for depth is iterative, therefore using a software program to assist with this calculation can be beneficial. A number of additional software packages are available to solve Manning's Equation by inputting known channel properties.

The designer should realize that uniform flow is more often a theoretical abstraction than an actuality (Calhoun, Compton, and Strohm 1971), namely, true uniform flow is difficult to find. Channels are sometimes designed on the assumption that they will carry uniform flow at normal depth, but because of ignored conditions the flow actually has depths that can be considerably different. Uniform flow computation provides only an approximation of the hydraulic conditions that will actually occur.

7.2 HEC-RAS Modeling

The most commonly used tool for open channel hydraulic modeling is the Hydrologic Engineering Center's River Analysis System (HEC-RAS) from the US Army Corps of Engineers. For the purpose of this chapter, discussion will focus on HEC-RAS's ability to perform one-dimensional steady flow analysis using a series of input parameters. Typical input parameters include flowrate, channel cross section geometry, roughness coefficients, main channel bank stations, etc. HEC-RAS has the capability to model bridges, culverts, weirs and spillways as well as address unsteady flow computations. In most cases, a subcritical HEC-RAS run is appropriate for natural channels since significant reaches of supercritical flow do not often occur in natural Front Range streams (Jarrett 1985). This section provides guidance on determining appropriate input parameters and reviewing output information when undertaking HEC-RAS modeling.

7.2.1 Cross Section Location

Cross sections should be placed relatively frequently along a channel reach in order to adequately evaluate the channel characteristics. Cross section placement should be governed by changes in discharge, channel width, slope, shape, roughness, and the location of hydraulic structures (bridge, culvert, grade control structure, etc.). Typical cross section spacing may be in the range of 200 to 400 feet or closer if conditions warrant. Refer to the *Hydraulic Structures* chapter and the *Culverts and Bridges* chapter guidance on cross section placement for grade control structures and bridges respectively. The HEC-RAS Hydraulic Reference Manual is an essential document to be familiar with when performing HEC-RAS analyses.

In addition to spacing of cross sections along a stream reach, the designer must consider the alignment of individual cross sections. Cross section should generally be oriented to be perpendicular to the channel centerline and the water flow path. At times it may be necessary to include deflections in the cross section in order to be perpendicular to flow in the channel terraces. Figure 8-26 illustrates an example of cross section placement and alignment to capture channel flow paths perpendicular to the cross section.

2D Flow Modeling

Two-dimensional hydraulic modeling is not addressed in this manual, although its use is becoming more widespread for evaluating complex hydraulic conditions. Guidance in this manual is limited to one-dimensional modeling using HEC-RAS. This is the primary tool for modeling stream restoration improvements.

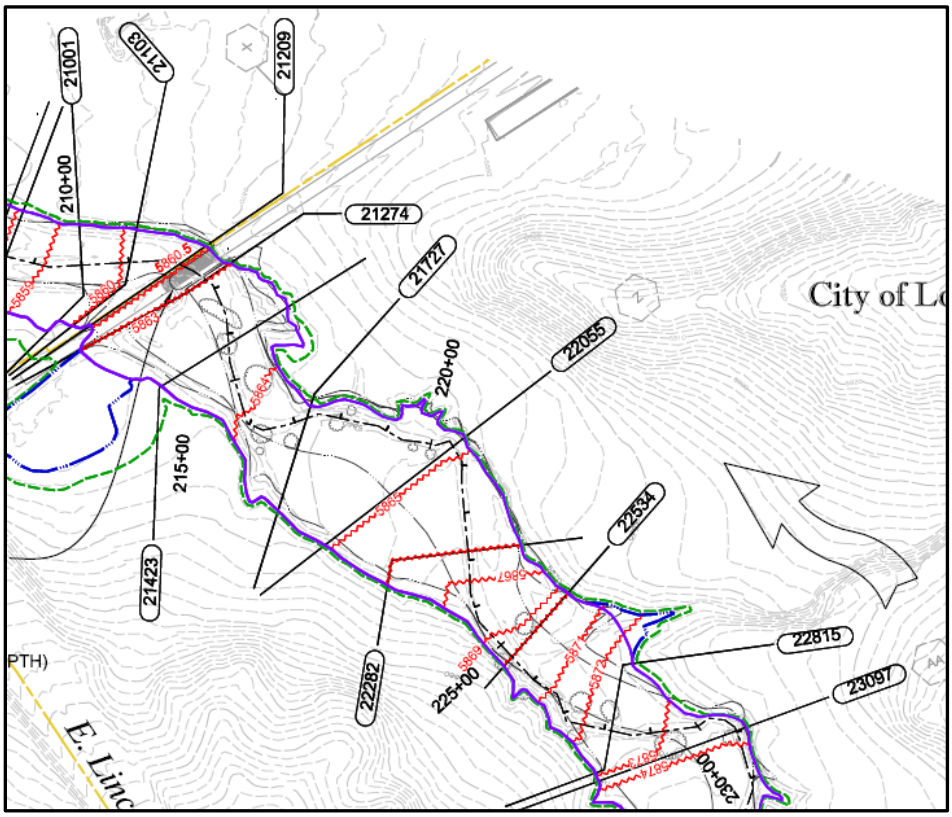


Figure 8-26. Example of HEC-RAS cross section placement and alignment

7.2.2 Cross Section Geometry

Required cross section input data includes station (x) and elevation (y) coordinates of the cross section, main channel bank stations, roughness coefficients, and contraction/expansion coefficients.

Cross Section Coordinates and Main Channel Bank Stations
Entering cross section coordinates can be accomplished in several different ways. There are several software packages that can generate cross section data from a digital terrain model and import it directly. Cross sections can also be entered manually. Regardless of the method, it is critical that the input coordinates accurately represent the horizontal and vertical geometry of cross sections, so back-checking for quality assurance is recommended.

Once the station and elevation coordinates for the channel cross section have been input into HEC-RAS, the main channel bank stations must be determined. It is generally recommended that the main channel be interpreted as a relatively narrow portion of the cross section. Figure 8-27 illustrates the main channel and terraces in a typical cross section. The bankfull channel comprises the deepest part of the cross section, often has a lower roughness value than the vegetated terraces, and typically experiences the highest flow velocities. Sometimes, small headwater channels and especially swales may have a vegetated bankfull channel as a result of minimal or no baseflow.

Required input for HEC-RAS includes reach lengths to the next downstream cross section. The downstream reach length for the main channel is measured along the established channel centerline. The downstream reach lengths for the left and right overbank is measured following the flowpath of water in the overbanks from the centroid of flow in the overbank of one cross section to the centroid of flow in the next section downstream. This means that the overbank distance on the inside of the bend will be less than the overbank distance on the outside of the bend.

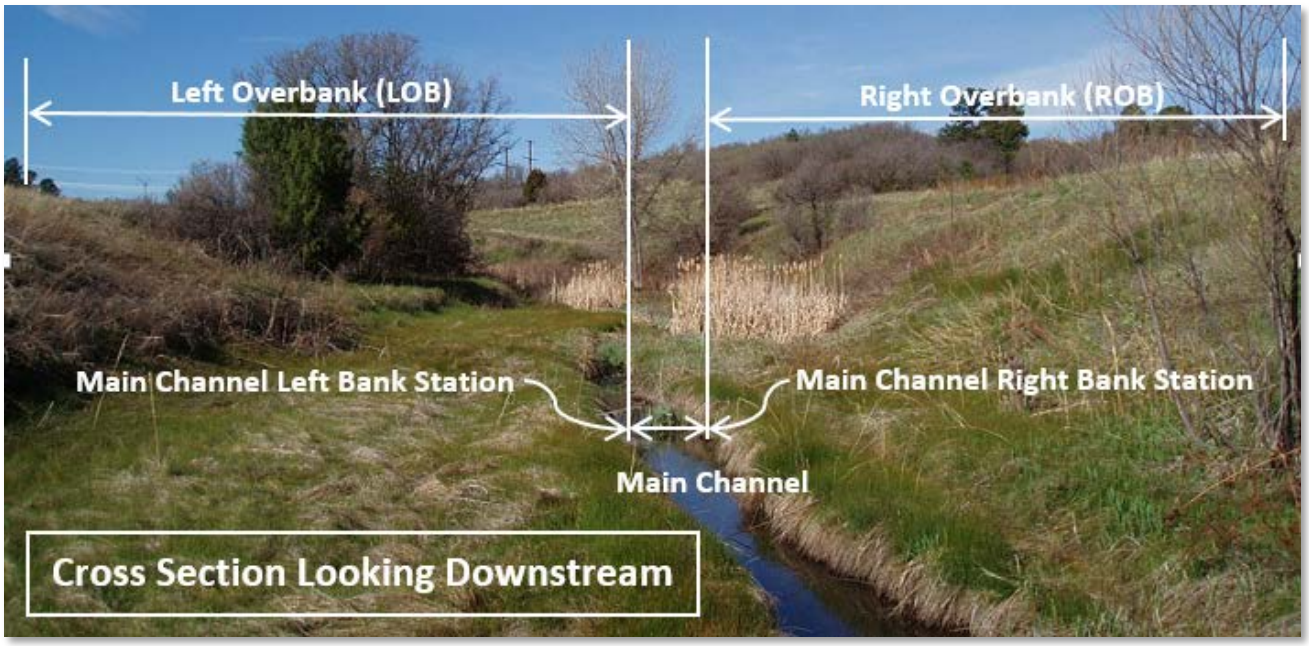


Figure 8-27. HEC-RAS cross section definitions

7.2.3 Roughness Coefficients

Required input also includes defining hydraulic roughness coefficients, or Manning's n values, for the main channel, left overbank and right overbank. For channel cross sections that are best described with varying values for Manning's n in the overbanks, the "Horizontal Variation in n Values" feature can be used. This feature allows the designer to specify a Manning's n value at each cross section coordinate.

Selecting roughness values for the main channel and overbanks of each cross section in the model is an important task. Because this tends to be somewhat subjective rather than deterministic, it is recommended that hydraulic modeling be conducted in two ways. Conservatively low roughness values should be used for assessing velocities, Froude numbers, and shear stresses. Conservatively high roughness values should be used for assessing water surface elevations and depths. The lack of vegetation in post construction conditions will result in higher channel velocities and greater potential for erosion. Channels with fully established vegetation will have reduced velocities but higher flow depths.

Table 8-5 provides low and high roughness values that are suitable for initial approximations of hydraulic conditions; however, it is the designer's responsibility to conduct a field reconnaissance of the stream reach being analyzed, characterize roughness conditions along the main channel and overbanks, and select appropriate roughness values. Additional information on estimating roughness values for grass overbanks and cobble channels is discussed below.

Table 8-5. Recommended roughness values

Location and Cover	When Assessing Velocity, Froude No., Shear Stress	When Assessing Water Surface Elevation and Water Depth
Main Channel (bankfull channel)		
Sand or clay bed	0.03	0.04
Gravel or cobble bed	0.035	0.07
Vegetated Overbanks		
Turfgrass sod	0.03	0.04
Native grasses	0.032	0.05
Herbaceous wetlands (few or no willows)	0.06	0.12
Willow stands, woody shrubs	0.07	0.16

(Source: Chow 1959, USDA 1954, Barnes 1967, Arcement and Schneider 1989, Jarrett 1985)

Roughness of Grass Overbanks

A common procedure for determining Manning's n for vegetated channels is documented in the *Handbook of Channel Design for Soil and Water Conservation* (hereinafter referred to as the NRCS Method). The NRCS Method uses the vegetation properties to establish a degree of retardance. The retardance is based upon the type of plants, the length and condition of the vegetation. Finding a solution for Manning's n becomes an iterative process using the following channel properties: slope, velocity and hydraulic radius. The documentation for the NRCS method contains a series of curves that provide solutions for Manning's n values based upon the vegetation retardance. Table 8-6 provides recommended retardance values for channels located along the Colorado Front Range with the given vegetation properties. Refer to the NRCS Method documentation for additional detail and guidance.

Table 8-6. Recommended retardance curve for vegetation in the Colorado Front Range

Vegetation Description	Retardance Curve
Fair Stand	
≤8" height	E
>8" height	D
Good Stand	
≤8" height	D
>8" height	C
Dense, Herbaceous Wetland	A

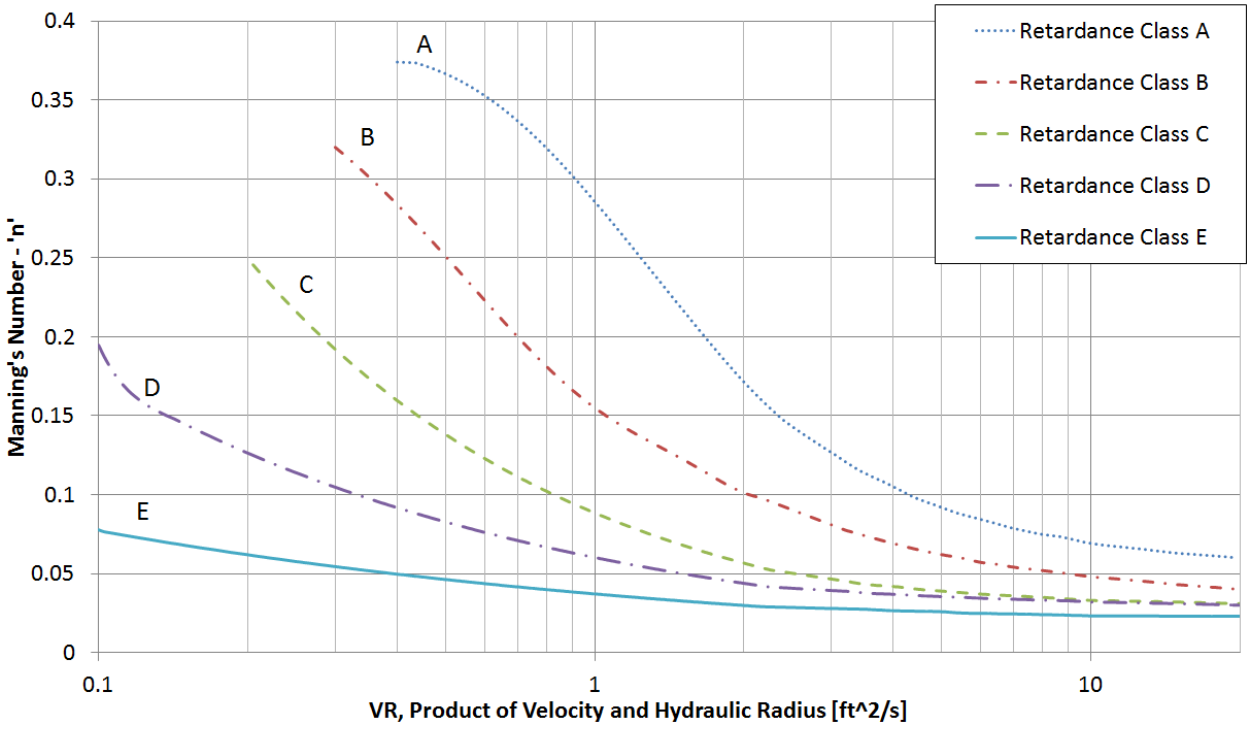


Figure 8-28. Manning's roughness in vegetated channels

Roughness of Cobble (Rock) Channels and Riprap Areas
There are multiple methods available for determining Manning's n values for cobble/rock lined channels and significant areas of riprap. Two relationships are shown below; it is the responsibility of the designer to evaluate the methods available and determine the approach most appropriate for the specific project conditions.

Determination of Roughness Coefficients for Streams in Colorado (Jarrett 1985)

$$n = 0.39S^{0.38}R^{-0.16}$$ Equation 8-8

Where:

S = channel slope (ft/ft)

R = hydraulic radius (ft)

The Manning's roughness coefficient, *n*, for a void-filled or soil riprap-lined channel may be estimated using:

$$n = 0.0395D_{50}^{1/6}$$ Equation 8-9

Where:

D_{50} = mean stone size (feet)

This equation is appropriate for computing channel capacity and associated flow depth, but when soil riprap is vegetated, velocity and shear computations should be based on the roughness provided by the vegetation and not the riprap.

This equation does not apply to grouted boulders or to very shallow flow (where hydraulic radius is less than, or equal to 2.0 times the maximum rock size). In those cases the roughness coefficient will be greater than indicated by this equation. The *Hydraulic Structures* chapter covers grouted boulder applications in detail.

7.2.4 Design Storms

HEC-RAS refers to design storms as "profiles" and allows a designer to add multiple profiles. Boundary conditions are defined for each profile and options consist of known water surface elevation, critical depth, normal depth or rating curve.

It is recommended that the designer evaluate multiple return periods (profiles) when evaluating a stream reach. These may include the "bankfull" event, 2-year, 5-year, 10-year, 100-year, and perhaps larger events. The 2 through 10-year profiles are important when a shared-use path is planned adjacent to the stream to ensure proper elevation of the past. See the *Stream Access and Recreational Channels* chapter for criteria regarding trails including low-flow crossings.

Evaluation of multiple design storms allows the designer to see variations in flow patterns for different storm events and the resulting velocities, flow depths, etc. In some cases it may be appropriate to modify Manning's n values based on the flow depth at a specific design storm to more accurately depict the flow conditions.

7.2.5 Output Variables

Results from a HEC-RAS steady flow analysis can be viewed in both tabular and graphical format. Tabular output can be generated at an individual cross section or a summary table can be produced that includes multiple cross sections and multiple storm events (profiles). The following is a list of key output variables that the designer should review during analysis (abbreviations used by HEC-RAS are indicated in parentheses).

- Water surface elevation (W.S. Elev)
- Critical water surface elevation (Crit W.S.)
- Froude Number (Froude #)
- Total flowrate within the cross section (Q Total), left overbank (Q Left), channel (Q Channel), and right overbank (Q Right)
- Average velocity in the main channel (Vel Chnl), left overbank (Vel Left), and right overbank (Vel Right)
- Hydraulic depth in the main channel (Hydr Depth C), left overbank (Hydr Depth L), and right overbank (Hydr Depth R)
- Specific Force for the cross section (Specif Force)
- Shear stress in the main channel (Shear Chan), left overbank (Shear LOB), and right overbank (Shear ROB)

The above list is just a small sampling of the variables that HEC-RAS can provide. The designer is responsible for selecting output variables, evaluating all aspects of the channel hydraulics, and determining the acceptable values for the channel parameters based upon the specific project.

Figure 8-29 is an example of tabular output for an individual cross section (referred to as *Detailed Output Table*). Data are provided for the entire cross section and also divided into the bankfull channel and the left/right overbanks, where appropriate.

In addition to the table for an individual cross section, HEC-RAS can also provide a summary table which includes all cross sections and all storm events (profiles) as specified (referred to as *Profile Output Table*). When using the *Profile Output Table* feature, the designer has the ability to create a custom table and specify the output variables that are included in the table, including those listed above. Creating a custom table in HEC-RAS is a useful way to see all of the data summarized at one location. Refer to the *Help* menu, *User's Manual* within HEC-RAS for definitions of the output variables available within HEC-RAS.

Plan: CEM Newlin Gulch DS Stonegate Pkw RS: 9130 Profile: 100-YR

E.G. Elev (ft)	5852.33	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.85	Wt. n-Val.	0.050	0.035	0.040
W.S. Elev (ft)	5851.49	Reach Len. (ft)	34.36	38.65	47.28
Crit W.S. (ft)	5849.94	Flow Area (sq ft)	224.32	72.46	423.45
E.G. Slope (ft/ft)	0.004579	Area (sq ft)	224.32	72.46	423.45
Q Total (cfs)	4720.00	Flow (cfs)	906.11	761.18	3052.70
Top Width (ft)	174.00	Top Width (ft)	78.16	9.87	85.96
Vel Total (ft/s)	6.55	Avg. Vel. (ft/s)	4.04	10.51	7.21
Max Chl Dpth (ft)	7.71	Hydr. Depth (ft)	2.87	7.34	4.93
Conv. Total (cfs)	69753.1	Conv. (cfs)	13390.7	11248.9	45113.4
Length Wtd. (ft)	41.12	Wetted Per. (ft)	78.79	10.36	87.19
Min Ch El (ft)	5843.77	Shear (lb/sq ft)	0.81	2.00	1.39
Alpha	1.27	Stream Power (lb/ft s)	237.90	0.00	0.00
Frctn Loss (ft)	0.19	Cum Volume (acre-ft)	1.80	9.74	3.64
C & E Loss (ft)	0.04	Cum SA (acres)	0.66	1.49	1.29

Figure 8-29. Example HEC-RAS tabular output for individual cross section

When performing a steady flow analysis with HEC-RAS, the user has the option to evaluate flow distribution at one or more cross section. The user can specify the interval of the distribution (e.g., every 10 feet along cross section or at other intervals) and then use the results to evaluate hydraulic parameters at specific locations on a cross section. This may be beneficial when determining erosion protection at the toe of the bankfull channel versus a location in the overbank. The designer can review the flow velocity at that specific location in the cross section and determine the appropriate erosion protection. Figure 8-30 is an example table summarizing the flow distribution at an individual cross section.

Plan: CEM Newlin Gulch DS Stonegate Pkw RS: 9130 Profile: 100-YR

	Pos	Left Sta	Right Sta	Flow	Area	W.P.	Percent	Hydr	Velocity	Shear	Power
		(ft)	(ft)	(cfs)	(sq ft)	(ft)	Conv	Depth(ft)	(ft/s)	(lb/sq ft)	(lb/ft s)
1	LOB	34.69	46.25	1.29	2.20	8.80	0.03	0.25	0.58	0.07	0.04
2	LOB	46.25	57.82	7.79	7.24	11.57	0.17	0.63	1.08	0.18	0.19
3	LOB	57.82	69.38	17.12	11.62	11.57	0.36	1.00	1.47	0.29	0.42
4	LOB	69.38	80.94	33.43	17.43	11.69	0.71	1.51	1.92	0.43	0.82
5	LOB	80.94	92.50	166.99	46.24	12.00	3.54	4.00	3.61	1.10	3.98
6	LOB	92.50	104.07	327.60	68.32	11.59	6.94	5.91	4.80	1.68	8.08
7	LOB	104.07	115.63	351.89	71.27	11.57	7.46	6.16	4.94	1.76	8.69
8	Chan	115.63	116.62	61.42	6.67	1.16	1.30	6.76	9.20	1.65	15.19
9	Chan	116.62	117.60	71.73	7.22	1.12	1.52	7.32	9.93	1.85	18.38
10	Chan	117.60	118.59	82.53	7.50	0.99	1.75	7.59	11.01	2.16	23.78
11	Chan	118.59	119.58	82.82	7.50	0.99	1.75	7.60	11.05	2.17	23.98
12	Chan	119.58	120.57	83.36	7.53	0.99	1.77	7.63	11.07	2.18	24.12
13	Chan	120.57	121.55	84.19	7.57	0.99	1.78	7.67	11.12	2.19	24.36
14	Chan	121.55	122.54	82.76	7.56	1.01	1.75	7.66	10.94	2.14	23.42
15	Chan	122.54	123.53	76.54	7.30	1.04	1.62	7.39	10.49	2.01	21.06
16	Chan	123.53	124.51	70.68	6.97	1.04	1.50	7.06	10.14	1.91	19.38
17	Chan	124.51	125.50	65.15	6.64	1.04	1.38	6.72	9.82	1.82	17.86
18	ROB	125.50	136.74	588.30	70.91	11.26	12.46	6.31	8.30	1.80	14.94
19	ROB	136.74	147.98	527.59	66.40	11.25	11.18	5.91	7.95	1.69	13.41
20	ROB	147.98	159.22	470.34	61.97	11.25	9.96	5.51	7.59	1.58	11.96
21	ROB	159.22	170.46	423.26	58.17	11.24	8.97	5.18	7.28	1.48	10.76
22	ROB	170.46	181.70	374.81	54.09	11.25	7.94	4.81	6.93	1.37	9.52
23	ROB	181.70	192.94	322.13	49.38	11.25	6.82	4.39	6.52	1.26	8.19
24	ROB	192.94	204.18	278.65	45.28	11.25	5.90	4.03	6.15	1.15	7.08
25	ROB	204.18	215.42	67.63	17.26	8.45	1.43	2.37	3.92	0.58	2.29

Figure 8-30. Example HEC-RAS tabular output for flow distribution at individual cross section

Graphical output can be in the form of a cross section, water surface profile, or rating curve. The user has the ability to specify the variables that are included on the graphical output. Figure 8-31 is an example plot of a cross section showing a velocity distribution. The velocity distribution is generated by turning on the flow distribution feature of HEC-RAS, as discussed earlier in this section.

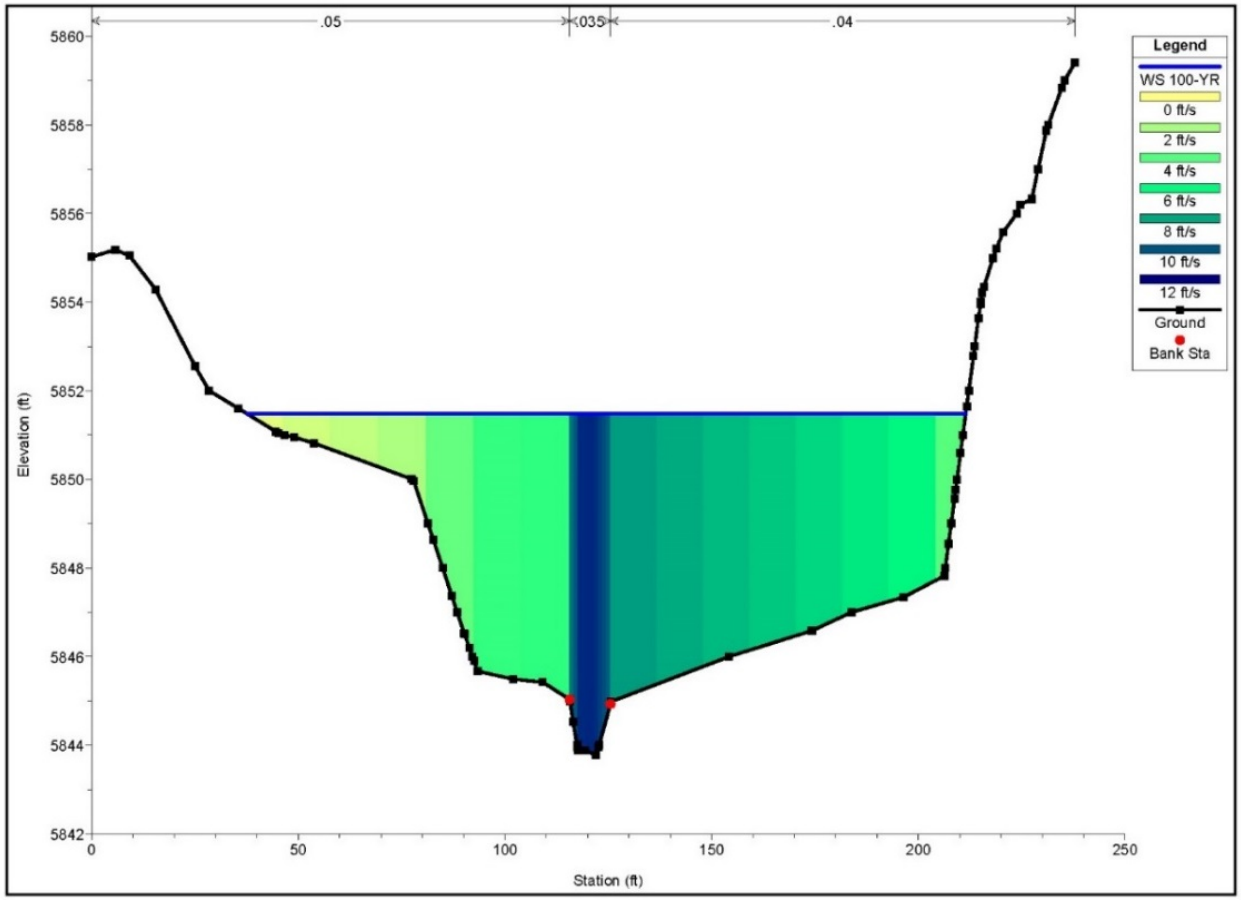


Figure 8-31. Example HEC-RAS cross section with velocity distribution

Using the *General Profile Plot* feature of HEC-RAS, multiple variables can be viewed in a profile format along the length of a stream. An example plot using this feature is shown in Figure 8-32 below. Figure 8-32 is a plot of shear stress for a channel reach which separates the output into the main channel, left overbank and right overbank.

The example plot indicates that overbank shear stress is highest near stations 200, 900, 1800 and extremely high near station 2600. The information shown in the figure would lead the designer to assess the ability of the overbank vegetation to resist the imposed shear in these stations. If the shear stress is greater than the estimated ability of the overbank to resist, the designer should assess the associated risks and consider whether steps should be taken to reinforce the overbank at these locations.

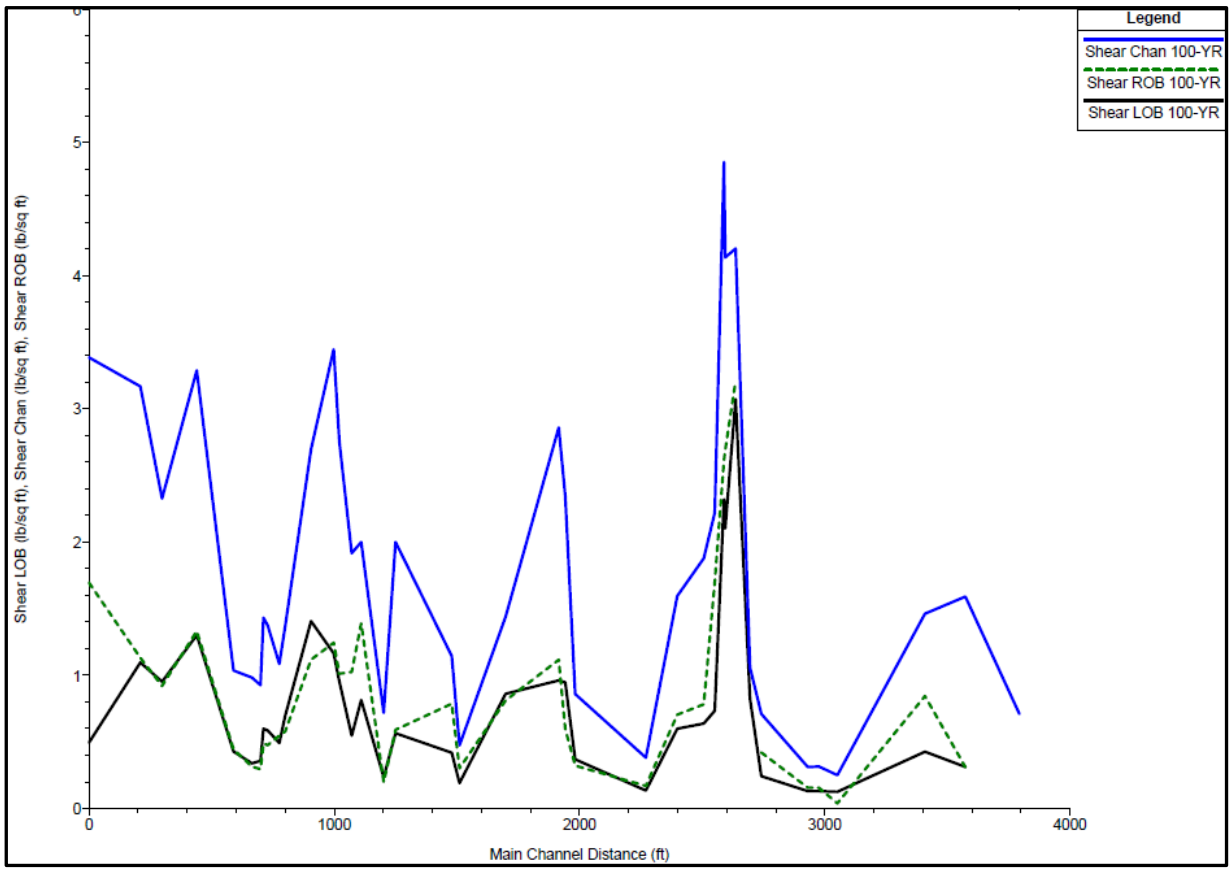


Figure 8-32. Example HEC-RAS general profile plot of shear stress

7.3 Evaluation of Erosion at Channel Bends

Special erosion control measures are often needed at bends. Riprap sizing should be based on locally higher velocities at the outside of a bend. An estimate of velocity along the outside of the bend can to be made using the following equation.

$$V_a = (-0.147 \frac{r_c}{T} + 2.176) V \qquad \text{Equation 8-10}$$

Where:

V_a = adjusted channel velocity for riprap sizing along the outside of channel bends (ft/sec)

V = mean channel velocity for the peak flow of the major design flow (ft/sec)

r_c = channel centerline radius (ft)

T = Top width of water during the major design flow (ft)

8.0 Rock and Boulders

In conditions where rock protection is required, it is recommended that soil riprap, void-filled riprap, or boulders be used. For small installations, and where vegetation is not anticipated, riprap over bedding material may also be used.

Soil riprap refers to riprap that has all void spaces filled with topsoil with the intention of supporting vegetative growth. Soil riprap is intended for use in applications where vegetative cover can be established and where the shear stress, imposed by frequently occurring flows, is less than the resistive strength of the vegetation and soil. The riprap layer is designed to remain stable and provide protection during the extreme events.

Void-filled riprap is designed to emulate natural rock riffle material found in steep gradient streams. It contains a well-graded mix of cobbles, gravels, sands, and soil that fills all voids and acts as an internal filter, therefore a separate bedding layer between subgrade and rock is not required. In applications where it is difficult to establish vegetation, void-filled riprap is better able to resist the direct, prolonged impingement of water on the riprap installation compared to soil riprap. However, void-filled riprap is more difficult to properly mix and install compared to soil riprap (see inset). UDFCD recommends review of the technical paper titled d*emonstration Project Illustrating Void-Filled Riprap Applications in Stream Restoration* (Wulliman and Johns 2011). This paper provides background on the derivation of void-filled riprap and its applications in stream restoration and is available the UDFCD website.

Photograph 8-18. Void-filled riprap is designed to emulate natural rock riffle material; it consists of a mix of rock, gravels, sands, and soil that is densely-packed and able to support riparian vegetation.

Table 8-7 provides a comparison between soil riprap and void-filled riprap.

Specifying Void-Filled Riprap

Void-filled riprap is far more challenging to properly mix and install than soil riprap and requires close designer involvement during construction to ensure the mixture is properly mixed and placed. When it is not properly mixed and/or placed, flows will wash away the void material and eventually start to also move the larger rock. Before specifying void-filled riprap, ensure that adequate construction observation time by a qualified individual is available as part of the construction budget. For more information on mixing and placing void-filled riprap see the technical paper titled *Demonstration Project Illustrating Void-Filled Riprap Applications in Stream Restoration* (Wulliman and Johns 2011) and the UDFCD construction specifications, both available at www.UDFCD.org.

Table 8-7. Comparison of void-filled riprap and soil riprap

	Void-Filled Riprap	Soil Riprap
Advantages	▪ Better emulates natural streambed material. ▪ Provides better stability and armoring in riverine environments. ▪ Creates a dense, interlocking mass and functions as an effective internal filter, keeping water flows on the surface and reducing the likelihood that flows will displace the material and expose a weak spot in the subgrade. ▪ Provides a growing medium that supports riparian vegetation.	▪ Requires mixing of only two different materials and, therefore requires less effort to order, stockpile, and mix materials. ▪ Requires less expertise and oversight during mixing and placing. ▪ Organic material within the growing medium supports riparian vegetation.
Disadvantages	▪ Requires mixing up to five or six different aggregates in the proper proportions. This requires additional effort in ordering, stockpiling, mixing, and placing materials compared to soil riprap. ▪ Difficult to inspect after installation because small void-material can cover larger riprap. Need to inspect during placement. ▪ Requires construction observation for submittal and sample material review, adjustments to the mix proportions to compensate for varying material gradation, approval of test fields mixing operations, and observation of placement and compaction. ▪ Costs more than soil riprap. ▪ If not well mixed, pockets of small void material, especially near surface can wash out and unravel void-filled riprap installation. Need to continually monitor and make sure larger riprap is not displaced and located at surface to provide sufficient D_{50}.	▪ Does not provide the same level of stability and armoring in areas of direct, continuous flow impingement.

8.1 Riprap Sizing

Procedures for sizing rock to be used in soil riprap, void-filled riprap, and riprap over bedding are the same.

8.1.1 Mild Slope Conditions

When subcritical flow conditions occur and/or slopes are mild (less than 2 percent), UDFCD recommends the following equation (Hughes, et al, 1983):

$$d_{50} \geq \left[\frac{VS^{0.17}}{4.5(G_s - 1)^{0.66}} \right]^2 \qquad \text{Equation 8-11}$$

Where:

V = mean channel velocity (ft/sec)

S = longitudinal channel slope (ft/ft)

d_{50} = mean rock size (ft)

Gs = specific gravity of stone (minimum = 2.50, typically 2.5 to 2.7), Note: In this equation (Gs -1) considers the buoyancy of the water, in that the specific gravity of water is subtracted from the specific gravity of the rock.

Note that Equation 8-11 is applicable for sizing riprap for channel lining with a longitudinal slope of no more than 2%. This equation is not intended for use in sizing riprap for steep slopes (typically in excess of 2 percent), rundowns, or protection downstream of culverts. Information on rundowns is provided in Section 7.0 of the *Hydraulic Structures* chapter of the USDCM, and protection downstream of culverts is discussed in the *Culverts and Bridges* chapter. For channel slopes greater than 2% use one of the methods presented in 8.1.2.

Rock size does not need to be increased for steeper channel side slopes, provided the side slopes are no steeper than 2.5H:1V (UDFCD 1982). Channel side slopes steeper than 2.5H:1V are not recommended because of stability, safety, and maintenance considerations. See Figure 8-34 for riprap placement specifications. At the upstream and downstream termination of a riprap lining, the thickness should be increased 50% for at least 3 feet to prevent undercutting.

8.1.2 Steep Slope Conditions

Steep slope rock sizing equations are used for applications where the slope is greater than 2 percent and/or flows are in the supercritical flow regime. The following rock sizing equations may be referred to for riprap design analysis on steep slopes:

- CSU Equation, *Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II* (prepared by S.R. Abt, et al, Colorado State University, 1988). This method was developed for steep slopes from 2 to 20 percent.

- USDA- Agricultural Research Service Equations, *Design of Rock Chutes* (by K.M. Robinson, et al, USDA- ARS, 1998 Transactions of ASAE) and *An Excel Program to Design Rock Chutes for Grade*

Stabilization, (K.M. Robinson, et al, USDA- ARS, 2000 ASAE Meeting Presentation). This method is based on laboratory data for slopes from 2 to 40 percent.

- USACE Steep Slope Riprap Equation, *Hydraulic Design of Flood Control Channels, EM1110-2-1601*, (June 1994). This method is applicable for slopes from 2 to 20 percent.

All three of the steep slope methods are based on two key parameters: unit discharge and slope. Flow concentration is one of the main problems that can develop along steep riprap slopes; both CSU and USACE methods recommend that the design unit discharge be increased by a flow concentration factor. When using the CSU equation or the USDA method, increase the largest rock size by approximately 30% when specifying standard UDFCD riprap gradations. This increase accounts for the fact that the steep slope equations were developed using poorly graded rock (uniform in size) unlike the well-graded gradations in UDFCD specifications. Additionally, for the reasons described in the following section, it is typical to also apply a safety factor of 1.5 or more times the calculated D50 riprap size when using any of these steep slope riprap sizing methods. When using the CSU equation or the USDA method apply the safety factor after increasing the largest rock size by 30%.

8.1.3 Design Safety Factor

Whether in mild slope or steep slope conditions, consider a safety factor when specifying the sides of riprap. Sizing methods presented in this manual were developed from controlled laboratory conditions. Field installation of rock is much less precise compared to laboratory conditions. It is difficult to grade riprap flat across a channel bottom or in a manner that provides a uniform slope. Sometimes the riprap delivered from local quarries is slightly smaller than specified. Flow conditions in streams can be affected by a variety of elements including debris, sedimentation, vegetation, etc. and can result in flow concentrations. It is important to include a safety factor when using these equations because the variability associated with conditions in the field cannot be quantified.

8.2 Boulder and Riprap Specifications

Specific material and installation specifications for riprap and boulders can be found in UDFCD's Construction Specifications, available at www.udfcd.org.

8.2.1 Boulders

Boulders may be placed and grouted or placed without grout. When not grouted, boulders require careful design to provide a firm foundation and stable configuration as well as properly graded backfill material sized to prevent migration of fine subgrade material through voids in the boulders. All stacked boulders require consideration of stability and any stacked boulder configuration over six feet in height requires a structural analysis to confirm proper design. Additionally, some municipalities require structural analysis and a building permit for walls greater than four feet.

Grouted boulders should follow the general guidelines described as part of the sections on grouted boulder grade control structures in the *Hydraulic Structures* Chapter and in the UDFCD Construction Specifications. See Figure 8-36 for typical construction of a grouted boulder bank protection.

8.2.2 Soil Riprap

Soil riprap is intended for use in applications where vegetative cover can be established in the riprap. When installed outside of the low-flow channel, UDFCD frequently specifies 4 to 6 inches of topsoil on top of soil riprap to help establish vegetation. Soil used in the voids and placed on top of the soil riprap

should meet the description for viable topsoil composition for Colorado native plant establishment and upland areas as defined in the *Revegetation* chapter. See Figure 8-34 for gradation and placement of both riprap and soil riprap. Also see Figure 13 –19 in the *Revegetation* chapter for a fabric staking detail that can be used where fabric is specified over soil riprap. The combination of straw and coir mat is frequently used to help retain soil and seed. This is especially useful when topsoil is placed on top of soil riprap and then seeded. Specifications for mixing and installing soil riprap are further addressed in the UDFCD Construction Specifications.

8.2.3 Void-Filled Riprap

Void-filled riprap contains a well-graded mix of cobbles, gravels, sands, and soil that fills all voids and acts as an internal filter.

In addition to specifying the D_{50} rock size, individual material components that will make up the mix needed to be specified. The gradation of each material component should be specified by identifying a variety of particle sizes (from large to small) and the range of allowable "passing" percentages for each particle size. See Figure 8-35 for typical mixes of various sized rock, however, the designer should specify any mix adjustments based on the requirements of a particular project.

Photograph 8-18. Void-filled riprap is designed to emulate natural riffles, consisting of a mix of rock, gravels and sands that is densely-packed and able to support riparian vegetation.

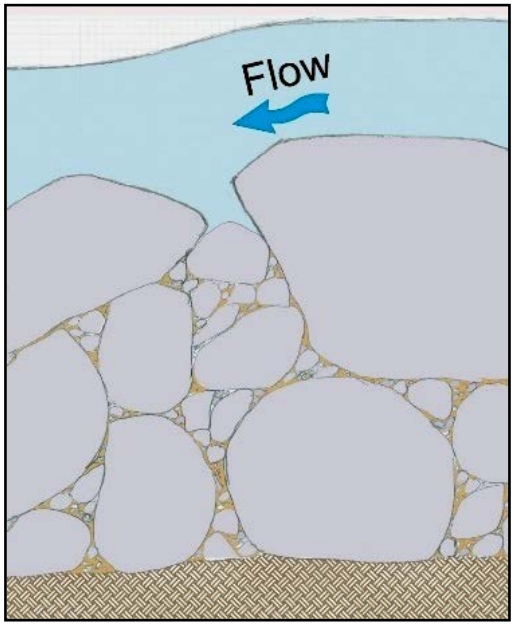


Figure 8-33. Small rock of void-filled riprap becomes "wedged in" under larger rock (Source: Muller Engineering Company)

Photograph 8-19. Seven-inch minus crushed surge is a key ingredient to fill gaps between riprap.

Photograph 8-20. Four-inch minus pit run surge is also an important ingredient to fill gaps between riprap.

Photograph 8-21. Void-filled riprap after placement and compaction.

Sufficient construction oversight by an engineer and/or a construction inspector knowledgeable in mixing and placing void-fill riprap is essential. This includes reviewing rock material submittals, field observation during initial mixing, and observation during placement of void-filled riprap. These construction services are summarized below; detailed specifications for mixing and placing void-filled riprap are provided in the UDFCD Construction Specifications available at www.udfcd.org.

1. **Material Submittals.** Laboratory test certificates, gradations, and suppliers for all materials included in the riffle rock mix should be submitted for review. If there is difficulty finding material that meets the specified gradation for a particular component, this can often be resolved by selecting a different supplier for that component.

2. **Mixing Void-Filled Riprap.** Individual void-filled riprap materials are typically delivered and unloaded onsite in separate stockpiles. Mixing is typically accomplished using a front end loader to add the proper "loader bucket" proportions of each material into one combined stockpile. Once all the materials have been added, the pile is mixed thoroughly to blend the materials together using the loader or large track hoe excavator. The goal is to fill the voids of the base riprap material **without displacing the riprap**. The interlocking nature of riprap in the mixed material needs to remain essentially the same as if the riprap was placed without void-fill material.

   The specified mix proportions are noted as approximate because the two surge materials vary somewhat between different suppliers and variations in gravel pits. Therefore, it is important that the design engineer is onsite during the first mixing operation to make slight adjustments to the proportions if necessary.

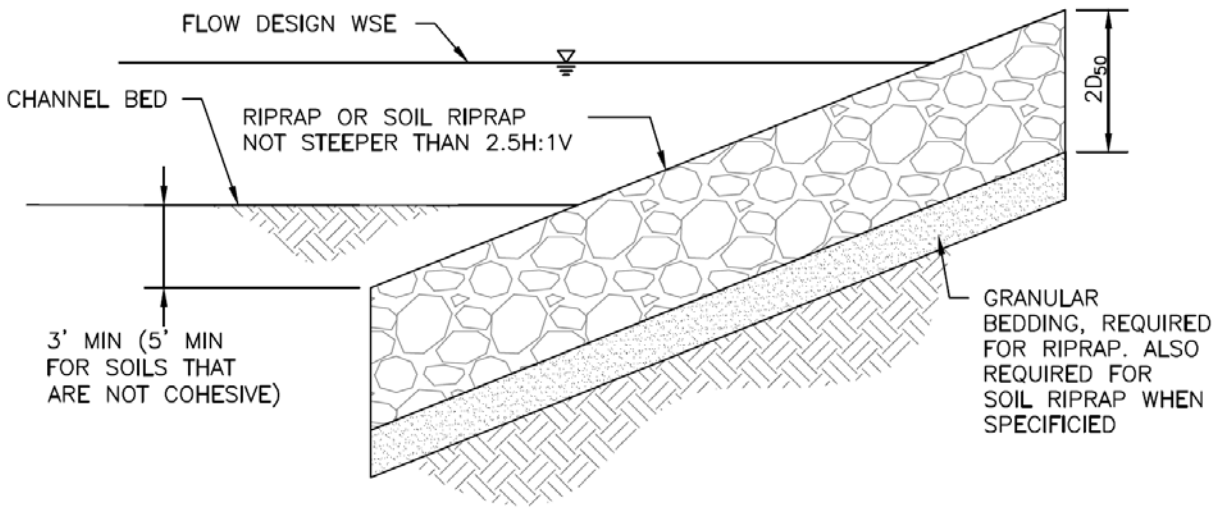
3. **Placing Void-Filled Riprap**. Void-filled riprap can be challenging to place as it has a tendency to segregate. Finer sands and gravels will separate from the larger riprap. Contractors must take care to minimize segregation when hauling the mixed material from the stockpile to the installation location.

   Loose material must be placed in a single lift of sufficient height such that final grade will be achieved upon compaction. In most cases, some additional mixing with a track excavator is needed after the initial placement to make sure that void-filled riprap is thoroughly mixed and that there is no segregation or areas where the void-filled riprap consists primarily of the smaller void-fill materials. A pocket of fine void-fill materials near the surface, without sufficient larger riprap, can get washed out and create flow concentrations that could unravel the void-filled riprap installation. **The goal is to fill the riprap voids without displacing riprap.**

   The last step is to compact the loosely placed void-filled riprap material by driving over it with a heavy duty loader or similar equipment. Water should be added, if necessary, so that the moisture content of the mixture is at optimum conditions during the compaction process.

   It is important that the finished top elevation of the void-filled riprap layer closely matches design grades to within a tolerance of 0.10 feet. Having a tight elevation tolerance helps to minimize development of flow concentrations. Finally, if for some reason the compacted material ends up below final grade, it is not acceptable to allow placement of only the smaller void-fill material or additional top dressing cobbles to achieve final grade. In such cases it is necessary to add more standard sized void-filled riprap and remix the entire thickness of rock to achieve the design section.

   To ensure proper mixing and placement of void-filled riprap, UDFCD recommends construction of a test section. Requiring the approval of a test section helps to ensure that the contractor understands construction requirements at the start of a project and can make adjustments as necessary during construction.



RIPRAP DESIGNATION	% SMALLER THAN GIVEN SIZE BY WEIGHT	INTERMEDIATE ROCK DIMENSION (INCHES)	D_{50}* (INCHES)
TYPE VL	70 – 100 50 – 70 35 – 50 2 – 10	12 9 6 2	6
TYPE L	70 – 100 50 – 70 35 – 50 2 – 10	15 12 9 3	9
TYPE M	70 – 100 50 – 70 35 – 50 2 – 10	21 18 12 4	12
TYPE H	70 – 100 50 – 70 35 – 50 2 – 10	30 24 18 6	18
*D_{50} = MEAN ROCK SIZE			

Figure 8-34. Riprap and soil riprap placement and gradation (part 1 of 3)

SOIL RIPRAP NOTES:

1. ELEVATION TOLERANCES FOR THE SOIL RIPRAP SHALL BE 0.10 FEET. THICKNESS OF SOIL RIPRAP SHALL BE NO LESS THAN THICKNESS SHOWN AND NO MORE THAN 2—INCHES GREATER THAN THE THICKNESS SHOWN.

2. WHERE "SOIL RIPRAP" IS DESIGNATED ON THE CONTRACT DRAWINGS, RIPRAP VOIDS ARE TO BE FILLED WITH NATIVE SOIL. THE RIPRAP SHALL BE PRE—MIXED WITH THE NATIVE SOIL AT THE FOLLOWING PROPORTIONS BY VOLUME: 65PERCENT RIPRAP AND 35 PERCENT SOIL. THE SOIL USED FOR MIXING SHALL BE NATIVE TOPSOIL AND SHALL HAVE A MINIMUM FINES CONTENT OF 15 PERCENT. THE SOIL RIPRAP SHALL BE INSTALLED IN A MANNER THAT RESULTS IN A DENSE, INTERLOCKED LAYER OF RIPRAP WITH RIPRAP VOIDS FILLED COMPLETELY WITH SOIL. SEGREGATION OF MATERIALS SHALL BE AVOIDED AND IN NO CASE SHALL THE COMBINED MATERIAL CONSIST PRIMARILY OF SOIL; THE DENSITY AND INTERLOCKING NATURE OF RIPRAP IN THE MIXED MATERIAL SHALL ESSENTIALLY BE THE SAME AS IF THE RIPRAP WAS PLACED WITHOUT SOIL.

3. WHERE SPECIFIED (TYPICALLY AS "BURIED SOIL RIPRAP"), A SURFACE LAYER OF TOPSOIL SHALL BE PLACED OVER THE SOIL RIPRAP ACCORDING TO THE THICKNESS SPECIFIED ON THE CONTRACT DRAWINGS. THE TOPSOIL SURFACE LAYER SHALL BE COMPACTED TO APPROXIMATELY 85% OF MAXIMUM DENSITY AND WITHIN TWO PERCENTAGE POINTS OF OPTIMUM MOISTURE IN ACCORDANCE WITH ASTM D698. TOPSOIL SHALL BE ADDED TO ANY AREAS THAT SETTLE.

4. ALL SOIL RIPRAP THAT IS BURIED WITH TOPSOIL SHALL BE REVIEWED AND APPROVED BY THE ENGINEER PRIOR TO ANY TOPSOIL PLACEMENT.

GRADATION FOR GRANULAR BEDDING		
U.S. STANDARD SIEVE SIZE	PERCENT PASSING BY WEIGHT	
	TYPE I CDOT SECT. 703.01	TYPE II CDOT SECT. 703.09 CLASS A
3 INCHES	—	90 — 100
1½ INCHES	—	—
¾ INCHES	—	20 — 90
⅜ INCHES	100	—
#4	95 — 100	0 — 20
#16	45 — 80	—
#50	10 — 30	—
#100	2 — 10	—
#200	0 — 2	0 — 3

RIPRAP BEDDING

Figure 8-34. Riprap and soil riprap placement and gradation (part 2 of 3)

THICKNESS REQUIREMENTS FOR GRANULAR BEDDING			
RIPRAP DESIGNATION	MINIMUM BEDDING THICKNESS (INCHES)		
	FINE–GRAINED SOILS [1]		COARSE–GRAINED SOILS [2]
	TYPE I (LOWER LAYER)	TYPE II (UPPER LAYER)	TYPE II
VL (D_{50} = 6 IN)	4	4	6
L (D_{50} = 9 IN)	4	4	6
M (D_{50} = 12 IN)	4	4	6
H (D_{50} = 18 IN)	4	6	8
VH (D_{50} = 24 IN)	4	6	8

NOTES:
1. MAY SUBSTITUTE ONE 12–INCH LAYER OF TYPE II BEDDING. THE SUBSTITUTION OF ONE LAYER OF TYPE II BEDDING SHALL NOT BE PERMITTED AT DROP STRUCTURES. THE USE OF A COMBINATION OF FILTER FABRIC AND TYPE II BEDDING AT DROP STRUCTURES IS ACCEPTABLE.
2. FIFTY PERCENT OR MORE BY WEIGHT RETAINED ON THE #40 SIEVE.

Figure 8-34. Riprap and soil riprap placement and gradation (part 3 of 3)

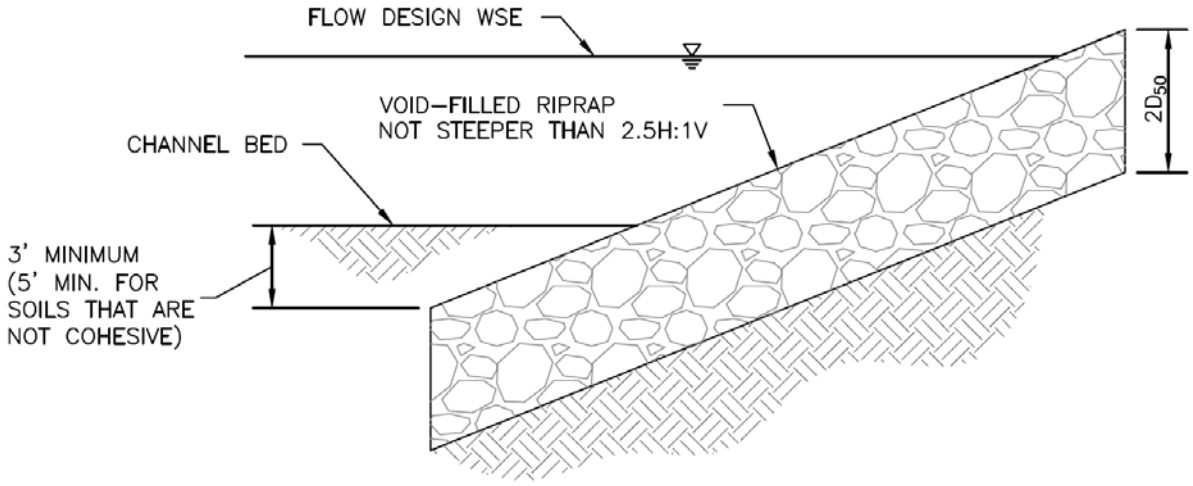


TABLE 1. MIX REQUIREMENTS FOR TYPE VL AND L VOID–FILLED RIPRAP (D_{50} = 6 TO 9 INCH)		
APPROPRIATE PROPORTIONS (BY VOLUME)	MATERIAL TYPE	MATERIAL DESCRIPTION
6 PARTS	RIPRAP	D_{50} = 6 INCH (TYPE VL) OR D_{50} = 9 INCH (TYPE L), SEE TABLE 3
1 PART	VOID–FILL MATERIAL	VTC (VEHICLE TRACKING CONTROL) ROCK (CRUSHED ROCK WITH 100% PASSING 4–INCH SIEVE, 50–70% PASSING 3–INCH SIEVE, 0–10% PASSING 2–INCH SIEVE)
1 PART	VOID–FILL MATERIAL	4–INCH MINUS PIT RUN SURGE (ROUND RIVER ROCK AND SAND, WELL GRADED, 90–100% PASSING 4–INCH SIEVE, 70–80% PASSING 1½–INCH SIEVE, 40–60% PASSING ⅜–INCH SIEVE, 10–30% PASSING #16 SIEVE)
1 PART	VOID–FILL MATERIAL	TYPE II BEDDING (CRUSHED ROCK WITH 100% PASSING 3–INCH SIEVE, 20–90% PASSING ¾–INCH SIEVE, 0–20% PASSING #4 SIEVE, 0–3% PASSING #200 SIEVE)
½ TO 1 PART	VOID–FILL MATERIAL	NATIVE TOPSOIL

VOID–FILLED RIPRAP PLACEMENT AND GRADATION

Figure 8-35. Void-filled riprap placement and gradation (part 1 of 3)

TABLE 2. MIX REQUIREMENTS FOR TYPE M AND H VOID–FILLED RIPRAP (D_{50} = 12 TO 18 INCH)		
APPROPRIATE PROPORTIONS (BY VOLUME)	MATERIAL TYPE	MATERIAL DESCRIPTION
6 PARTS	RIPRAP	D_{50} = 12–INCH (TYPE M) OR D_{50} = 18–INCH (TYPE H), SEE TABLE 3
2 PART	VOID–FILL MATERIAL	7–INCH MINUS CRUSHED ROCK SURGE (100% PASSING 7–INCH SIEVE, 80–100% PASSING 6–INCH SIEVE, 35–50% PASSING 3–INCH SIEVE, 10–20% PASSING 1½–INCH SIEVE)
1 PART	VOID–FILL MATERIAL	VTC (VEHICLE TRACKING CONTROL) ROCK (CRUSHED ROCK WITH 100% PASSING 4–INCH SIEVE, 50–70% PASSING 3–INCH SIEVE, 0–10% PASSING 2–INCH SIEVE)
1 PART	VOID–FILL MATERIAL	4–INCH MINUS PIT RUN SURGE (ROUND RIVER ROCK AND SAND, WELL GRADED, 90–100% PASSING 4–INCH SIEVE, 70–80% PASSING 1½–INCH SIEVE, 40–60% PASSING ⅜–INCH SIEVE, 10–30% PASSING #16 SIEVE)
1 PART	VOID–FILL MATERIAL	TYPE II BEDDING (CRUSHED ROCK WITH 100% PASSING 3–INCH SIEVE, 20–90% PASSING ¾–INCH SIEVE, 0–20% PASSING #4 SIEVE, 0–3% PASSING #200 SIEVE)
½ TO 1 PART	VOID–FILL MATERIAL	NATIVE TOPSOIL

TABLE 3. VOID–FILLED RIPRAP PLACEMENT AND GRADATION			
RIPRAP DESIGNATION	% SMALLER THAN GIVEN SIZE BY WEIGHT	INTERMEDIATE ROCK DIMENSION (INCHES)	D_{50}* (INCHES)
TYPE VL	70 – 100 50 – 70 35 – 50 2 – 10	12 9 6 2	6
TYPE L	70 – 100 50 – 70 35 – 50 2 – 10	15 12 9 3	9
TYPE M	70 – 100 50 – 70 35 – 50 2 – 10	21 18 12 4	12
TYPE H	70 – 100 50 – 70 35 – 50 2 – 10	30 24 18 6	18
*D_{50} = MEAN ROCK SIZE			

NOTE: MIX ON SITE AND PRIOR TO PLACEMENT

Figure 8-35. Void-filled riprap placement and gradation (part 2 of 3)

VOID–FILLED RIPRAP PLACEMENT AND GRADATION NOTES:

1. WHERE "VOID–FILLED RIPRAP" IS DESIGNATED ON THE CONTRACT DRAWINGS, RIPRAP SHALL BE MIXED WITH THE MATERIALS AND ASSOCIATED PROPORTIONS LISTED IN TABLE 1 OR TABLE 2 TO FILL THE VOIDS OF THE RIPRAP.

2. THE MIX PROPORTIONS PROVIDED IN TABLE 1 AND TABLE 2 ARE APPROXIMATE AND ARE SUBJECT TO ADJUSTMENT BY THE ENGINEER.

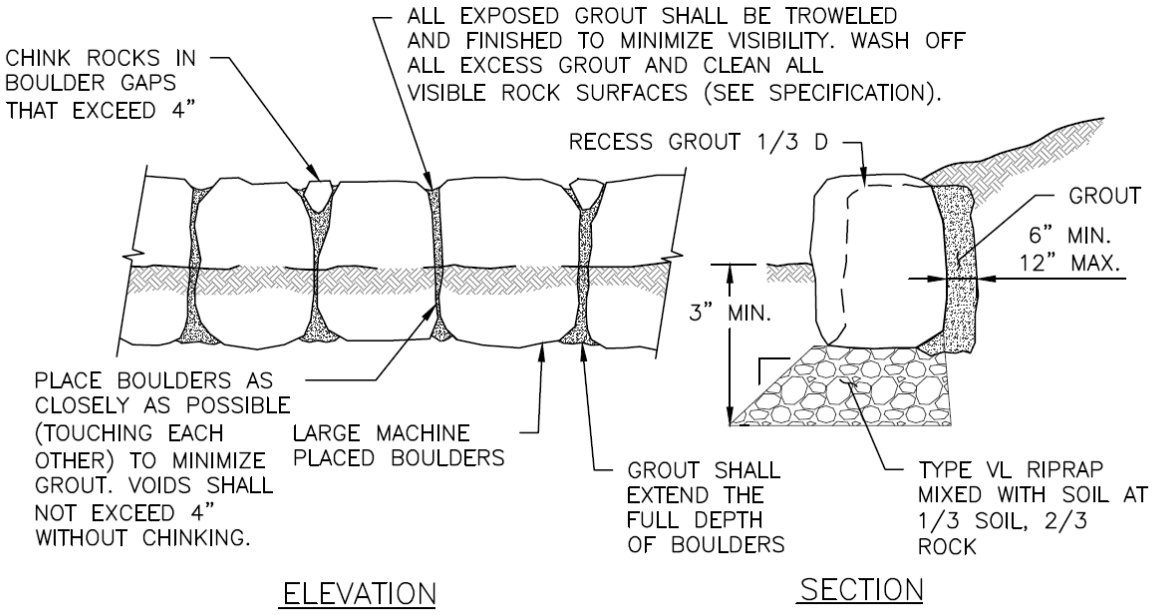
3. THE RIPRAP AND VOID–FILLED MATERIALS SHALL BE STOCKPILED SEPERATELY AND THOROUGHLY MIXED PRIOR TO PLACEMENT AND SHALL BE INSTALLED AND COMPACTED SO THAT A DENSE, INTERLOCKED LAYER OF RIPRAP AND VOID–FILL MATERIAL IS PROVIDED WITH RIPRAP VOIDS COMPLETELY FILLED. THE LOOSE MATERIAL SHALL BE PLACED IN A SINGLE LIFT OF SUFFICIENT HEIGHT SUCH THAT FINAL GRADE WILL BE ACHIEVED UPON COMPACTED. IF THE COMPACTED MATERIAL IS BELOW FINAL GRADE, PLACEMENT OF ONLY THE SMALLER VOID–FILL MATERIALS TO ACHIEVE FINAL GRADE IS NOT PERMITTED. IN SUCH CASES IT IS NECESSARY TO ADD MORE STANDARD SIZED VOID–FILLED RIPRAP AND REMIX THE ENTIRE THICKNESS OF ROCK TO ACHIEVE THE DESIGN SECTION. SEGREGATION OF MATERIALS SHALL BE AVOIDED AND IN NO CASE SHALL THE COMBINED MATERIAL CONSIST PRIMARILY OF THE VOID–FILL MATERIALS. THE DENSITY AND INTERLOCKING NATURE OF RIPRAP IN THE MIXED MATERIAL SHALL ESSENTIALLY BE THE SAME AS IF THE RIPRAP WAS PLACED WITHOUT FILLING THE VOIDS.

4. COMPACTION OF THE VOID–FILLED RIPRAP SHALL BE PERFORMED BY WHEEL ROLLING WITH HEAVY RUBBER–TIRED EQUIPMENT (E.G. FRONT END LOADER). THE MOISTURE CONTENT OF THE MIXTURE SHALL BE AT OPTIMUM CONDITIONS PRIOR TO COMPACTION AND WATER SHALL BE ADDED, AS NECESSARY, AT THE DIRECTION OF THE ENGINEER.

5. WHERE INDICATED ON THE DRAWINGS, A SURFACE LAYER OF MOIST TOPSOIL SHALL BE PLACED OVER THE VOID–FILLED RIPRAP. THE TOPSOIL SURFACE LAYER SHALL BE COMPACTED TO APPROXIMATELY 85% OF MAXIMUM DENSITY AND WITHIN TWO PERCENTAGE POINTS OF OPTIMUM MOISTURE IN ACCORDANCE WITH ASTM D698. TOPSOIL SHALL BE ADDED TO ANY AREAS THAT SETTLE.

6. ALL VOID–FILLED RIPRAP THAT IS BURIED WITH TOPSOIL SHALL BE REVIEWED AND APPROVED BY THE ENGINEER PRIOR TO ANY TOPSOIL PLACEMENT.

Figure 8-35. Void-filled riprap placement and gradation (part 3 of 3)



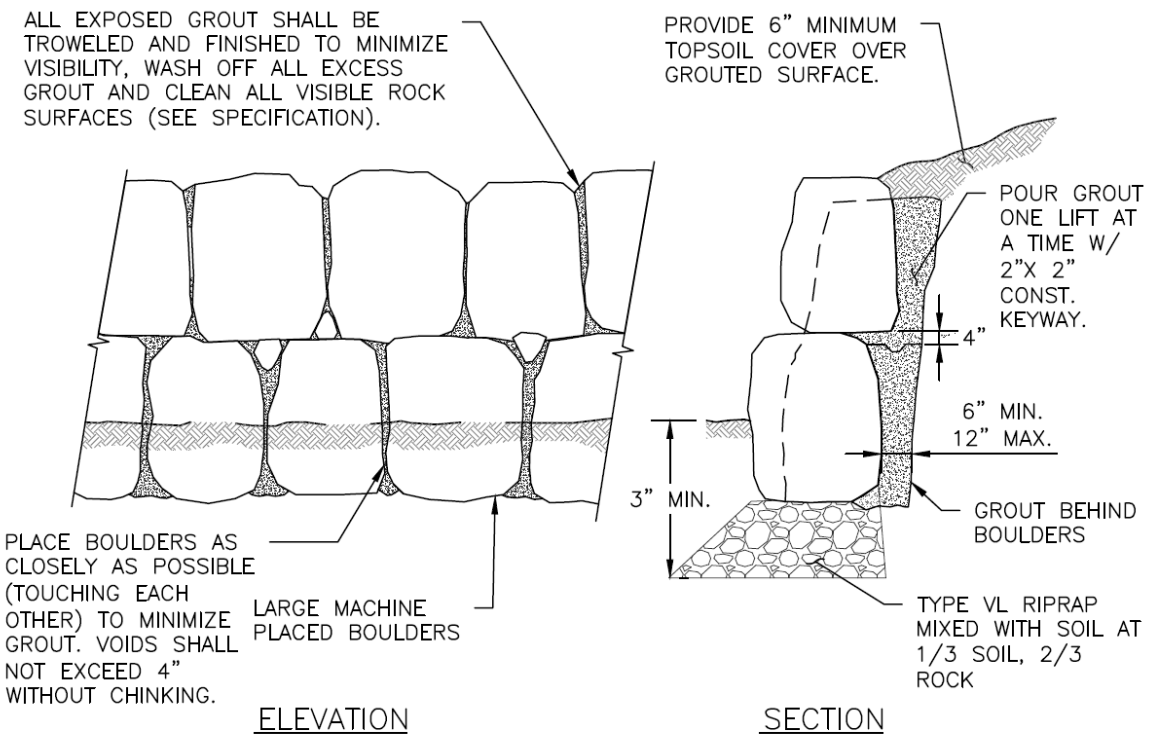


Figure 8-36. Sample grouted boulder section

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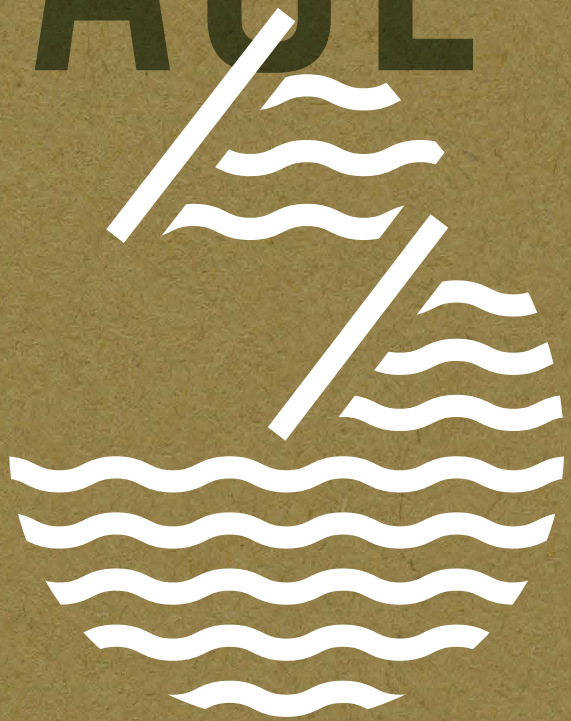

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Structures, Storage, and Recreation

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1.0 Structures in Streams

Photograph 9-1. This grouted boulder drop structure exemplifies the opportunity available for creating an attractive urban hydraulic setting for a riparian corridor.

Hydraulic structures are used to guide and control water flow in streams. Structures described in this chapter consist of grade control structures and outfall structures for various applications and conditions.

The discussion of grade control structures in this chapter addresses the hydraulic design and grouted boulder, sculpted concrete, and vertical drop structures, whereas the *Open Channels* chapter discusses the placement of grade control structures in the stream and the *Stream Access and Recreational Channels* chapter covers safety considerations relevant to all urban streams and specialized design of boatable hydraulic structures.

The outfalls section provides design guidance for various types of pipe end treatment and rock protection to dissipate hydraulic energy at outfalls of storm drains and culverts. Related design information is covered in the *Streets, Inlets, and Storm Drains* and *Culverts and Bridges* Chapters.

Considered environmental, ecological, and public safety objectives in the design of each structure. The proper application of hydraulic structures can reduce initial and future maintenance costs by managing the character of the flow to best meet all project needs.

The shape, size, and features of hydraulic structures vary widely for different projects, depending upon the design discharge and functional needs of the structure. Hydraulic design procedures discussed herein govern design of all structures. For the design of unique structures that may not fit the guidance provided, hydraulic physical modeling or computational fluid dynamics (CFD) modeling may be beneficial.

Guidance for Using this Chapter

- Determine if the project can be designed using the simplified method (Section 2.2) or if a detailed design is required (Section 2.3).
- Perform soils and seepage analyses as necessary for the design of the foundation and seepage control system (Section 2.4). Additional analysis of forces acting on a structure may be necessary and should be evaluated on a case-by-case basis (Section 2.5).
- Use criteria specific to the type of drop structure to determine the final flow characteristics, dimensions, material requirements, and construction methods. Refer to Section 2.6 for Grouted Stepped Boulder (GSB) drop structures or to Section 2.7 for Sculpted Concrete (SC) drops.
- Refer to the *Trails and Recreations Channels* chapter for design of boatable structures and other criteria required for public safety.

2.0 Grade Control Structures

2.1 Overview

Photograph 9-2. Grouted stepped boulder drop structures such as this one in Denver's Bible Park can be safe, aesthetically pleasing, and provide improved aquatic habitat besides performing their primary hydraulic function of energy dissipation.

As discussed in the *Open Channels* Chapter, urbanization increases the rate, frequency and volume of runoff in natural streams and, over time, this change in hydrology may cause streambed degradation, otherwise known as down cutting or head cutting. Stabilization improvements to the stream are necessary prior to or concurrent with development in the watershed. Stream stabilization is the third step of the *Four Step Process to Stormwater Management* (see Chapter 1 of Volume 3 of this manual).

"Drop structures" are broadly defined. Drop structures provide protection for high velocity hydraulic conditions that allow a drop in channel grade over a relatively short distance. They provide controlled and stable locations for a hydraulic jump to occur, allowing for a more stable channel downstream where flow returns to subcritical. This chapter provided specific design guidance for the following basic categories of drop structures:

- Grouted stepped boulder (GSB) drop structures
- Sculpted concrete (SC drop structures
- Vertical drop structures

The design of the drop structure crest and the provision for the low flow channel directly affect the ultimate configuration of the upstream reach. A higher unit flow will pass through the low flow area than will pass through other portions of the stream cross section. Consider the situation in design to avoid destabilization of the drop structure and the stream. It is also important to consider the major flood, the path of which frequently extends around structure abutments.

Design grade control structures for fully developed future basin conditions, in accordance with zoning maps, master plans, and other relevant documents. The effects of future hydrology and potential down cutting will negatively impact the channel.

There are two fundamental systems of a drop structure that require design consideration: the hydraulic surface-drop system and the foundation and seepage control system. The surface drop system is based on project objectives, stream stability, approach hydraulics, downstream tailwater conditions, height of the drop, public safety, aesthetics, and maintenance considerations. The material components for the foundation and seepage control system are a function of soil and groundwater conditions. One factor that influences both systems is the potential extent of future downstream channel degradation. Such degradation could cause the drop structure to fail.

See the *Stream Access and Recreational Channels* chapter for special design issues associated with drop structures in boatable channels.

Drops in series require full energy dissipation and return to normal depth between structures or require specialized design beyond the scope of this manual.

Evaluate drop structures during and after construction. Secondary erosion tendencies will necessitate additional bank and bottom protection. It is advisable to establish construction contracts and budgets with this in mind.

The sections that follow provide guidance on drop structure design using either a simplified design method or a more detailed hydraulic design method. The designer must evaluate each method and determine which is appropriate for the specific project.

Key Considerations during Planning and Early Design of a Drop Structure

- Identify the appropriate range of drop height based on the stable channel slope (as provided in the master plan or based on guidance provided in the *Open Channels* chapter). Limit the net drop height to five feet or less to avoid excessive kinetic energy and avoid the appearance of a massive structure. Vertical drops should not exceed 3 feet at any location to minimize the risk of injury from falling. With a 12-inch stilling basin, this limits the net drop height to two feet.
- Design with public safety in mind. Structures located in streams where boating, including tubing, is anticipated require additional considerations. See the *Stream Access and Recreational Channels* chapter.
- Begin the process of obtaining necessary environmental permits, such as a Section 404 permit, early in the project.
- Evaluate fish passage requirements when applicable. This may also be a requirement of environmental permits.

2.2 Simplified Design Procedures for Drop Structures

2.2.1 Introduction

The simplified design procedure can be used for grade control structures meeting design criteria provided in Table 9-1 and where all of the following criteria are met:

- Maximum unit discharge for the design event (typically the 100-year) over any portion of the drop structure is 35 cfs/ft or less,
- Net drop height (upstream channel invert less downstream channel invert exclusive of stilling basin depth) is 5 feet or less,
- Drop structure is constructed of GSB or SC,
- Drop structure is located within a tangent section and at least twice the distance of the width of the drop at the crest both upstream and downstream from a point of curvature,
- Drop structure is located in a reach that has been evaluated per the design requirements of the *Open Channel* chapter.

The simplified design procedures provided herein do not consider channel curvature, effects of other hydraulic structures, or unstable beds. If any of these conditions exist or the criteria above are not met, a detailed analysis is required per Section 2.3. Even if the criteria are met and the simplified design procedures are applied, checking the actual hydraulics of the structure using the detailed comprehensive hydraulic analysis may yield useful design insight.

There is a basic arrangement of upstream channel geometry, crest shape, basin length, and downstream channel configuration that will result in optimal energy dissipation. The following sections present simplified relationships that provide basic configuration and drop sizing parameters that may be used when the above criteria are met.

2.2.2 Geometry

Table 9-1 below summarizes the specific design and geometric parameters applicable to drop structures designed using the simplified design procedures. Additional discussion is provided in the sections following for some of the specific parameters summarized in the table. Graphical depiction of the geometric parameters listed in Table 9-1 can be found in Figure 9-11 through 9-14 for GSB drop structures and Figures 9-16 through 9-21 for SC drop structures.

Table 9-1. Design criteria for drop structures using simplified design procedures

Design Parameter	Requirement to Use Simplified Design Procedures	
	GSB Drop Structure	**SC Drop Structure**
Maximum Net Drop Height (H_d)	5 feet[1]	
Maximum Unit Discharge over any Portion of Drop Width	35 cfs per foot of drop width (see Section 2.2.3)	
Maximum Longitudinal Slope (Steepest Face Slope)	4(H):1(V) (see Section 2.2.4 for additional discussion)	
Minimum Stilling Basin Depression (D_b)	1 foot (see Section 2.2.6 for additional discussion and requirements for non-cohesive soils)	2 feet (see Section 2.2.6 for additional discussion and requirements for non-cohesive soils)
Minimum Length of Approach Riprap (L_a):	8 feet	
Minimum Stilling Basin Length (L_b):	Determine using Figure 9-1 (see Section 2.2.4)	
Minimum Stilling Basin Width (B)	same as crest width	
Minimum Cutoff Wall Depth	6 feet (for cohesive soils only, see Section 2.2.6 for additional discussion)	
Minimum Length of Riprap Downstream of Stilling Basin	10 feet	
Minimum D_{50} for Approach and Downstream Riprap	12 inches	
Minimum Boulder Size for Drop Structure	Per Figure 9-1	N/A

[1]This is considered a large drop structure and is only appropriate where site specifics do not accommodate installation of smaller drop structures. Urban Drainage and Flood Control District (UDFCD) recommends the height of the drop structure not exceed 3 feet.

2.2.3 Unit Discharge

The unit discharge is an important design parameter for evaluating the hydraulic performance of a drop structure. In order to use the simplified design procedures, the design event maximum unit discharge over any portion of the drop structure width is 35 cfs/ft. This value is derived from recommended values for velocity and depth listed in the *Open Channels* chapter. Typically, this maximum unit discharge will occur in the low-flow channel, but in rare circumstances may be in the overbanks. Determine the design unit discharge at the crest of the drop structure and at a channel cross section 20 to 50 feet upstream of the crest. Depending on the depth of the low-flow channel at these two locations, the unit discharge could differ at the sections. Normally, the maximum unit discharge of the cross sections and exercise judgement regarding the appropriate unit discharge used for the drop structure design. Further discussion on the hydraulic evaluation of a channel cross section is in Section 2.3.6.

2.2.4 Longitudinal Slope of the Drop Structure Face

The longitudinal slope of the structure face should be no steeper than 4(H):1(V), while even flatter slopes will improve safety. Flatter longitudinal face slopes (i.e., flatter than 8(H):1(V), help to mitigate overly retentive hydraulics at higher tailwater depths that can cause submerged hydraulic jump formation and create reverse rollers with "keeper" waves which are a frequent cause of drowning deaths in rivers. Where possible roughen the face of the drop by developing a series of slopes rather than a smooth surface. Individual steps and differences in vertical elevation should be no greater than 3 feet in any location to limit consequence associated with slip and fall during dry conditions. The *Stream Access and Recreational Channels* chapter provides additional longitudinal slope considerations for water-based recreation and in-channel safety as well as other avoidance techniques for overly-retentive drop structures.

Overly Retentive Hydraulics

Drop faces should have a longitudinal slope no steeper than 4(H):1(V). The formation of overly retentive hydraulics is a major drowning safety concern when constructing drop structures. Longitudinal slope, roughness and drop structure shape all impact the potential for dangerous conditions. See the *Stream Access and Recreational Channels* chapter for additional criteria.

2.2.5 Stilling Basin

Typically, drop structures include a hydraulic jump dissipater basin. The stilling basin should be depressed in order to start the jump near the toe of the drop face, per the requirements in Table 9-1. A sill should be located at the basin end to create a transition to the downstream invert elevation. The profiles for GSB (Figure 9-12) and SC (Figure 9-17) drop structures include options for both non-draining and draining stilling basins. Where it is undesirable to have standing water, provide an opening in the end sill.

When using the simplified design, the length of the stilling basin (L_b) can be determined using Figure 9-1. Figure 9-1 provides the required stilling basin length for both GSB and SC drop structures up to a unit discharge of 35 cfs/ft. If the proposed drop structure does not fit within the requirements of the simplified design, complete a detailed hydraulic analysis as described in Section 2.3.

In non-cohesive soil channels and channels where future degradation is expected, especially where there is no drop structure immediately downstream, it is generally recommended that the stilling basin be eliminated and the sloping face extended five feet below the downstream future channel invert elevation (after accounting for future streambed degradation). A scour hole will form naturally downstream of a structure in non-cohesive soils and construction of a hard basin is an unnecessary cost. Additionally, a hard basin would be at risk for undermining. See Figure 9-12 for the profile of the GSB and Figure 9-17 for that of an SC in this configuration. In some cases, the structure may have a net drop height of zero immediately after construction, but is designed with a long-term net height of 3 to 5 feet to accommodate future lowering of the channel invert.

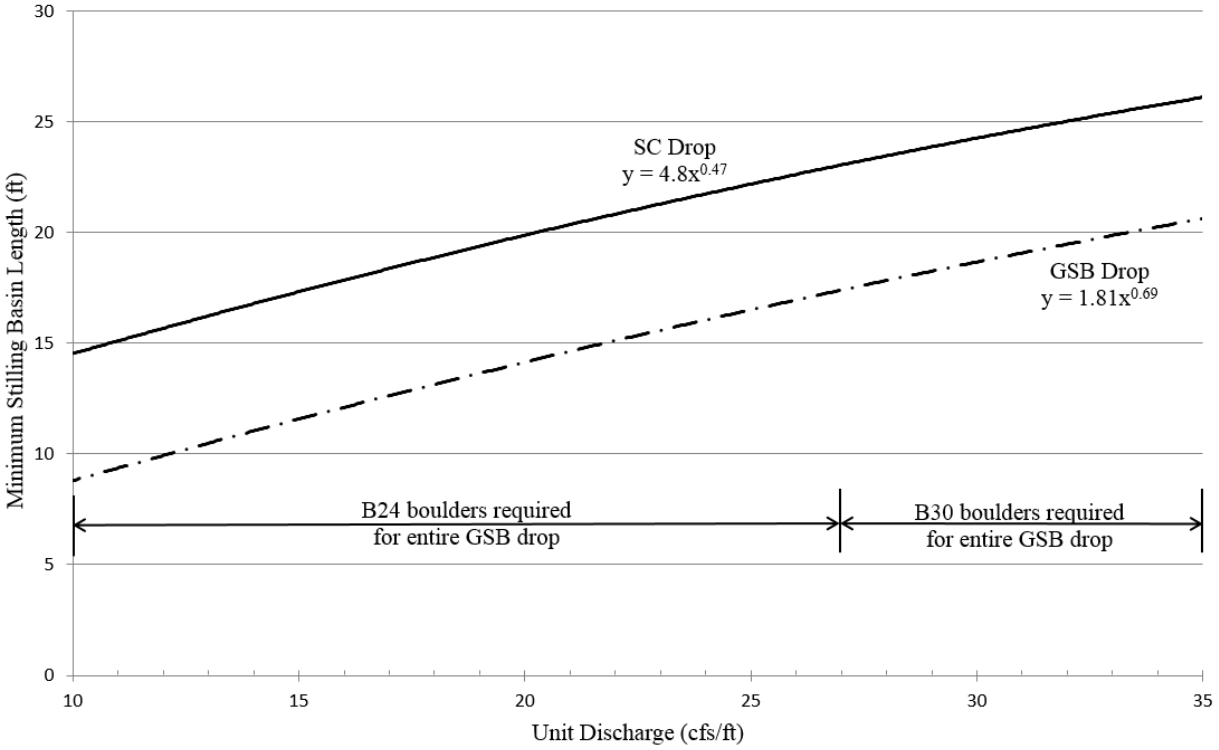


Figure 9-1. Stilling basin length based on unit discharge (for simplified design procedure)

2.2.6 Seepage Analysis and Cutoff Wall Design

The simplified drop structure design only applies to drops with cutoffs located in cohesive soils. Therefore, it is necessary to determine surface and subsurface soil conditions in the vicinity of a proposed drop structure prior to being able to use the simplified approach for cutoff design. For a drop structure constructed in cohesive soils meeting all requirements of a simplified design, the cutoff wall must be a minimum of six feet deep for concrete and ten feet deep for sheet pile.

If a proposed drop structure meets the requirements of the simplified approach, but is located in non-cohesive soils, guidance on determining the required cutoff wall depth is described in Section 2.4.

Photograph 9-4. View of the sheet pile cutoff wall and steel reinforcement for a sculpted concrete drop structure prior to the concrete placement. Note the steel reinforcement has been spot welded to the sheet pile.

The vertical seepage cutoff wall should be located upstream of the crest and can be constructed of either concrete or sheet pile. One of the most important details for grade control structures involves the interface between the seepage cutoff wall and the remainder of the structure. Regardless, of the material used for the cutoff wall, the structure should completely bury the interface between the wall and structure. This eliminates the unattractive view of the cutoff wall within the drop structure and provides a more effective seal at the interface. To ensure a good seal, specify that the contractor must fully clean the surface of the cutoff wall prior to the construction of the interface. Figures 9-7 through 9-9 provide multiple options (for both GSB and SC drop structures) for connecting the verticle cutoff wall to the drop structure. Additionally, the cutoff wall should extend beyond the low-flow channel and five to ten feet into the bank on each side of the structure as shown in Figure 9-27.

Take special care when designing cutoff walls for drops in series. This typically requires a deeper wall or a wall at each crest.

2.2.7 Low-flow Channel

The crest of the drop structure is frequently shaped similarly to, although sometimes slightly shallower than, the upstream low-flow channel. It is also typical that the shape transition along the face of the structure in an effort to disperse the flow and dissipate energy over the width of the drop structure. This geometry is recommended unless the stream is boatable. The low-flow channel can then be re-established beyond the end sill of the drop structure. In some circumstances protection in the low-flow channel may need to extend further downstream than protection in the main channel. This should be evaluated on a case-by-case basis. When the stream is boatable, it is typically preferred that flows remain concentrated through the drop.

2.3 Detailed Drop Structure Hydraulic Analysis

2.3.1 Introduction

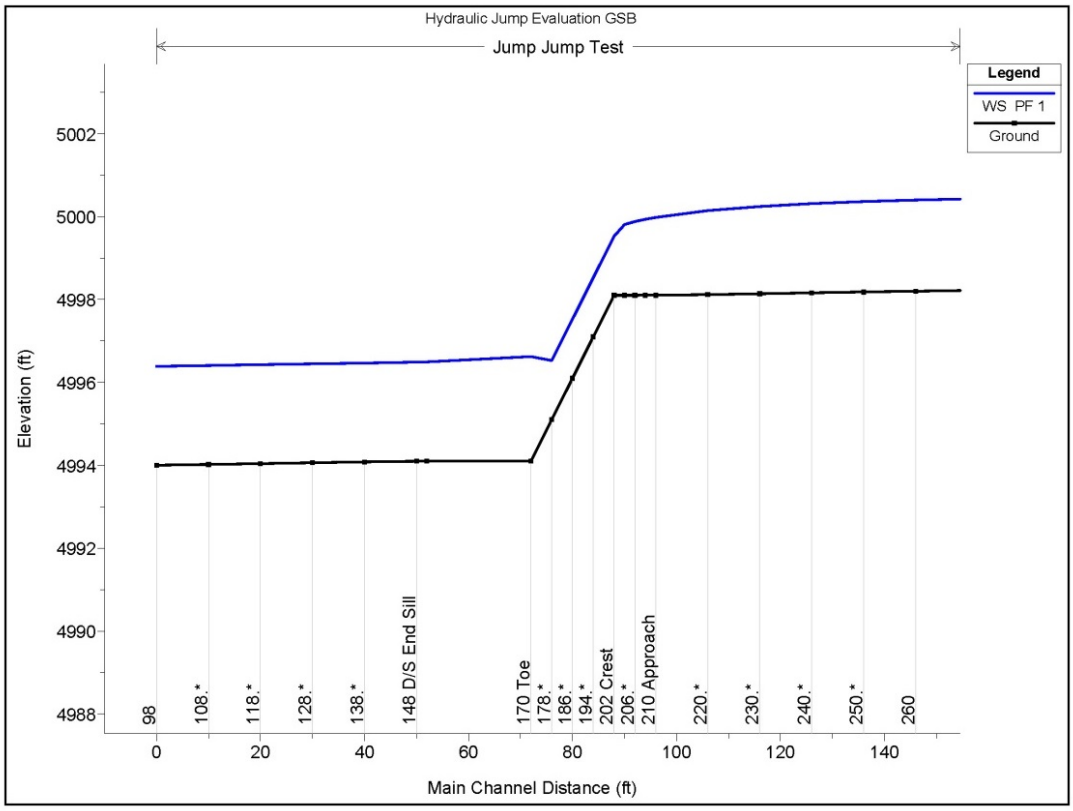
When the parameters of a proposed drop structure do not fit within the criteria of a simplified design (see Section 2.2), or when a designer desires a more thorough analysis of drop structure hydraulics, a detailed hydraulic analysis is conducted. The guidelines presented in this section assume that the designer is using HEC-RAS to assist with the detailed computations necessary for drop structure analysis. It is important to be familiar with the HEC_RAS variables selected for the computations and the effect these variables have on the results of the analysis. The analysis guidelines discussed in this section are intended to assist the engineer in addressing critical hydraulic design factors.

2.3.2 Cross Section Placement

Appropriate placement of cross sections is important when completing a hydraulic analysis of a drop structure using HEC_RAS. Place cross-sections at the following locations:

- Upstream of Drop (50 feet +/-) where channel is at normal depth
- Drop Approach (5 feet +/- upstream of drop crest)
- Drop Crest
- Toe of Drop
- Upstream and at Drop End Sill
- Downstream of Drop (50 feet +/-) where channel has recovered to normal depth

In addition to the locations above, use the "cross section interpolation" option in HEC_RAS. At a minimum, add interpolated cross sections (denoted with * in Figure 9-2) along the drop face. Interpolated cross sections upstream of the drop crest and downstream of the end sill may also be beneficial. Figure 9-2 provides a sample channel profile from HEC_RAS with cross section locations for reference.



*Denotes Interpolated Cross Section

Figure 9-2. Sample HEC_RAS profile with cross section locations for hydraulic analysis

2.3.3 Mannings's Roughness Coefficient for Drop Structures

Depending on the type of materials and the relative depth, select the appropriate roughness parameters for the HEC-RAS model. Table 9-2 provides roughness parameter recommendations and references for both sculpted concrete and grouted boulder drop structure.

Table 9-2. Approximate Manning's roughness at design discharge for stepped drop structure

Stepped sculpted concrete where step heights equal 25% of drop	0.025[1]
Grouted Boulders	See Figure 9-3

[1] This assumes an approach channel depth of at least 5 feet. Values would be higher at lesser flow depths.

The equations typically used for riprap and provided in the *Open Channels* chapter do not apply to boulders and grouted boulders because of their near uniform size and because the voids may be completely or partially filled with grout. Therefore, the Manning's roughness values for grouted boulders are based on (Chow 1959; Oliver 1967; Anderson et. Al 1973; Henderson 1966; Barnes 1967; Smith and Murray 1975; Stevens et. Al. 1976; Bathurst, Li and Simons 1979; and Stevens 1984). The roughness coefficient varies with the depth of flow relative to the size of the boulders and the depth of grout used to lock them in place.

The following equations may be used to find the recommended Manning's *n* as a function of flow depth over height of the boulders, *y/D*, as represented by the curves in Figure 9-3:

When the upper one-half (plus or minus 1inch) of the rock height is ungrouted, the equation for *n* is:

$$n_{24"-42"(1/2)} = \frac{0.097\left(y/D\right)^{0.16}}{\ln\left(2.55y/D\right)} \qquad \text{Equation 9-1}$$

When the upper one-third (plus or minus 1 inch) of the rock height is ungrouted, the equation for *n* is:

$$n_{24"-42"(2/3)} = \frac{0.086\left(y/D\right)^{0.16}}{\ln\left(2.55y/D\right)} \qquad \text{Equation 9-2}$$

Where:

y = depth of flow above top of rock (feet)

D = diameter of the boulder (feet)

The upper limit for Equation 9-1 is $n \leq 0.104$ and for Equation 9-2 is $n \leq 0.092$. Determine the value for "y" by reviewing the HEC_RAS cross sections and determining an appropriate representation of the average flow depth over the structure. If the value for *y/D* is < 1, use 1.

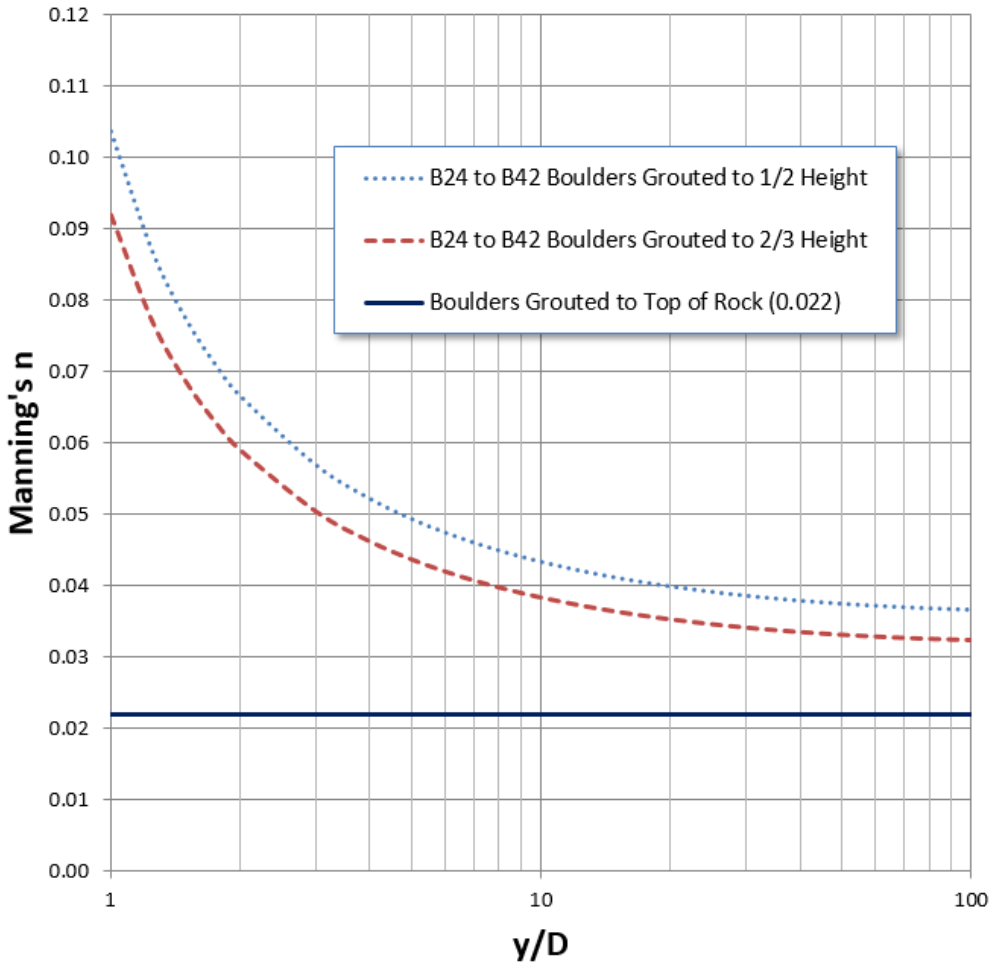


Figure 9-3. Recommended Manning's n for flow over B24 to B42 grouted boulders

Using a stepped grouted rock placement and grouting only the lower ½ of the rock on the drop face creates a significantly higher Manning's n roughness coefficient and, as a result, greater flow depth and lower velocity, reducing the boulder size needed to have a stable structure. Refer to Section 2.6.3 for discussion on boulder sizing for GSB drop structures.

2.3.4 Hydraulic Jump Formation

Once the location and geometry of the drop structure cross sections have been determined, evaluate the HEC-RAS model for the design flow under both subcritical and supercritical flow conditions. To minimize the stilling basin length, use a downstream tailwater depth great enough to force a hydraulic jump to start near the toe of the drop face. This requires that the specific force of the downstream tailwater be greater than the specific force of the supercritical flow at the toe of the drop. The tailwater is modeled by a subcritical water surface (M1 backwater or M2 drawdown curve) profile analysis that starts from a downstream control point and works upstream to the drop structure basin. Model the depth and specific force at the toe of the drop by a supercritical water surface (S2 drawdown curve) profile analysis starting at the crest of the drop and running down the drop face.

Using the output from the subcritical and supercritical HEC-RAS hydraulic models, calculations should be completed to verify that the specific force associated with the downstream tailwater is greater than the specific force of the supercritical flow at the toe of the drop, not only for the design discharge, but for flows corresponding to more frequent events. Specific force can be calculated using equation 9-3 (Chow 1959):

$$F = \frac{Q^2}{gA} + \bar{z}A \qquad \text{Equation 9-3}$$

Where:

F = specific force

Q = flow at cross section

g = acceleration of gravity

$\bar{z}$ = distance from the water surface elevation to the centroid of the flow area (A)

A = area of flow

The required tailwater depth is determined using Equation 9-4 (Chow 1959). This equation applies to rectangular channel sections and should be applied to a rectangular portion of flow within a drop structure. For irregular (non-rectangular) channel shapes, the designer should apply Equation 9-4 using the unit discharge within a rectangular segment of the drop crest. Assuming the low-flow channel is incorporated into the drop crest and this portion of the crest has the largest unit discharge, the rectangular portion would extend over the bottom width of the low-flow channel. See Section 2.3.6 for additional discussion on evaluating the conditions in both the low-flow channel and the overbanks.

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1+8F_1^2} - 1\right) \qquad \text{Equation 9-4}$$

Where:

y_2 = required depth of tailwater (also called the sequent depth, in feet)

y_1 = depth of water at drop toe, feet (taken from cross section at drop toe, supercritical HEC-RAS model)

F_1 = Froude Number = $V_1/(gy_1)^{1/2}$ (based on depth and velocity at drop toe)

Calculate the required tailwater depth (y_2) using Equation 9-4. Compare the results of this calculation to the modeled tailwater depth determined in the subcritical HEC-RAS model at the upstream side of the end sill (channel depth plus Db). The modeled tailwater depth must be greater than or equal to the calculated required headwater depth for a hydraulic jump to start near the toe of the drop. If the modeled tailwater depth is less than required, the drop structure geometry must be re-evaluated. One option is to increase the depth of the stilling basin, thereby increasing the effective tailwater depth and specific force, and another is to widen the crest of the drop or reduce the depth of the low-flow channel to produce a smaller unit discharge.

2.3.5 Hydraulic Jump Length

After the hydraulic jump has been analyzed using the guidelines provided in Section 2.3.4, the jump length must be calculated. This will aid the designer in determining the appropriate stilling basin length and the need for additional rock lining downstream of the end sill. The following values are required to determine the hydraulic jump length:

y_2 = required depth of tailwater (feet)

F_1 = Froude Number = $V_1/(gy_1)^{1/2}$ (based on depth and velocity at drop toe)

Use the above values to determine the length of the hydraulic jump (L) in Figure 9-4. Note that this figure is for horizontal channels, which is appropriate for most applications in the UDFCD region. Curves for sloping channels (from 5 to 25%) are in Chow, 1959.

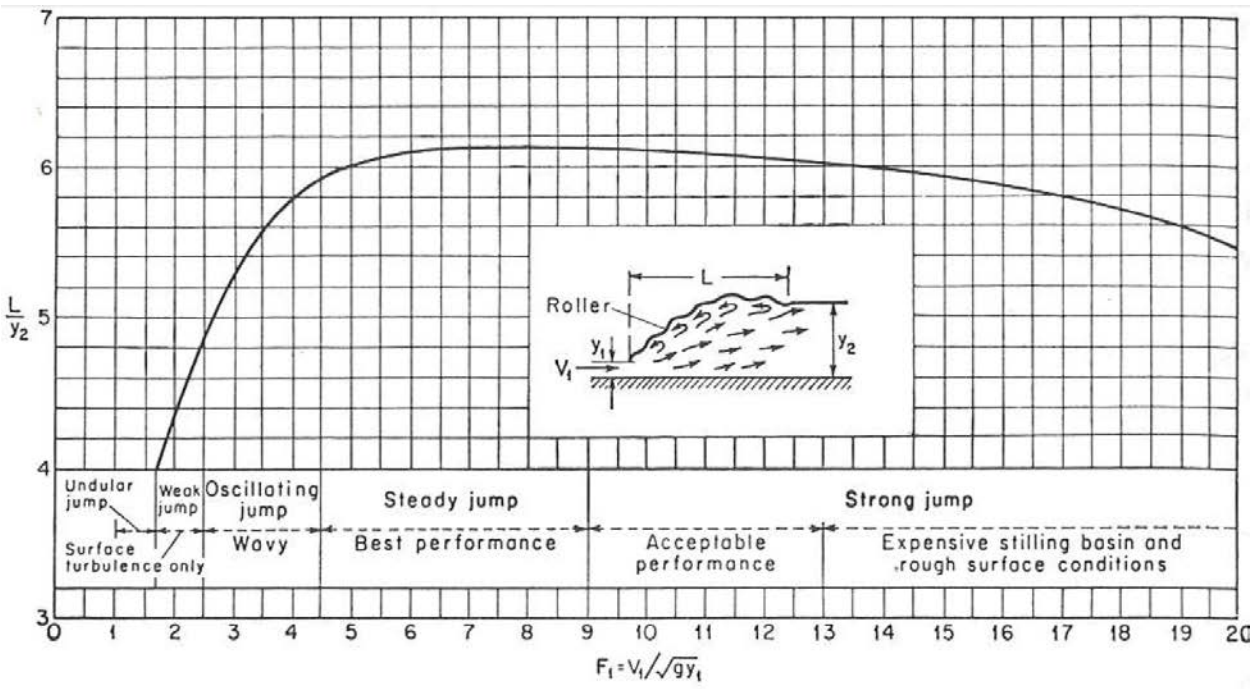


Figure 9-4. Length in terms of sequent depth of jumps in horizontal channels
(Source: US Bureau of Reclamation, 1955)

UDFCD recommends a hard-lined stilling basin (sculpted concrete, grouted boulders, or concrete grout) that is at least 60% of the hydraulic jump length (L). Extend riprap downstream of the sill and provide protection for at least the balance of the full hydraulic jump length (see Figure 9-5). Determine riprap size using the equations provided in the *Open Channels* chapter for channel lining.

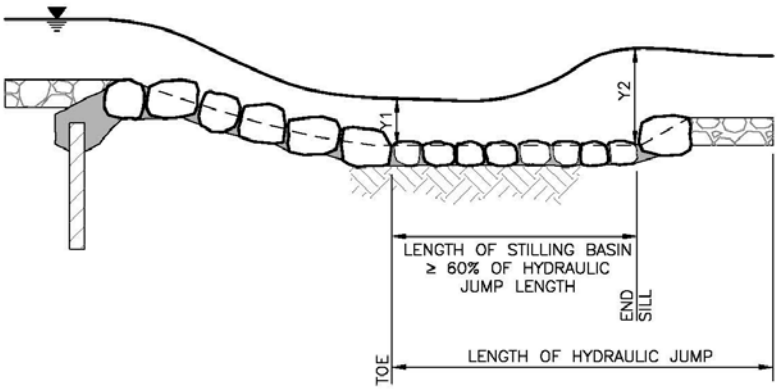


Figure 9-5. Stilling basin profile

2.3.6 Evaluation of Low-flow Channel versus Overbanks

Review the HEC-RAS model to evaluate the hydraulic conditions in both the low-flow channel and the overbanks at the crest and 20 to 50 feet upstream of the crest and determine the maximum representative unit discharge (See Section 2.2.3). Check the shear velocity in the overbanks of low-flow drops to determine if protection in this area is appropriate.

Use the "worst case" hydraulic scenario to design the entire drop structure. In most conditions, the low-flow channel will see the greater unit discharge and velocity and therefore represent the "worst case." HEC-RAS provides output tables to assess the conditions in both the low-flow and overbanks (see Figure 9-6).

Certain site conditions may warrant a separate evaluation for the low-flow channel and overbanks. In some cases, the designer may elect to extend the stilling basin longer in the low-flow channel area than the overbanks; however, in such cases the transition in basin length should be gradual rather than abrupt.

Plan: extrasec Jump Jump Test RS: 202 Profile: PF 1

E.G. Elev (ft)	5001.06	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.65	Wt. n-Val.	0.05	0.05	0.05
W.S. Elev (ft)	5000.41	Reach Len. (ft)	4	4	4
Crit W.S. (ft)	5000.41	Flow Area (sq ft)	69.05	23.09	69.05
E.G. Slope (ft/ft)	0.027778	Area (sq ft)	69.05	23.09	69.05
Q Total (cfs)	1000	Flow (cfs)	400.13	199.74	400.13
Top Width (ft)	118.47	Top Width (ft)	54.23	10	54.23
Vel Total (ft/s)	6.2	Avg. Vel. (ft/s)	5.8	8.65	5.8
Max Chl Dpth (ft)	2.31	Hydr. Depth (ft)	1.27	2.31	1.27
Conv. Total (cfs)	6000	Conv. (cfs)	2400.8	1198.4	2400.8
Length Wtd. (ft)	4	Wetted Per. (ft)	54.56	10	54.56
Min Ch El (ft)	4998.1	Shear (lb/sq ft)	2.19	4	2.19
Alpha	1.09	Stream Power (lb/ft s)	12.72	34.64	12.72
Frctn Loss (ft)	0.1	Cum Volume (acre-ft)	0.03	0.46	0.03
C & E Loss (ft)	0	Cum SA (acres)	0.03	0.2	0.03

Figure 9-6. Sample HEC-RAS output for cross section located at drop crest

2.3.7 Evaluate Additional Return Period Flow Rates

Evaluate the design flow and then assess additional return-period flow rates, as appropriate. For all flows, the actual downstream tailwater should be greater than the tailwater required to force a hydraulic jump to start near the toe of the drop structure face. When this condition is met for a range of events a stilling basin length of 60% of the hydraulic jump length should be adequate.

2.3.8 Rock Sizing for Drop Approach and Downstream of End Sill

Calculate the appropriate rock size for the drop approach and downstream of the end sill. The hydraulic conditions at the approach include the acceleration effects of the upstream drawdown as the water approaches the drop crest. Turbulence generated from the hydraulic jump will impact the area downstream of the end sill. Determine riprap size using the equations provided in the *Open Channels* chapter for channel lining. Because normal depth conditions do not exist upstream and downstream of the drop structure, refer to the HEC-RAS output and use the energy grade line slope (rather than channel slope) to determine the appropriate riprap size.

Riprap at the approach and downstream of the end sill should be a minimum D_{50} of 12-inches, or larger as determined using the channel lining equation in the *Open Channels* chapter. Use either void-filled or soil-filled riprap in these areas.

2.4 Seepage Control

2.4.1 Introduction

Subgrade erosion caused by seepage and structure failures caused by high seepage pressures or inadequate mass are two failure modes of critical concern.

Seepage analyses can range from hand-drawn flow nets to computerized groundwater flow modeling. Use advanced geotechnical field and laboratory testing techniques confirm permeability values where complicated seepage problems are anticipated. Several flow net analysis programs are currently available that are suitable for this purpose. Full description of flow net analysis is beyond the scope of the Urban Storm Drainage Criteria Manual (USDCM). Referred to Cedergren 1967; USBR 1987; and Taylor 1967 for more information and instruction in the use of flow net analysis techniques. See Section 2.4.3 for Lane's Weighted Creep method, a simplified approach.

2.4.2 Weep Drains

Install weep drains in all grade control structures greater than 5 feet in net height or as recommended by the geotechnical engineer. Weep drains assist in reducing the uplift pressure on a structure by providing a location for groundwater to escape safely through a filter. For concept, see Figure 9-10. Weep drains should be placed outside of the low-flow path of the structure and spaced to provide adequate relief of subsurface pressures.

2.4.3 Lane's Weighted Creep Method

As a minimum level of analysis and as a first order of estimation, Lane's Weighted Creep (Lane's) Method can be used to identify probable seepage problems, evaluate the need for control measures, and estimate rough uplift forces. It is not as definitive as the flow net analyses mentioned above. Lane's method was proposed by E.W. Lane in 1935. This method was removed from the 1987 revision of *Design of Small Dams* (USBR 1987), possibly indicating greater use of flow net and computer modeling

methods or perhaps for other reasons not documented. Although Lane's method is relatively well founded, it is a guideline, and when marginal conditions or complicated geological conditions exist, use the more sophisticated flow-net analysis.

The essential elements of Lane's method are as follows:

1. The weighted-creep distance through a cross section of a structure is the sum of the vertical creep distances, Lv (along contact surfaces steeper than 45 degrees), plus one-third of the horizontal creep distances, L_H (along contact surfaces less than 45 degrees).

2. The weighted-creep head ratio is defined as:

$$C_W = \frac{\left(\frac{L_H}{3} + L_V\right)}{H_S} \qquad \text{Equation 9-5}$$

Where:

C_W = creep ratio

H_S = differential head between analysis points (ft)

3. Reverse filter drains, weep holes, and pipe drains help to reduce seepage problems, and recommended creep head ratios may be reduced as much as 10% if they are used.

4. In the case where two vertical cutoffs are used, then Equation 9-6 should be used along with Equation 9-2 to check the short path between the bottom of the vertical cutoffs.

$$C_{W2} = \frac{\left(L_{V-US} + \quad 2L_{H-C} + L_{V-DS}\right)}{H_S} \qquad \text{Equation 9-6}$$

Where:

C_{W2} = creep ratio where two vertical cutoffs are used

$L_{V\text{-}US}$ = vertical distance on the upstream side of the upstream cutoff (ft)

$L_{V\text{-}DS}$ = vertical distance on the downstream side of the downstream cutoff (ft)

$L_{H\text{-}C}$ = horizontal distance between the two vertical cutoffs (ft)

5. If there are seepage lengths upstream or downstream of the cutoffs, they should be treated in the numerator of Equation 9-6 similar to Equation 9-5. Seepage is controlled by increasing the total seepage length such that C_W or C_{W2} is raised to the value listed in Table 9-3. Test soils during design and again during construction.

6. Estimate the upward pressure in design by assuming that the drop in uplift pressure from headwater to tailwater along the contact line of the drop structure is proportional to the weighted-creep distance.

Table 9-3. Lane's weighted creep: Recommended minimum ratios

Material	Ratio
Very fine sand or silt	8.5
Fine sand	7.0
Medium sand	6.0
Coarse sand	5.0
Fine gravel	4.0
Medium gravel	3.0
Coarse gravel including cobbles	3.0
Boulders with some cobbles and gravel	3.0
Soft clay	3.0
Medium clay	2.0
Hard clay	1.8
Very hard clay or hardpan	1.6

2.4.4 Foundation/Seepage Control Systems

As a general rule, groundwater flow cutoffs should not be installed at the downstream ends of drop structures. They can cause greater hydraulic uplift forces than would exist without a downstream cutoff. The design goal is to relieve the hydrostatic pressures along the structure and not to block the groundwater flow and cause higher pressures to build up.

The hydraulic engineer must calculate hydraulic loadings that can occur for a variety of conditions such as dominant low flows, flood flows, design flows and other critical loading scenarios. A geotechnical engineer should combine this information with the on-site soils information to determine foundation requirements. Both engineers should work with a structural engineer to establish final loading diagrams and to determine and size structural components.

The designer needs to be cognizant of field conditions that may affect construction of a drop structure, including site water control and foundation moisture and compaction. A common problem is destabilization of the foundation soils by rapid local dewatering of fine-grained, erosive soils or soils with limited hydraulic conductivity. Since subsurface water control during construction is so critical to the successful installation of a drop structure, the designer needs to develop ways to ensure that the contractor adequately manages subsurface water conditions.

During construction, check design assumptions in the field including the actual subgrade condition with respect to seepage control assumptions be inspected and field verified. Ideally, the engineer who established the design assumptions and calculated the required cutoffs should inspect the cutoff for each drop structure and adjust the cutoff for the actual conditions encountered. For example, if the inspection of a cutoff trench reveals a sandy substrate rather than clay, the designer may choose to extend the cutoff trench, or specify a different cutoff type. Pre-construction soil testing is an advisable precaution to minimize changes and avoid failures.

Proper dewatering in construction will also improve conditions for construction structures. See Fact Sheet SM-08, Temporary Diversion Methods, located in Volume 3 of this manual.

2.5 Detailed Force Analysis

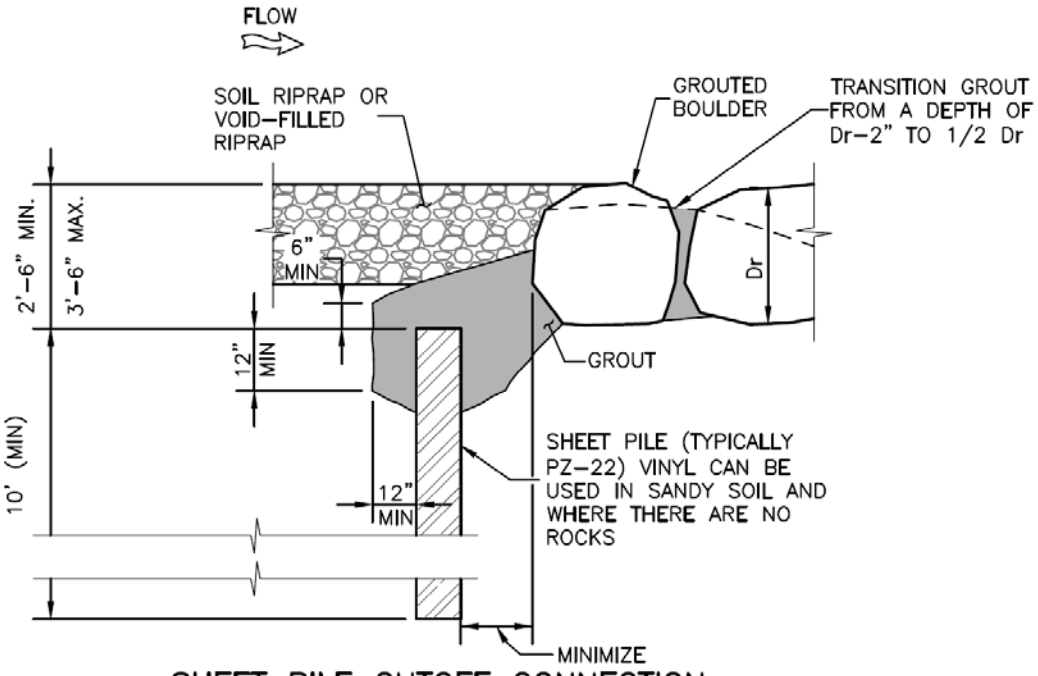
Each component of a drop structure has forces acting upon it that the design engineer should consider. While a brief summary of these forces is provided in this section, it is beyond the scope of this manual to provide detailed guidance on the evaluation of these forces. It is the design engineer's responsibility to properly account for potential forces in the drop structure design.

While a detailed force analysis may not be necessary for drop structures developed using the guidelines presented in the simplified design procedures, the designer may want to check forces acting on a drop structure. The critical design factors are seepage cutoff and relief and pressure fluctuations associated with the hydraulic jump that can create upward forces greater than the weight of water and structure over the point of interest.

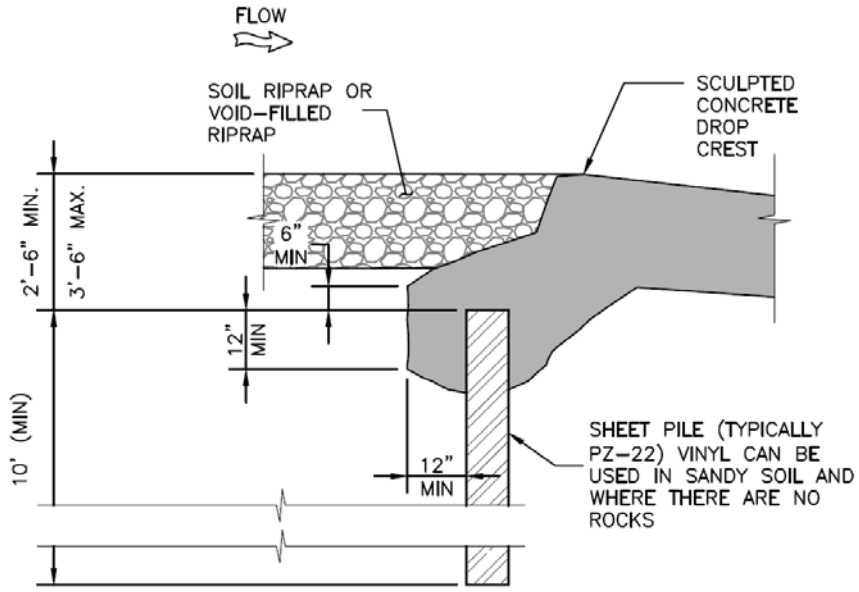
In addition to seepage uplift pressure, the designer should also evaluate the following forces on a drop structure:

- Shear Stress
- Buoyant Weight of Structure
- Impact, Drag and Hydrodynamic Lift Forces
- Turning Force
- Friction
- Frost Heave
- Dynamic Pressure Fluctuations

See Appendix A for additional discussion regarding drop structure force analysis.



SHEET PILE CUTOFF CONNECTION
(GSB)



SHEET PILE CUTOFF CONNECTION
(SC)

Figure 9-7. Sheet pile cutoff wall upstream of drop structure

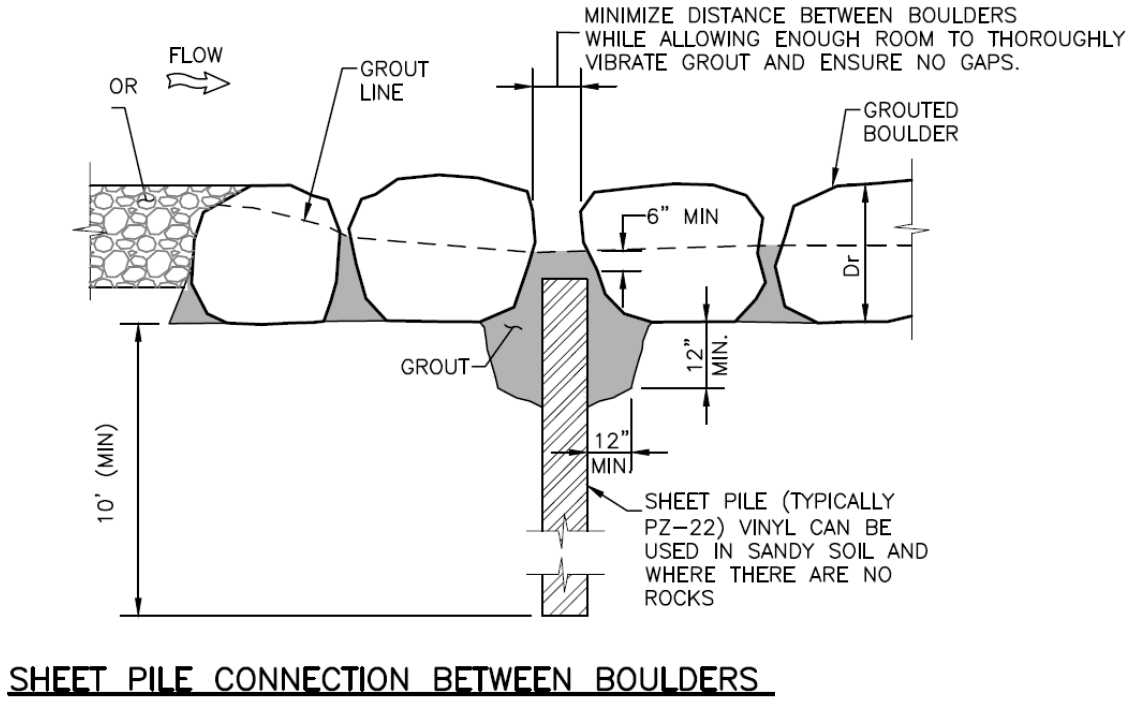


Figure 9-8. Sheet pile cutoff wall connections between boulders

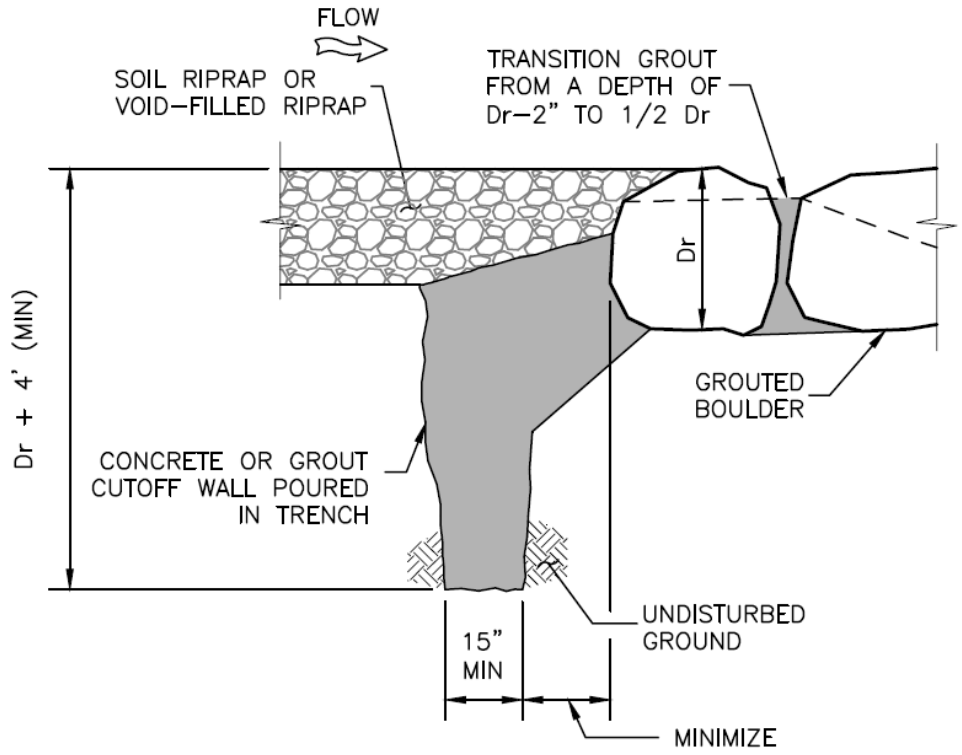


Figure 9-9. Concrete or grout cutoff wall upstream of drop structure

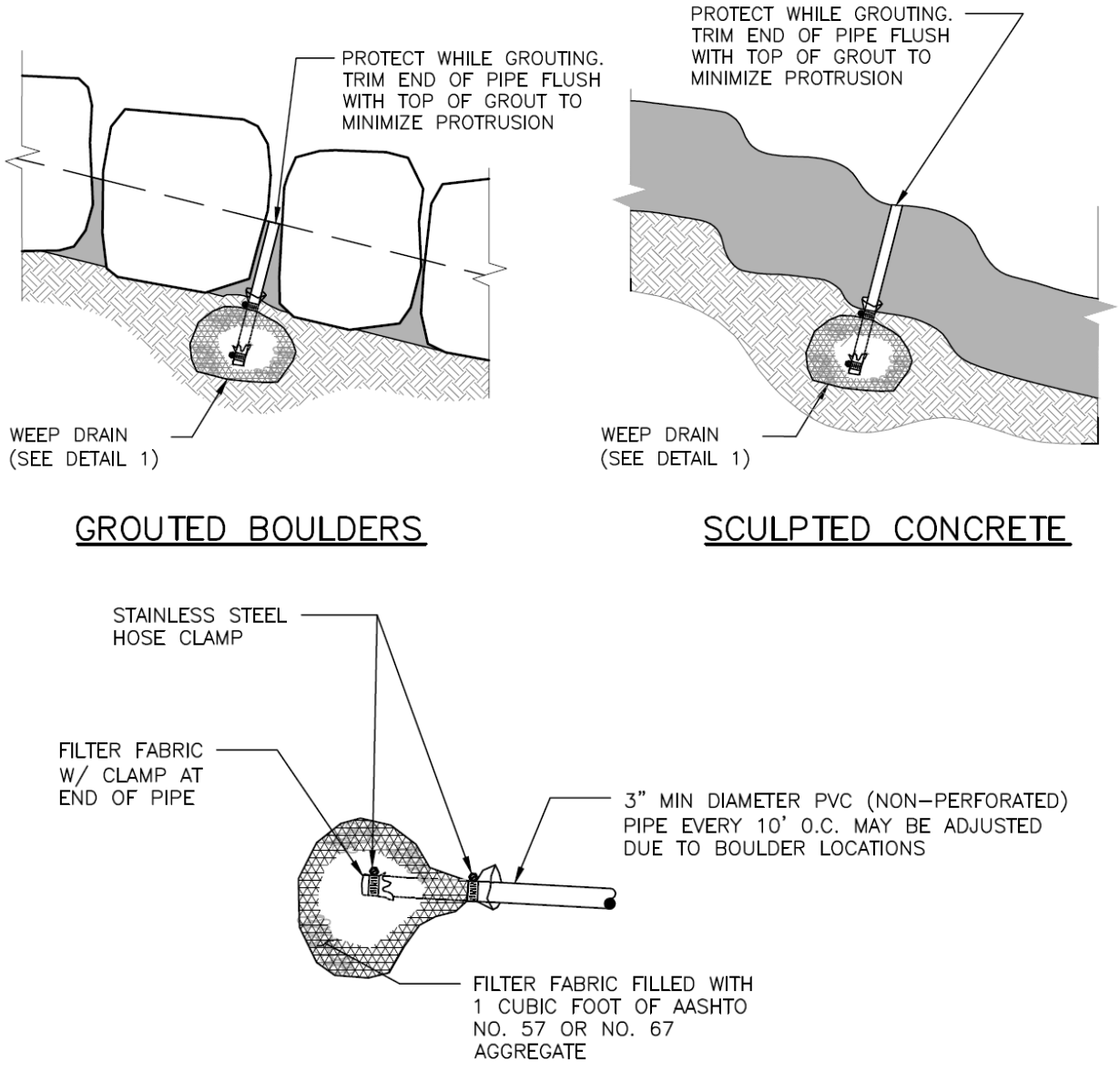


Figure 9-10. Weep drains

2.6 Grouted Stepped Boulder Drop Structures

2.6.1 Description

Grouted stepped boulder (GSB) drop structures have gained popularity in the UDFCD region due to close proximity to high-quality rock sources, design aesthetics, and successful applications. The quality of rock used and proper grouting procedure are very important to the structural integrity.

To improve appearance, cover the grouted boulders above the low-flow section and on the overbanks with local topsoil and revegetated. This material has potential to wash out but when able to become vegetated, has a more attractive and natural appearance.

2.6.2 Structure Complexity

An enlarged plan view of the structure will be necessary for all projects. The amount of detail shown on that plan view will vary depending on the structure complexity, which should be determined early in the design phase.

Sample plans for GSB drop structures are provided in this chapter and are referred to as either "basic" or "complex". A basic structure generally has more of a linear shape with little variation in the step widths and heights. A complex structure will be non-linear with more variation, which may result in a need for more details and cross sections. It is imperative that adequate detail be provided for a complex structure to be constructed as intended.

Photograph 9-5. Example of stepped downstream face for a grouted boulder drop structure. Note dissipation of energy at each step for low flows.

Figures 9-11 through 9-13 illustrate the general configuration of a GSB drop structure. These figures include plan view, profile, and cross sections at key locations along the drop structure. Figure 9-14 provides an example configuration for a complex GSB drop structure, including a plan view and profile. These figures also serve as an example of the recommended level of detail for construction drawings.

2.6.3 Design Criteria

Hydraulic analysis and design of GSB drop structures should be according to Section 2.2 (simplified design procedures) or Section 2.3 (detailed hydraulic analysis), as appropriate. In addition, the following guidance also applies to structures constructed of grouted boulders.

Boulder Sizing
Boulder sizing for GSB drop structures constructed using the simplified method can be determined using Figure 9-1. For drop structures that do not meet the criteria for the simplified design method, the following procedure should be used to determine boulder size.

1. If the vertical distance from the drop toe to the drop crest is less than or equal to six feet, determine the critical velocity for the design flow in both the low-flow channel and the overbanks. This velocity occurs just upstream of the drop crest. For drop structures up to six feet in height, gradually varied flow acceleration is considered negligible. If the vertical distance from the drop toe to the drop crest is greater than six feet, determine the actual velocity at the drop toe using S2 curve drawdown calculations for the design flow in both the low-flow channel and the overbanks. This can be done using either the standard step or the direct step method. If a detailed hydraulic analysis has been completed using HEC-RAS (see Section 2.3), then the actual velocity is provided in the HEC-RAS output and the critical velocity can be taken from the section just upstream of the drop structure.

2. Calculate rock-sizing parameter, R_p (dimensionless), for both segments of the cross section (overbanks and in the low-flow channel):

$$R_p = \frac{VS^{0.17}}{(S_s - 1)^{0.66}} \qquad \text{Equation 9-7}$$

Where:

V = critical velocity, V_c (for drop structure heights up to six feet) or drawdown velocity at the toe of the drop (for drop height exceeding six feet)

S = slope along the face of the drop (ft/ft)

S_s = specific gravity of the rock (Assume 2.55 unless the quarry certifies a higher value.)

Note that for drop heights exceeding six feet, Equation 9-7 becomes iterative, since Manning's roughness coefficient is a function of the boulder size, from Equation 9-1 or 9-2.

3. Select minimum boulder sizes for the cross-section segments within and outside the low-flow channel cross-section from Table 9-4. If the boulder sizes for the low-flow channel and the overbank segments differ, UDFCD recommends using only the larger sized boulders throughout the entire structure. Mistakes during construction are more common when specifying multiple rock sizes within the same structure.

Table 9-4. Boulder sizes for various rock sizing parameters

Rock Sizing Parameter, R_p	Grouted Boulders [1]
	Boulder Classification [2]
Less than 5.00	B24
5.00 to 5.59	B24
5.60 to 6.99	B36
7.00 to 8.00	B48

[1] Grouted to no less than 1/3 the height (+1"/- 0"), no more than 1/2 (+0"/- 1") of boulder height.
[2] See *Open Channels* chapter.

Grout
Grout all boulders to a depth of one-half their height through the approach, sloping face, and basin areas. Grout should extend near full depth of the rock at the upstream crest and around the perimeter of the structure where it is adjoining the earth in order to provide stability of the approach channel. See Figure 9-15 for grout placement and material specifications.

Edge Wall
Construct a wall that extends roughly 3 feet below the top surface of the structure around the entire perimeter of the GSB drop structure. See Figure 9-22 for an edge wall detail. An edge wall is especially necessary for structures designed to convey less than the 100-year flow but is also beneficial for structures that do span the 100-year flow. In addition, use buried riprap around the perimeter of the structure when this is the case. The transition between soil and the grouted boulders can become a problem if not properly addressed during design and construction. Ensure compaction around the perimeter of the structure and grade this area higher than the structure to promote sheet flow onto the structure.

Additional Design Guidance
Grouted boulders must cover the crest and cutoff and extend downstream through the stilling basin (when applicable), or through the embedded toe of the drop structure when a stilling basin is not included. Place boulders to create a stepped appearance, which helps to increase roughness. Additional information regarding riprap and boulders is in the *Open Channels* chapter.

2.6.4 Construction Guidance

Grouted boulder drop structures require significant construction oversight. During placement of the rock and construction in general, disturb the subgrade as little as possible to reduce the potential for piping under the structure. Good subgrade preparation, careful rock placement, and removal of loose materials will reduce potential piping. Do not place granular bedding (or subgrade fill using granular materials) between subgrade and the boulders. This can cause piping. Place boulders directly on undisturbed subgrade where possible. Where the design requires over excavation and/or fill or where wet or poor subgrade exists onsite, ensure proper density and compaction. See Division 31 specifications available at www.udfcd.org. When fill is required, it is best to fill and compact to a set elevation (or sloped surface)

and then “carve” the surface as necessary to place boulders. See figure 9-15 for a placement detail.

Proper grout placement provides overall mass sufficient to offset uplift and reduces piping under the structure. The greatest risk lies with a “sugar-coated” grout job, where the grout does not penetrate the voids fully between the rock and the subgrade and leaves voids below the grout that act as a direct piping route for water, guaranteeing early failure. Ensure grout thickness set at one-half the boulder height, but no more than two-thirds the boulder height (except at the crest and around the perimeter of the structure where the grout should be near grade). Limiting grout thickness also improves the overall appearance of the grouted boulder structure.

Problems with rock density, durability and hardness are of concern and can vary widely for different locations. Inspect the rock at regular intervals to meet minimum physical dimensions, strengths, durability and weights as defined in the specifications.

As stated earlier, it is important to compact the soil around the perimeter of the structure and leave it slightly higher than the structure to promote sheet flow onto the structure. If the soil settles, surface erosion along the edge of the concrete and ultimately structure piping may occur.

Grout used for GSB drop structures shall receive cold or hot weather protection in accordance with the UDFCD construction specifications (see www.udfcd.org).

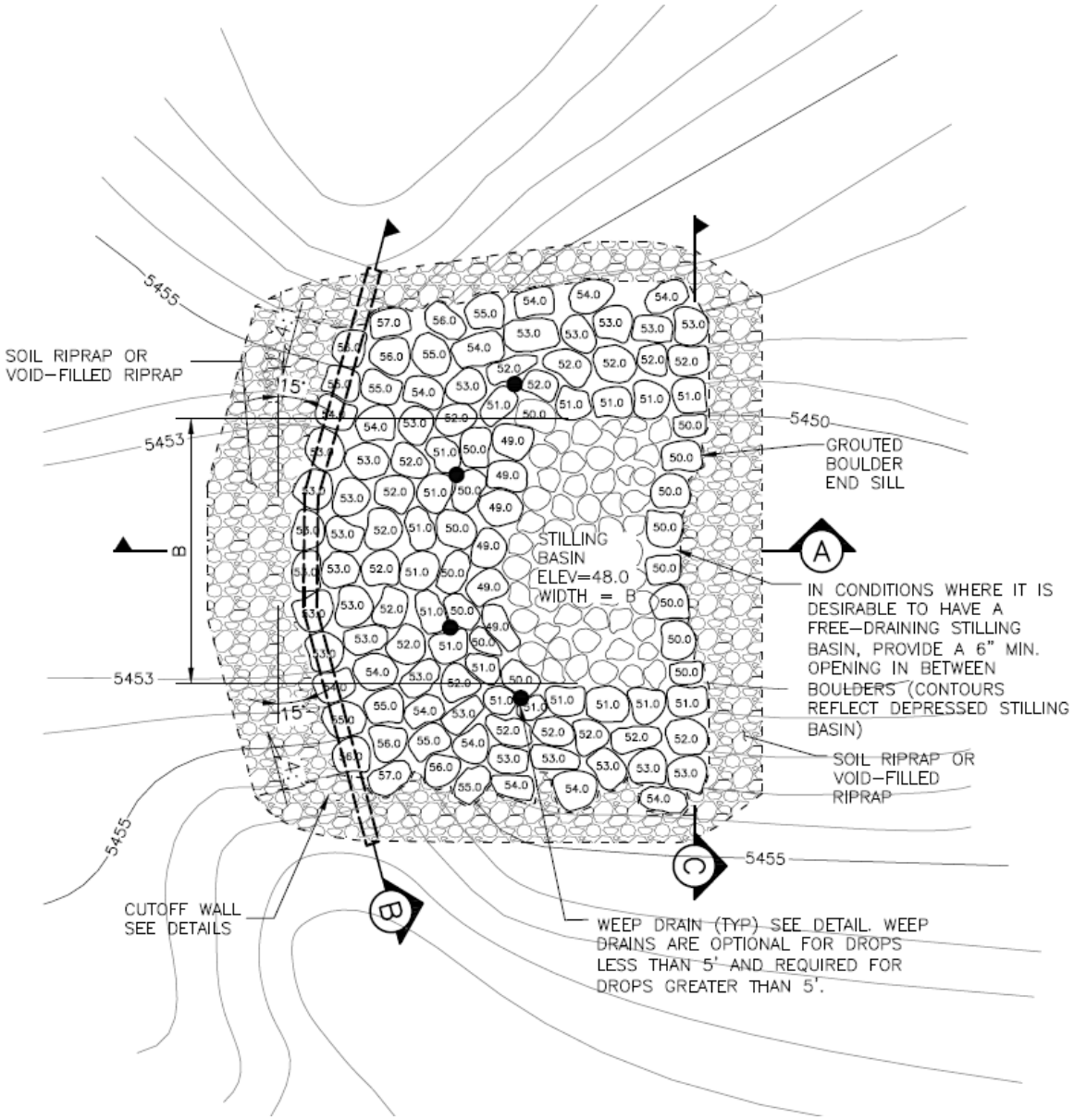


Figure 9-11. Example plan view of basic grouted stepped boulder drop structure

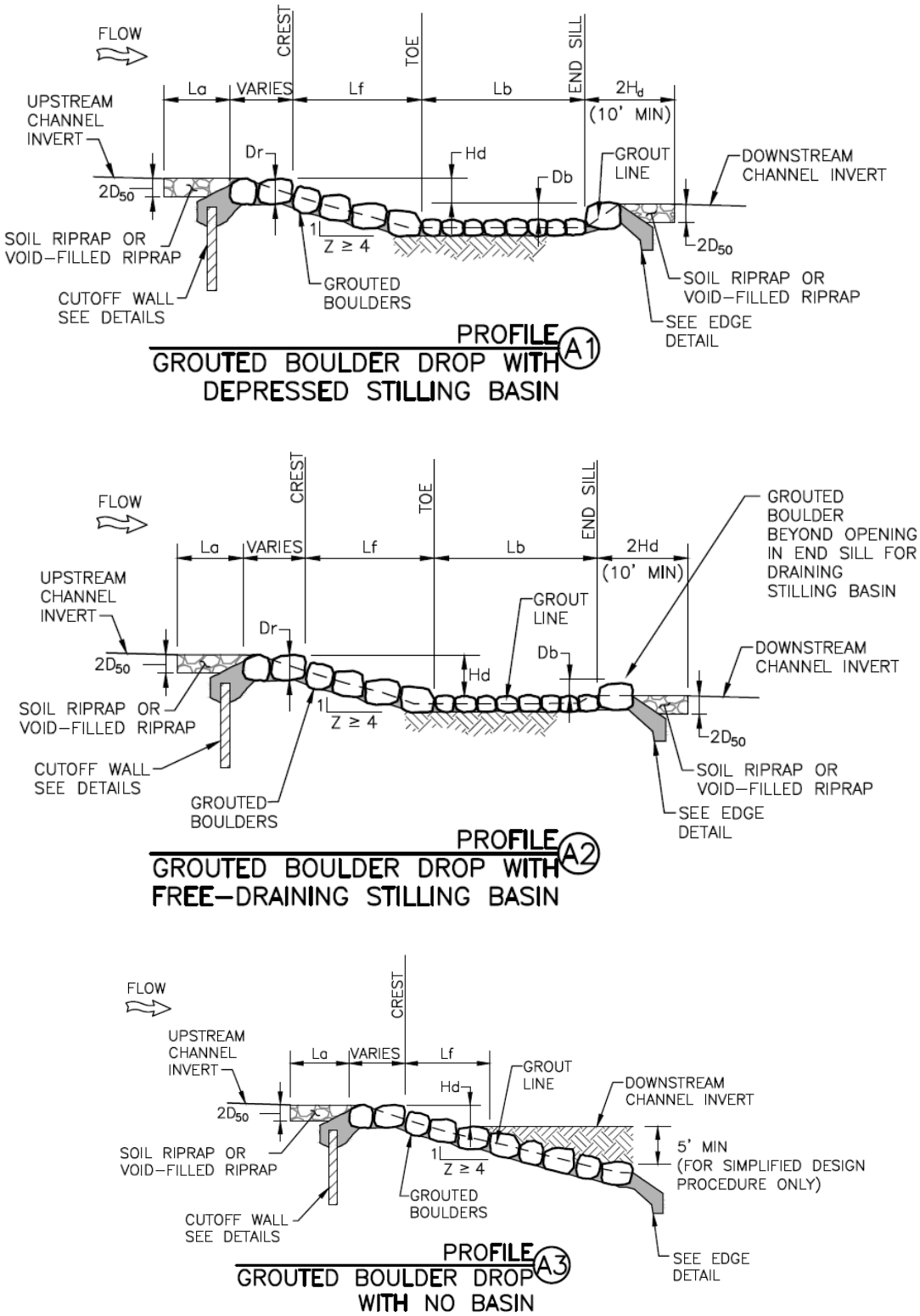


Figure 9-12. Cross sections of basic grouted stepped boulder drop structure

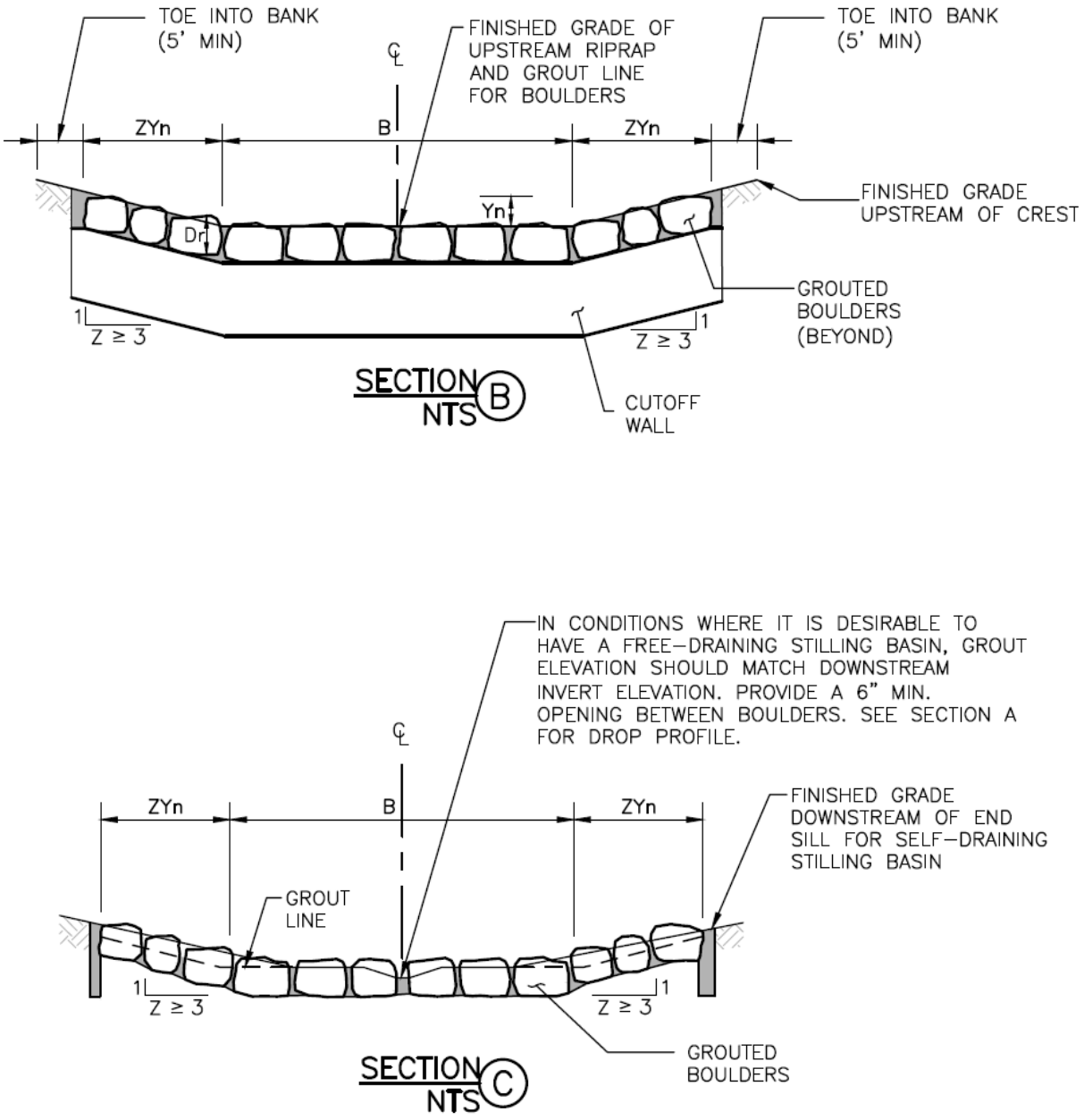


Figure 9-13. Cross sections of basic grouted stepped boulder drop structure

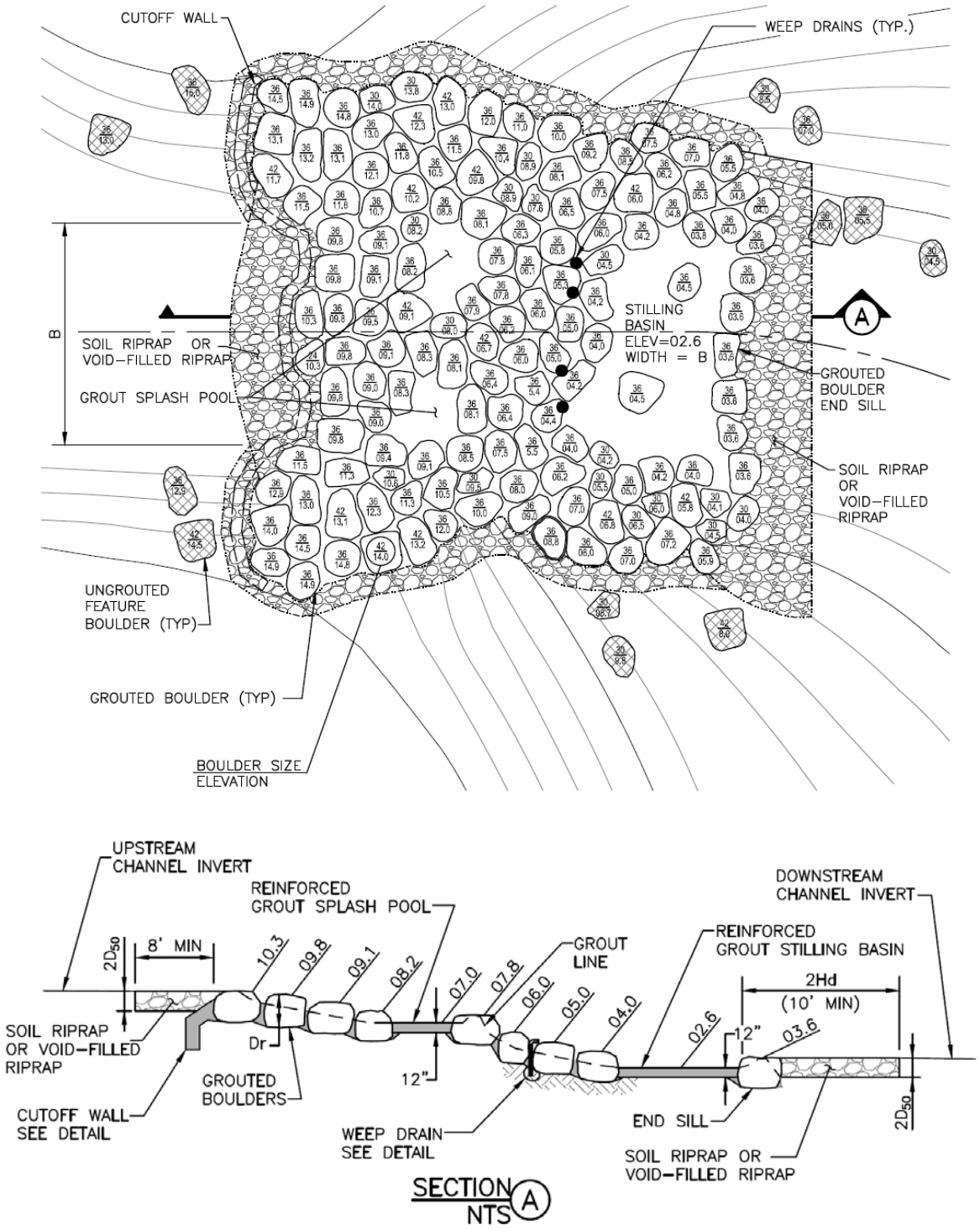
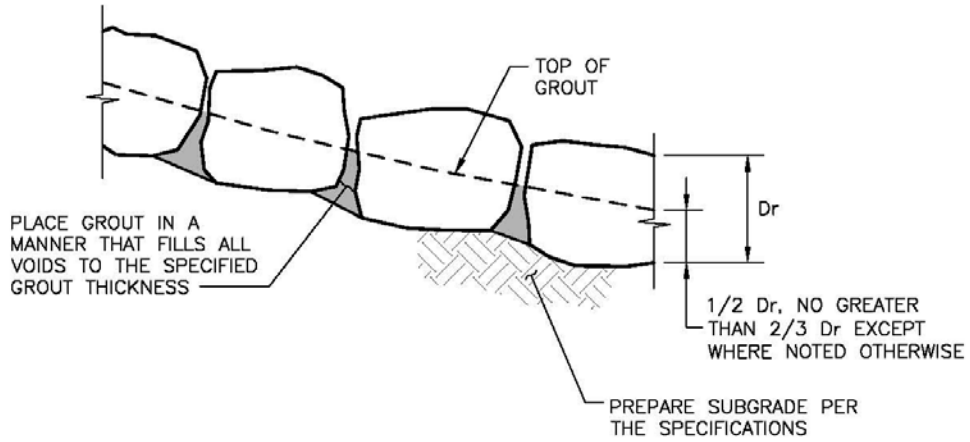


Figure 9-14. Example of complex grouted stepped boulder drop structure



BOULDER PLACEMENT NOTES:
1. PLACE BOULDERS WITH THE REQUIRED BOULDER HEIGHT VERTICAL. PLACE BOULDERS AS TIGHTLY TOGETHER AS POSSIBLE (WITHOUT TOUCHING) WHILE PROVIDING ENOUGH ROOM BETWEEN THEM TO THOROUGHLY VIBRATE THE GROUT AND TO ENSURE NO GAPS IN THE GROUT. THE SMALL DIMENSION OF A 2X4 CAN BE USED AS A GUIDE TO CHECK MINIMUM SPACING.
2. BEFORE GROUTING, CLEAN ALL DIRT AND MATERIAL FROM ROCK THAT COULD PREVENT THE GROUT FROM BINDING TO THE ROCK. KEEP BOULDERS FROM TOUCHING. AVOID SLIDING BOULDERS AGAINST SUBGRADE TO PROPERLY POSITION.

MATERIAL SPECIFICATIONS:
1. ALL GROUT SHALL HAVE A MINIMUM 28–DAY COMPRESSIVE STRENGTH EQUAL TO 3200 PSI.
2. ONE CUBIC YARD OF GROUT SHALL HAVE A MINIMUM OF SIX (6) SACKS OF TYPE II PORTLAND CEMENT.
3. A MAXIMUM OF 25% TYPE F FLY ASH MAY BE SUBSTITUTED FOR THE PORTLAND CEMENT.
4. THE AGGREGATE SHALL BE COMPRISED OF 70% NATURAL SAND (FINES) AND 30% ⅜–INCH ROCK (COARSE).
5. THE GROUT SLUMP SHALL BE BETWEEN 4–INCHES TO 6–INCHES.
6. AIR ENTRAINMENT SHALL BE BETWEEN 5.5% AND 7.5%.
7. TO CONTROL SHRINKAGE AND CRACKING, 1.5 POUNDS OF FIBERMESH, OR EQUIVALENT, SHALL BE USED PER CUBIC YARD OF GROUT.
8. COLOR ADDITIVE IN REQUIRED AMOUNTS SHALL BE USED WHEN SO SPECIFIED BY CONTRACT.

GROUT PLACEMENT SPECIFICATIONS:
1. SPECIAL PROCEDURES SHALL BE REQUIRED FOR GROUT PLACEMENT WHEN THE AIR TEMPERATURES ARE LESS THAN 40°F OR GREATER THAN 90°F. CONTRACTOR SHALL OBTAIN PRIOR APPROVAL FROM THE DESIGN ENGINEER OF THE PROCEDURES TO BE USED FOR PROTECTING THE GROUT.
2. GROUT SHALL BE DELIVERED BY MEANS OF A LOW PRESSURE (LESS THAN 10 PSI) GROUT PUMP USING A 2–INCH DIAMETER (MAXIMUM) NOZZLE.
3. FULL DEPTH PENETRATION OF THE GROUT INTO THE BOULDER VOIDS SHALL BE ACHIEVED BY INJECTING GROUT STARTING WITH THE NOZZLE NEAR THE BOTTOM AND RAISING IT AS THE GROUT FILLS, WHILE VIBRATING GROUT INTO PLACE USING A PENCIL VIBRATOR.
4. ALL GROUT BETWEEN BOULDERS SHALL BE TREATED WITH A BROOM FINISH.
5. AFTER GROUT PLACEMENT, EXPOSED BOULDER FACES SHALL BE CLEANED AND FREE OF GROUT.
6. ALL FINISHED GROUT SURFACES SHALL BE SPRAYED WITH A CLEAR LIQUID MEMBRANE CURING COMPOUND AS SPECIFIED IN ASTM C309.

Figure 9-15. Grouted boulder placement detail

2.7 Sculpted Concrete Drop Structure

Due to increased construction complexity associated with large vertical drops the scope of this section is limited to sculpted concrete drops six feet or less.

2.7.1 Description

Concrete faux rock is simply concrete that is sculpted, carved, textured, and colored to emulate real rock. In the past, sculpted concrete has been successfully used for retaining wall type structures and stream grade control structures. It can be an aesthetic alternative to grouted boulders in locations where natural sedimentary rock might be expected.

Geology in the UDFCD region east of the foothills primarily consists of sedimentary rock, of which there are five common types including sandstone, shale, conglomerate, limestone, and claystone. Claystone can be found in eroded streams where less dense soils have been washed away. Claystone is similar to sandstone; however, it is composed of finer particles. These layers of sedimentary rock become exposed due to uplift and erosion.

When considering the design for a new sculpted concrete structure, existing exposed sedimentary rock in the vicinity of the project should be used for guidance. Section 2.7.4 provides additional guidance for determining the appropriate finish for sculpted concrete.

Photograph 9-6. Exposed sedimentary rock.

Photograph 9-7. An eroded channel with exposed claystone layers.

2.7.2 Structure Complexity

Early in the design, determine what the expectations are regarding the appearance of the structure. An enlarged plan view of the structure will be necessary for all projects. The amount of detail shown on that plan view will vary depending on the complexity of the design.

Note that an overly complex design does not always result in a more aesthetically pleasing structure. Many quality structures have been constructed using very basic design plans and details. Simplifying the design can reduce confusion and misinterpretation during construction, and also matches the skill level of a greater number of potential bidding contractors.

For the purpose of presenting criteria for sculpted concrete drop structures, this manual refers to sculpted concrete structures as either “basic” or “complex”. Structure complexity is generally tied to the following three items.

1. **Overall structure footprint:** Non-linear shaped structures with varied edge delineations can be more attractive but require more detailing.

2. **Structure step widths and height:** Varied step widths and heights can improve the appearance of a structure but also adds construction complexity. Step widths can easily be delineated using boundary lines. Varying step heights requires finish grade point elevations to be added to the plan. The quantity of point elevations largely depends on the amount of desired elevation change.

3. **Sloped steps/flat steps:** Flat steps can be constructed based on a single contour or point elevation. If the surface is sloped, slope arrows and a series of point elevations to identify portions of the sloped top surface are beneficial.

Photograph 9-8. The first sculpted concrete structure in the UDFCD region was along Grange Hall Creek in Northglenn, Colorado. The shape and color was chosen to blend into the existing landscape which consisted of native grasslands.

If the design includes any of the three items discussed above (non-linear shape, varied step widths, or sloped steps), consider the proposed structure to be complex and prepare a more detailed plan view of the structure. Figures 9-19 and 9-20 present an example of such a plan. Note the additional finished grade point elevations and slope arrows compared to Figures 9-16 through 9-18, which provide details for a basic structure. Also included with the complex structure plan is a legend and notes with additional information regarding vegetation beds within the structure and surface treatment. This manual provides further discussion regarding these items later in the chapter, but it is important to note that these elements can also be incorporated into a simple structure without adding complexity. None of the figures in this section are intended as typical details but are provided as an example of the level of detail recommended for this type of design.

Photograph 9-9. A sculpted concrete drop structure along Marcy Gulch in Highlands Ranch, CO represents a basic structure design.

2.7.3 Design Criteria

Hydraulic analysis and design of SC drop structures should be according to Section 2.2 (simplified design guidance) or Section 2.3 (detailed hydraulic analysis), as appropriate. The following also apply to structures constructed of sculpted concrete.

Reinforcing Steel

Steel reinforcement is recommended in order to control temperature and shrinkage cracks. It is the responsibility of the designer to verify all structural components of SC drop structures during the design phase. Figure 9-21 provides guidance for rebar placement for SC structures with a flat subgrade and on an undulated subgrade. Larger walled sections within a given structure may require additional evaluation and design.

Photograph 9-10. This drop structure located along Oak Hills Tributary represents a complex design example.

Edge Wall

Provide an edge wall that extends roughly 3 feet below the top surface of the structure around the entire perimeter of the SC drop structure. See Figure 9-22 for an edge wall detail. An edge wall is especially important for structures designed to convey less than the 100-year flow but is also beneficial for structures that do span the 100-year flow. The transition between soil and the sculpted concrete can become a problem if not properly addressed during design and construction. During construction ensure compaction of the soil around the perimeter of the structure and grade the area to sheet flow onto the structure. If the soil settles, surface erosion along the edge of the concrete and ultimately structure piping may occur. In addition to the edge wall, install buried soil riprap around the perimeter of the structure when the drop structure does not span the 100-year floodplain. This reduces potential erosion.

Concrete Thickness

The concrete should be a minimum of 10 inches thick. As with the steel reinforcement, it is the design engineer's responsibility to complete a structural analysis to determine adequate concrete thickness for structure stability. It is preferred that the subgrade be excavated to closely mirror the finished structure surface, which will allow for the placement of concrete with a consistent thickness. In isolated locations, it may be necessary to thicken the concrete to meet design grades. Ideally, the thickened areas should not exceed 2 feet. Avoid multiple pours of separate layers of concrete over the majority of the structure.

Concrete versus Shotcrete

Either concrete mix or shotcrete mix are suitable for construction of sculpted concrete drop structures, however designers should be aware that there are advantages and disadvantages for each (See Table 9-5).

Table 9-5. Comparison of concrete and shotcrete

	Concrete	Shotcrete
	▪ Handling and placement can be performed by a large number of general contractors. ▪ Can be rapidly placed with the use of a concrete pump truck, roughly twice as fast as shotcrete. Construction of very large structures as a single pour in 1 day is possible.	▪ Generally has greater compressive strength and is more impervious than concrete. ▪ Can be placed in a uniform and consistent manner. Vibrating the shotcrete is not required. ▪ Can be placed to create vertical faces and overhangs.
		▪ Shotcrete placement is considered specialty type work and is performed by a limited number of contractors. ▪ Shotcrete placement is slow in comparison to concrete placement. ▪ Shotcrete structures may be more expensive than concrete.

2.7.4 Decorative Elements (Finishing)

Sculpted concrete finishing refers to modifications intended for visual enhancement. The contractor plays an important role in the finishing process and making the structure look attractive. When contractor selection is limited (e.g., the project is open bid), designers must provide adequate finishing guidance and recommendations on the construction plans.

Finishing is an all-encompassing word that can include:

- Troweling, sculpting, and carving
- Stamping
- Top dressing with sand, gravel, cobbles, or other materials
- Vegetation seams, pockets, or beds
- Coloring/Staining

Depending on the design objectives, a project may include a couple or all of these techniques. This section provides an overview and photograph illustrations of the techniques listed above.

Photo 9-11. Rock formation with horizontal weathering and surface erosion. Random pockets of vegetation create significant interest. Overall color is gray-white with lichen and other organic surface growth.

Examples in Nature
An abundance of natural formations exist throughout the UDFCD region. Rock formations can vary significantly even if separated by only a short distance. Differences in color, surface roughness, bed angles or strata line angles, and vegetation are apparent. A photographic log of different formations can be a valuable resource when designing, constructing, and finishing sculpted concrete structures. Photographs 9-11, 9-12, and 9-13 show three different rock formations found in the UDFCD region.

Photo 9-12. Generally horizontal layered rock formation. Surface texture varies with small pockets of vegetation. Overall color is brown with dark staining in the cracks. Close up view reveals significant granular material bedded into the surface.

Troweling, Sculpting, and Carving
Troweling, sculpting, and carving are all terms for the same general action. The contractor typically uses a concrete trowel, float, or other tool to shape the concrete and then carve lines, crevices, or cracks that emulate natural rock features. This requires a contractor with sculpted concrete experience and skill.

Some of the difficulties that may arise during this process include the following:

- Typically, several concrete finishers will work on the same structure producing several different styles of finish treatment within the same structure. Finishers should work together using the same general techniques and producing similar and uniform results.
- Proper sense of scale. Finishers perform the work from an arm's reach. At this close range, the finisher may over-carve the material giving an appearance of a busy and unnatural looking structure when viewed from a distance.
- Style selection. There are many different styles of sculpting and carving. The owner, engineer, and finishers may all have a different vision.

Photographs can be helpful in developing consensus between owner, engineer and contractor. Be as specific as possible with the contractor regarding all of the structure attributes when reviewing photographs. It may be preferred to replicate some characteristics in the photographs and leave out some of the others. Construction of a test panel of sculpted concrete before performing the final structures can also be beneficial. A test panel that is approximately 10 feet by 10 feet is typically adequate in order to practice overall form as well as some of the detailing. If the first panel does not achieve the objectives, construct a second. This is a better alternative to practicing and developing techniques on the structures.

For proper sense of scale, periodically take time to step away from the structure and look at it from a more typical viewing distance. This will allow the finishers to see the structure as a whole.

Photo 9-13. Severely uplifted rock formation with layers standing nearly vertical. Surface texture varies within the layers but is mostly smooth. Vegetation appears to grow out of the seams, not necessarily from pockets. Overall color is a light chalky tan.

Photograph 9-14. Subtle carving and shaping can often produce the desired results. Notice the single horizontal carving that runs through just one of the steps and is extended into the crest of the structure. Horizontal carvings on all of the steps would be excessive and distract from the overall aesthetics.

Stamping

Stamping adds surface texture and requires less skill compared to sculpting and carving. Stamping is most often performed using texture mats or skins, which are rubber molds made from real rock surfaces. When pressing the texture mats into wet concrete, the concrete takes the textured surface of the mat. Texture mats are available with a variety of texture styles and relief. Use a liquid or powder release agent to keep the concrete from sticking to the mats. While texture mats are specifically for texturing concrete, a finisher could use an unlimited amount of other materials to create unique or desired finishes.

Photograph 9-15. Texturing a sculpted concrete drop with a rubber skin.

Top Dressing with Sand, Gravel, Cobbles or Other Materials

Top dressing a structure with sand, gravel, or cobbles adds texture to the surface of sculpted concrete. While some natural rock formations have a very smooth surface finish, many contain grains of sand and pebbles cemented together. This is typical of the sandstone and conglomerate types of sedimentary rock common in the UDFCD region. It is important to press the material into the sculpted concrete shortly after carving and before the concrete sets. Additionally, the material should be washed clean and free of debris to promote bonding to the concrete. The majority of the material will remain in place over time, but with freeze-thaw, some of it will dislodge. Wetting the material immediately before placement can help reduce the percentage of material that dislodges over time.

Photograph 9-16. Completed sculpted concrete drop structure with loose sand, gravel and cobble embedded into the surface.

Photograph 9-17. Small vegetation pockets can be formed using PVC, lumber, or other items. Removed these items shortly before or after the concrete cures. If done after the concrete cures, coat the items with a lubricant to facilitate removal.

Vegetation Seams, Pockets or Beds

A characteristic of natural rock formations is that grasses, shrubs, and trees can be found living in cracks within the rock. Pairing rock and vegetation helps make the structure appear natural. However, it can be difficult to establish vegetation within a concrete structure. Depending on the stream, dryland vegetation beds and seams should stay above certain minimum flood elevations as they won't tolerate frequent flooding. If placed too low and vegetation does not become established, this leaves a vulnerable area in the structure for piping. A slightly thickened edge of sculpted concrete around the seam or bed is typically adequate. In some cases where flow overtopping is a more significant concern, toewalls around the perimeter of the bed or seam may be necessary along with filter material in the bottom of the bed to guard against piping. Filter material should not be installed along the entire structure, but rather at the specific vegetation bed or seam to reduce the likelihood of piping under the structure, especially at the crest. Geotextile can be used for this purpose or a graded filter system could be constructed.

Plants do not necessarily need a large bed to be sustainable. Consult with an ecologist or other qualified specialist for both proper plant selection and bed construction. For example, a plant species that thrives on the north facing side of a sculpted concrete structure may not be able to live on the south facing side of the same structure where sunlight and heat are more intense. Consider the daily amount of sunlight anticipated, reflective and absorptive heat of the sculpted concrete, and water requirements.

The incorporation of wetland vegetation planting pockets should also be considered and have a higher success rate as conditions for wetland vegetation are favorable within a depressed concrete lined portion of the structure as long as the stream base flow is routed through the basin. These planting pockets should be located outside of the primary energy dissipation area of the structure. This will allow the plants to develop a healthy root structure and hold the plants in place during large flows.

Photograph 9-18. The surface of the sculpted concrete can be depressed to capture and direct rainwater to the vegetation.

Photograph 9-19. Grass growth in a vegetation pocket shortly after seeding.

Photograph 9-20. During the structure subgrade preparation, vegetation beds and pockets were delineated and soil was removed. After the sculpted concrete placement was complete, topsoil was placed in the beds and seeding and planting was performed.

Another method to add color to sculpted concrete is to apply a stain to the finished and cured concrete surface. There are several products available specifically made for concrete. Another acceptable method is to add water to exterior acrylic latex paint until it has the consistency of a stain. This allows for a wide range of available colors. Stains are typically applied by hand-held bottle sprayers, mechanical sprayers, and sponges.

If a test panel has already been constructed, use this panel to practice to develop the desired color scheme. The process of staining includes layering multiple shades of color. Typically light colored stains are applied first followed by darker accent shades. Applying a light coat of watered down black stain as the final coat will create a weathered or aged surface appearance. As with any finishing technique, the experience level of the finisher plays a key role in the outcome.

Photograph 9-24. Stained concrete in foreground with natural rock in the background.

2.7.5 Construction Guidance

For sculpted concrete drop structures, concrete is often placed in a few hours. It is therefore very important to plan the overall appearance of the structure well in advance of concrete placement. Coordinating details with the contractor should occur during subgrade preparation and tying of steel reinforcement. Construction guidance is provided below.

Photograph 9-25. An example of a "skim coat" applied to the prepared subgrade.

- **Subgrade Preparation.** The structure subgrade should be adequately dewatered prior to the commencement of excavation or fill. All fill material should be placed on a minimum 12-inch depth of stripped, scarified, moisture conditioned, and compacted subgrade. During excavation, it is recommended that the contractor cover the exposed subgrade with blanket to avoid excessive drying or erosion. If excessive drying does occur, surface wetting of the soil should be performed.

Photograph 9-26. Spray paint is used on the "skim coat" of a sculpted concrete structure prior to concrete placement to identify the locations for fracture lines and other features.

- **Skim Coat.** Keeping steel reinforcement clean can be a challenge. The use of blanketing can help. Another option is to apply a "skim coat" (also sometimes referred to as a "flash coat"). Skim coating consists of placing approximately 1 to 2 inches of shotcrete on the prepared subgrade. This alternative can be used with either concrete or shotcrete structures. Avoid the use of aggregate to stabilize or protect the subgrade. Skim coating will also protect the subgrade from weather and provide a clean and stable surface for placing and tying steel.

- **Concrete Placement.** Concrete placement is a quick process. In order to be properly prepared for a concrete pour, it is important to coordinate the desired finished structure appearance with the contractor. Example photographs of similar sedimentary rock can be used to help communicate the desired finish. A test panel or section is recommended when varied textures and finishing will be incorporated. Another successful approach is to spray paint fracture lines or mark locations on the subgrade where texturing or features are desired. It is imperative that the contractor have an adequate number of workers present to place the concrete, survey design grades, trowel and carve the concrete, as well as perform all other finishing details.

Cautions Associated with Sculpted Concrete Construction

1. Skill and experience on the part of the contractor helps produce an attractive structure.

2. Subgrade excavation/compaction and placement of reinforcing steel must conform to complex, irregular shapes and slopes within design tolerances.

3. Placing, shaping, and carving of concrete/shotcrete must take place within a narrow range of water content and a short window of time. This requires planning, favorable weather conditions, an adequately-sized crew, appropriate pace, and a high degree of organization on the contractor's part.

4. Care needs to be taken to avoid overworking concrete/shotcrete as vertical faces are shaped and trowelled; otherwise, cracking and sloughing can occur.

5. Inspection and adjustment of grades to meet the design intent must take place during placement of concrete/shotcrete.

6. Skill is required to shape, carve and stain the exposed surfaces of the sculpted concrete in an attractive manner that emulates natural rock formations.

7. Consider hot and cold weather conditions to ensure satisfactory finishing and curing of the concrete/shotcrete.

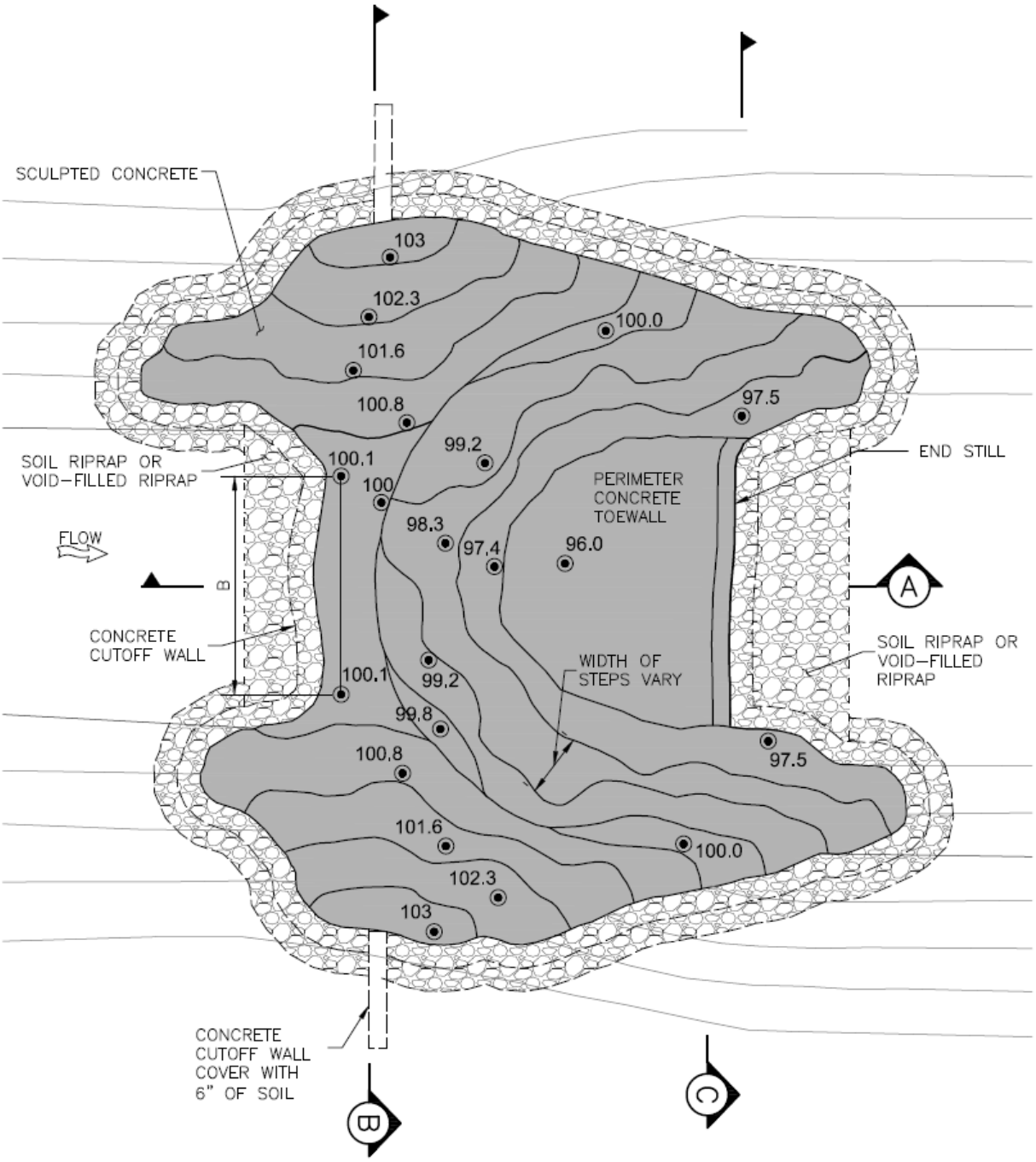


Figure 9-16. Example plan view of basic sculpted concrete drop structure

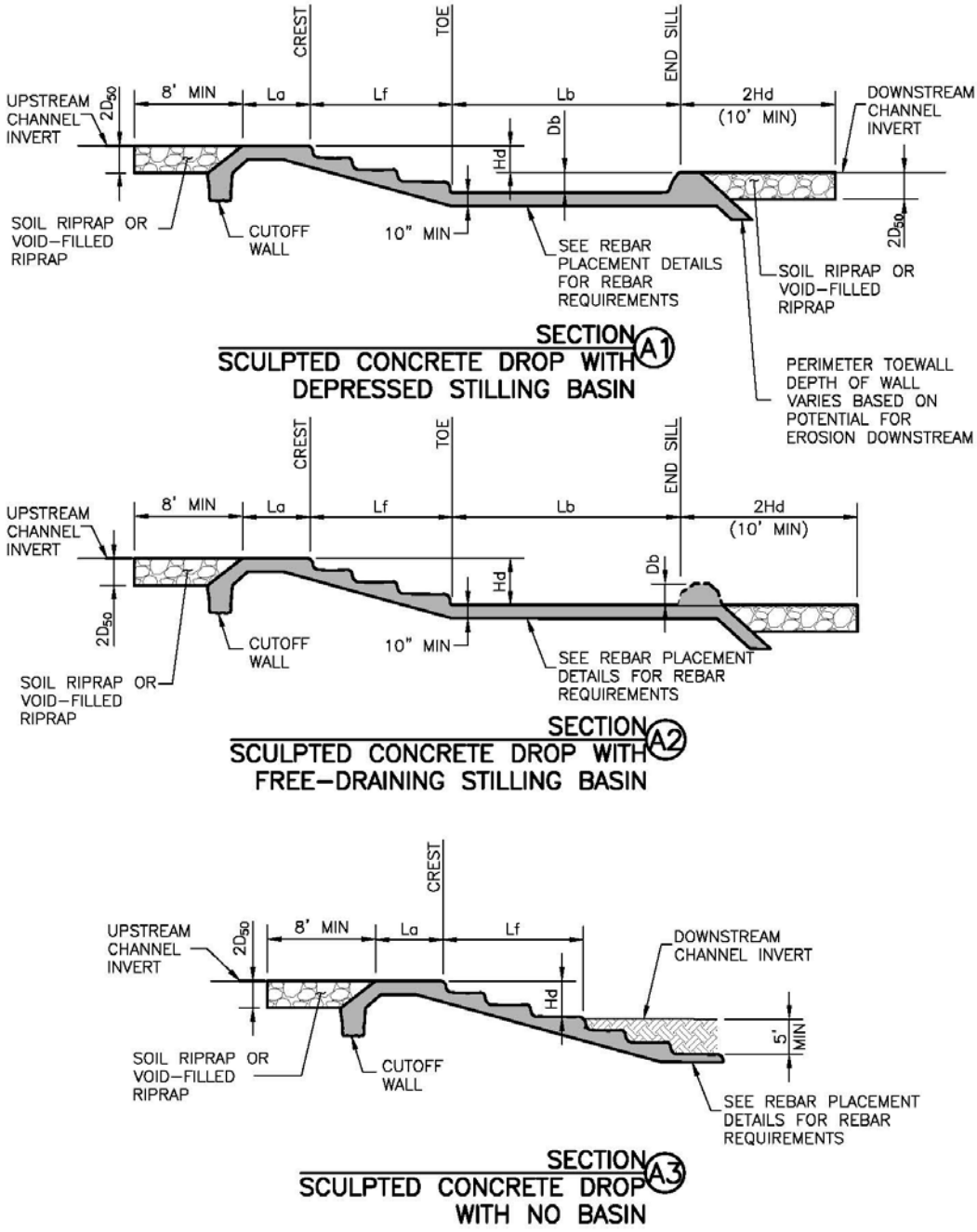


Figure 9-17. Example profiles of basic sculpted concrete drop structure

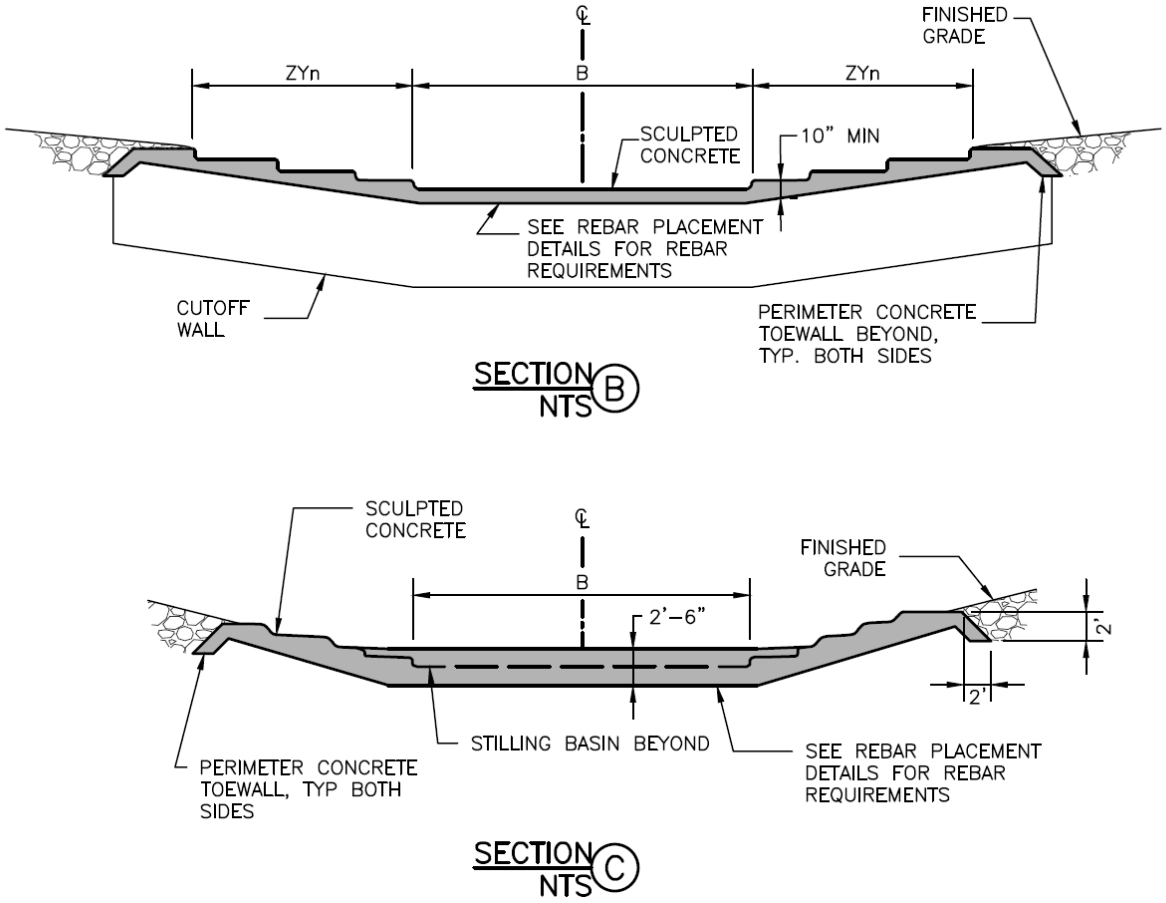


Figure 9-18. Example cross sections of basic sculpted concrete drop structure

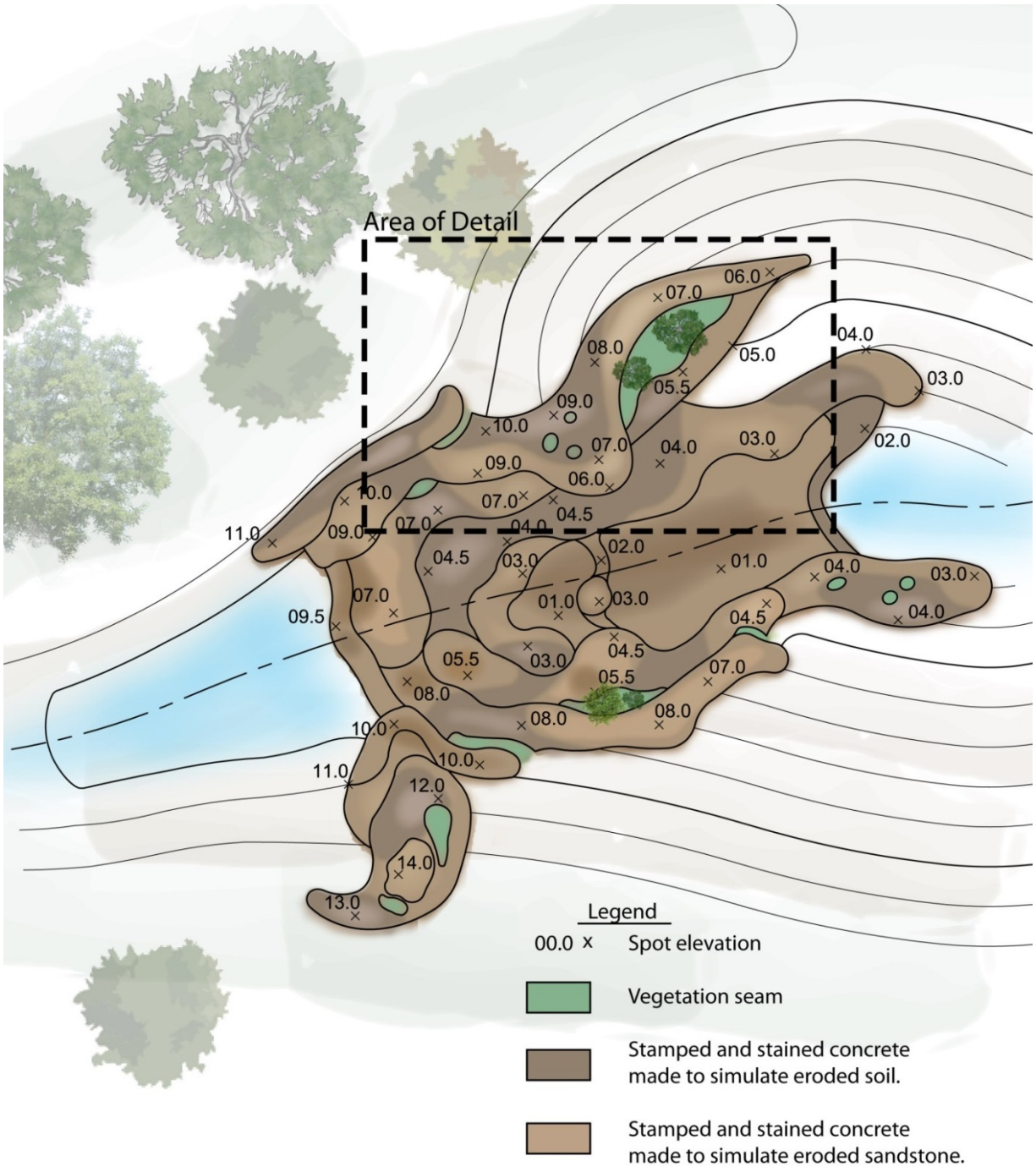


Figure 9-19. Example plan view of complex sculpted concrete drop structure

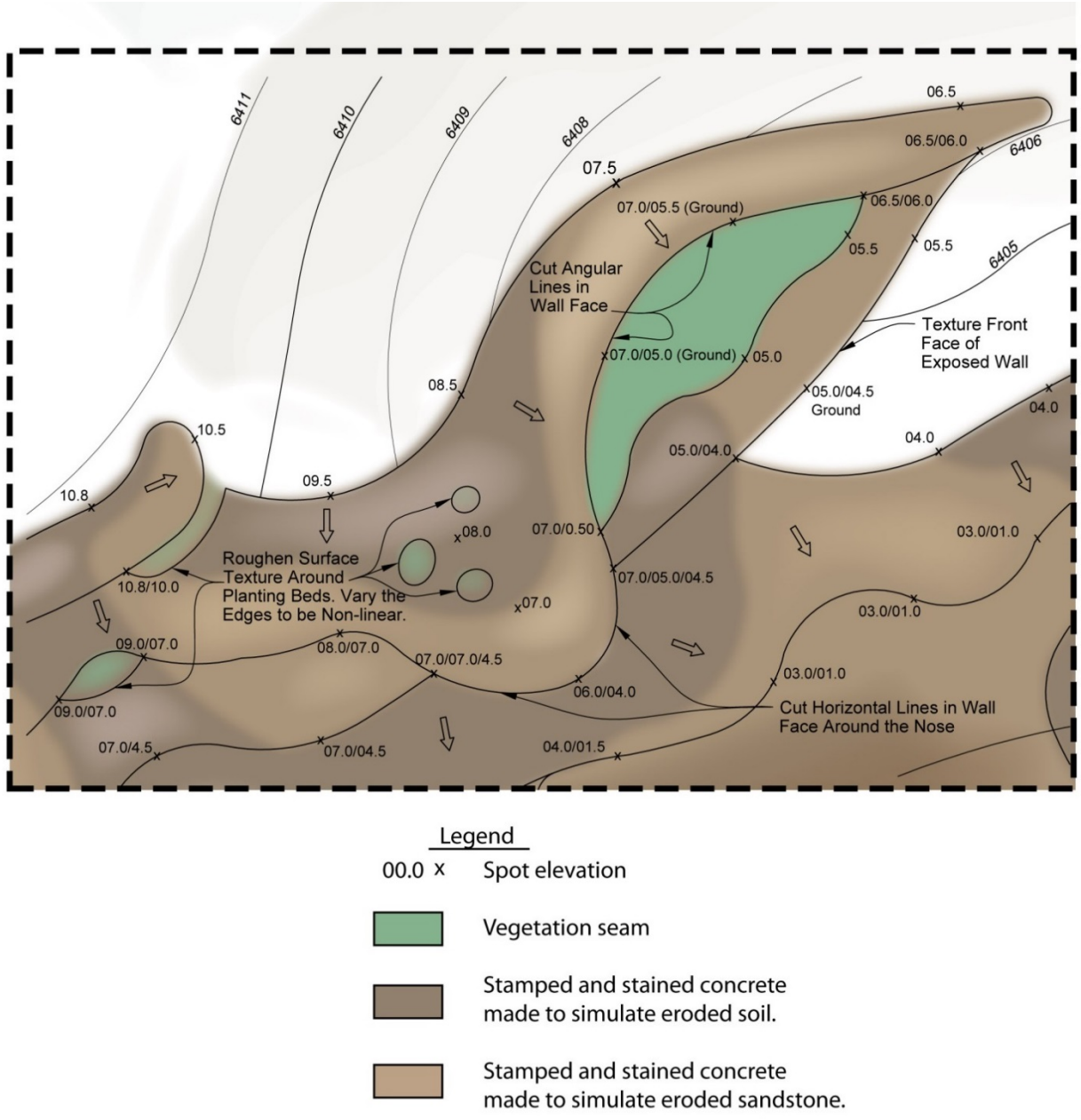


Figure 9-20. Example detailed view of complex sculpted concrete drop structure

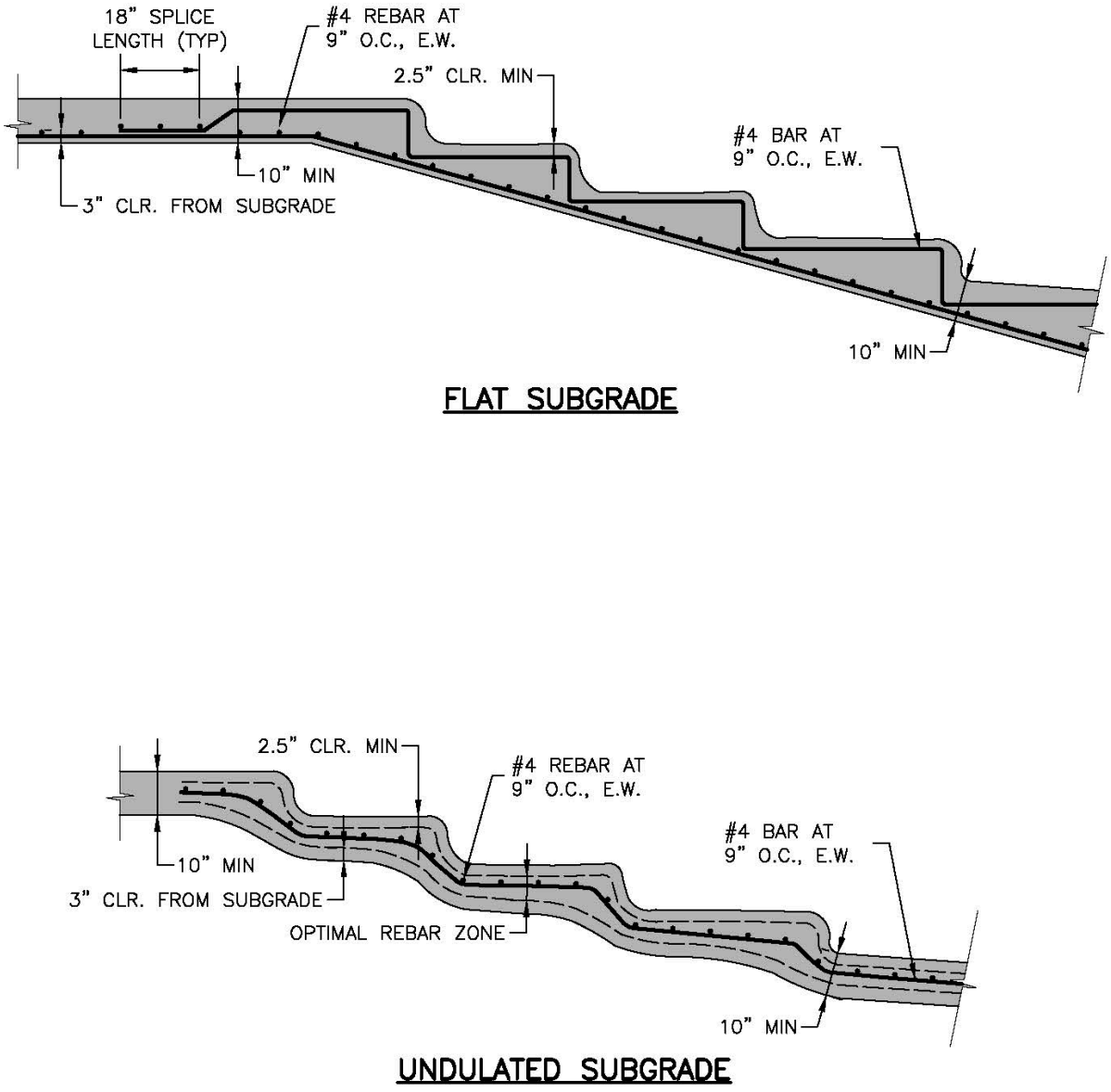
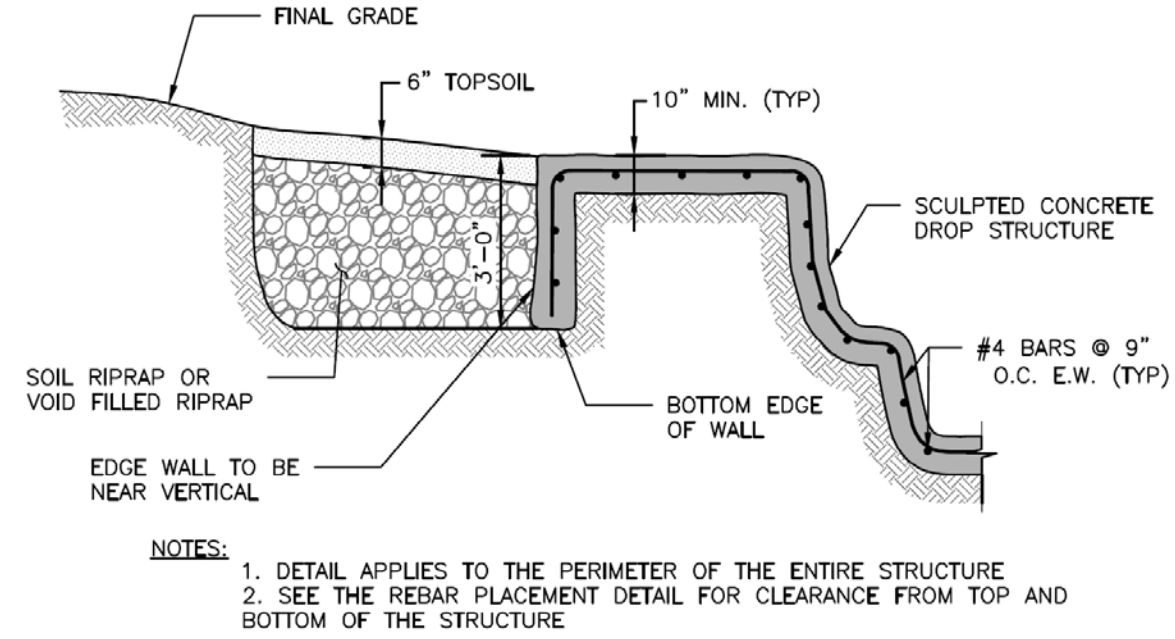
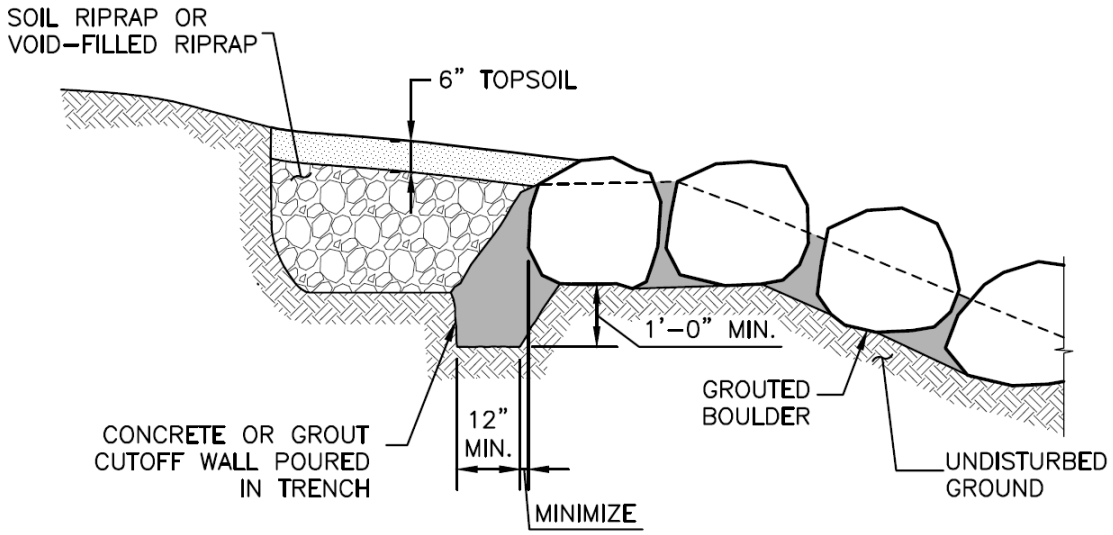


Figure 9-21. Rebar placement for sculpted concrete drop structures



STRUCTURE EDGE WALL DETAIL (SC)



STRUCTURE EDGE WALL DETAIL (GSB)

NTS

Figure 9-22. Structure edge wall details

2.8 Vertical Drop Structure Selection

2.8.1 Description

Photograph 9-27. Keeping vertical drops small improves safety during both wet and dry conditions.

Vertical drop structures are discouraged for a number of safety reasons but can be an effective tool for controlling grade especially in locations where it is important to minimize the footprint of the drop structure and where there is little-to-no chance of recreation or access by minors. It is important to note that vertical structures can cause dangerous hydraulic conditions, including keeper waves, during wet weather and should be used only where appropriate. In addition, vertical drop structures are to be avoided due to impingement energy, related maintenance and turbulent hydraulic potential (ASCE and WEF 1992). Vertical drop structures should not be used on a channel where fish passage is a concern. Whenever used, it is recommended that the net drop structure height (upstream invert to downstream invert) be limited to 2 feet. This will allow for the addition of a 1-foot deep stilling basin immediately downstream of the crest. Drop structures frequently attract children during dry and wet conditions. Heights in excess of 3 feet are a falling hazard. In addition, a vertical drop structure should never be constructed where the design flow exceeds 500 cfs or a unit discharge of 35 cfs/ft.

2.8.2 Design Criteria

The hydraulic phenomenon provided by a vertical drop structure is a jet of water that overflows the crest wall into a hard basin below. The jet hits the basin and is redirected horizontally. With sufficient tailwater, a hydraulic jump is initiated. Otherwise, the flow continues horizontally in a supercritical mode until the specific force of the tailwater is sufficient to force the jump. Energy is dissipated through turbulence in the hydraulic jump. Size the basin immediately downstream of the vertical wall to contain the supercritical flow and the erosive turbulent zone (see Figure 9-23).

Vertical drops are not appropriate where:

- Fish passage is needed,
- Design flow (over the length of the drop) exceeds 500 cfs or a unit discharge of 35 cfs/ft,
- Net drop height is greater than 2 feet, or
- The stream is boatable or there are other concerns related to in-channel safety.

1. The design approach uses the unit discharge in the main and low-flow channel to determine separately the water surface profile and jump location in these zones.

   (Chow 1959) presents the hydraulic analysis for the “Straight Drop Spillway.”

The drop number, D_n, is defined as:

$$D_n = \frac{q^2}{\left(gY_f^3\right)}$$ Equation 9-8

Where:

q = unit discharge (cfs/ft)

Y_f = height from the crest to the basin floor (ft)

g = acceleration of gravity = 32.2 ft/sec^2

For hydraulic conditions at a point immediately downstream of where the nappe hits the basin floor, the following variables are defined as illustrated in Figure 9-23:

$$\frac{L_d}{Y_f} = 4.3D_n^{0.27}$$

$$\frac{Y_p}{Y_f} = 1.0D_n^{0.22}$$

$$\frac{Y_1}{Y_f} = 0.54D_n^{0.425}$$

$$\frac{Y_2}{Y_f} = 1.66D_n^{0.27}$$

Drop Number for a Vertical Drop:

The drop number, D_n is a function of the unit discharge and vertical distance between the crest of the drop and the basin floor. From this value, the following can be determined:

- Location of the impingement,
- Depth of the pool under the nappe,
- Flow depth just downstream of the point of impingement,
- Sequent depth required to force the hydraulic jump

These values are necessary to properly place boulders (or baffles) for dissipation as well as determine the length of the basin.

Where:

Y_f = height from the crest to the basin floor (ft)

L_d = length from the crest wall to the point of impingement of the jet on the floor or the nappe length (ft)

Y_p = pool depth under the nappe just downstream of the crest (ft)

Y_1 = flow depth on the basin floor just below where the nappe contacts the basin (ft)

Y_2 = tailwater depth (sequent depth) required to cause the jump to form at the point evaluated (ft)

In the case where the tailwater does not provide a depth equivalent to or greater than Y_2, the jet will wash downstream as supercritical flow until its specific force is sufficiently reduced to allow the jump to occur. This requires the designer to also check normal depth just downstream of the drop to ensure that it is equal or greater than Y_2.

Determination of the distance to the hydraulic jump, D_j, requires a separate water surface profile analysis for the main and low-flow zones (See Section 2.3.6 for additional guidance). Any change in tailwater affects the stability of the jump in both locations.

The hydraulic jump length, L_j, is approximated as 6 times the sequent depth, Y_2. Where tailwater provides a depth equivalent to or greater than Y_2, the design basin length, L_b, includes nappe length, L_d, and 60% of the jump length, L_j. (The subscripts "m" and "l" in Equations 9-8 and 9-9 refer to the main and low-flow zones, respectively). Where the tailwater is not sufficient to force the jump at the point of impingement, the distance from this point to the jump must be added to the basin length in the below equations.

At the main channel zone:

$$L_{bm} = L_{dm} + 60\% \left(6Y_{2m}\right) \qquad \text{Equation 9-9}$$

At the low- flow zone, without boulders to break up the jet:

$$L_{bl} = L_{dl} + 60\% \left(6Y_{2l}\right) \qquad \text{Equation 9-10}$$

1. Caution is advised regarding the higher unit flow condition in the low-flow zone. Large boulders and meanders in the low-flow zone of the basin may help dissipate the jet and may reduce the extent of armoring downstream along the low-flow channel. When large boulders are used as baffles in the impingement area of the low-flow zone, the low-flow basin length L_{bl}, may be reduced, but not less than L_{bm}. Boulders should project into the flow 0.6 to 0.8 times the critical depth. They should be located between the point where the nappe hits the basin and no closer than 10 feet from the basin end.

2. The basin floor elevation should be designed as depressed or free-draining similar to the stilling basin for stepped grouted boulder drop structures. A depressed basin adds to the effective tailwater depth for jump control. The basin is typically constructed of grouted boulders (24-inch minimum). The stilling basin must be evaluated for seepage uplift (Section 2.4) and other hydraulic forces.

3. Use a sill at the end of the stilling basin to assist in causing the hydraulic jump to form in the basin. Soil riprap or void filled riprap should be used downstream of the sill to minimize any local scour caused by the lift over the sill.

4. Use caution to avoid boulder placement such that flow impinges the channel side slopes of the basin.

5. Determine crest wall and footer dimensions by conventional structural methods. Underdrain requirements should be determined from seepage analysis.

6. Seepage uplift conditions require evaluations for each use. Complete a seepage analysis to provide for control and weight/size of components (see Section 2.4).

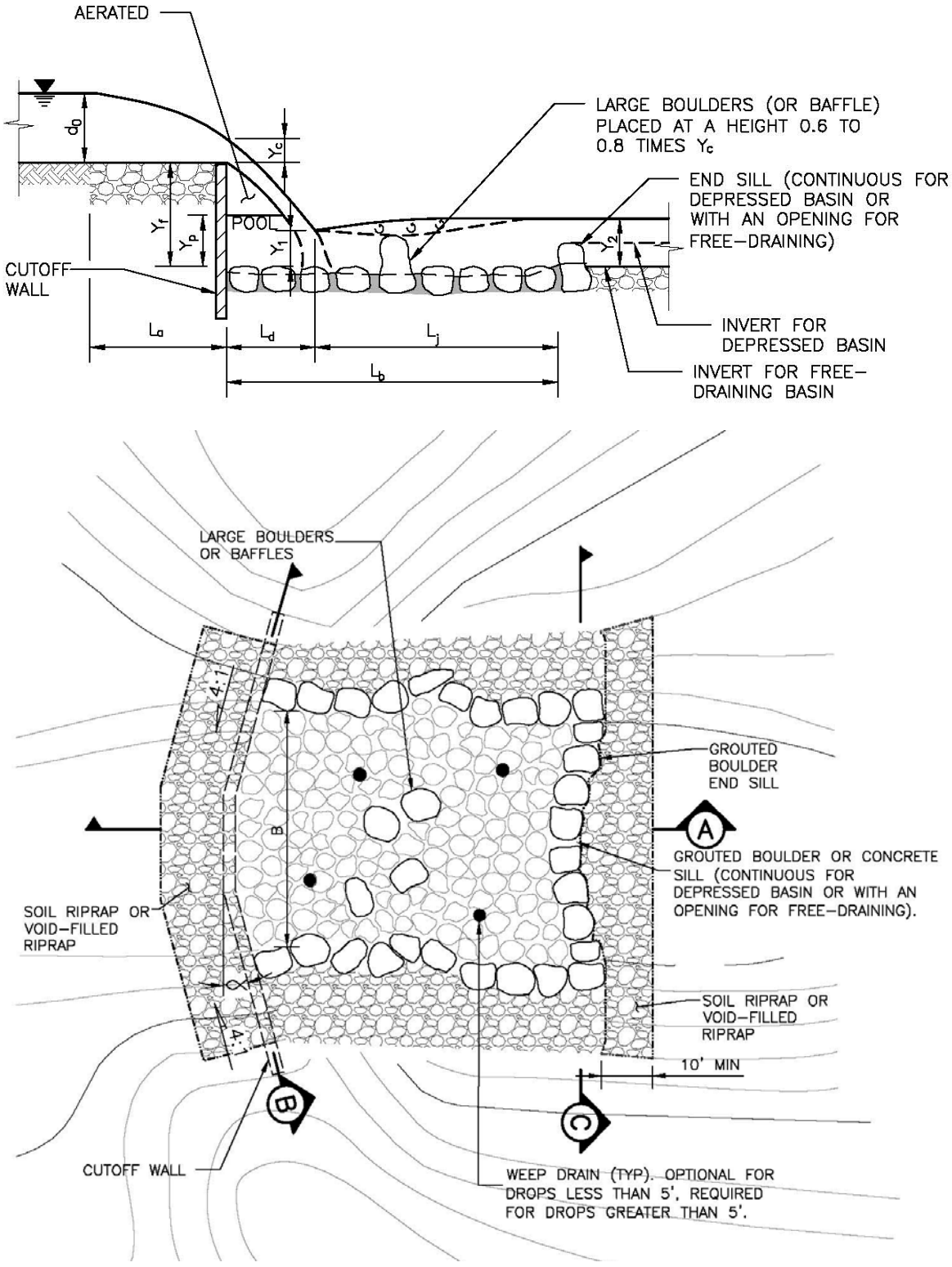


Figure 9-24. Example vertical drop structure plan

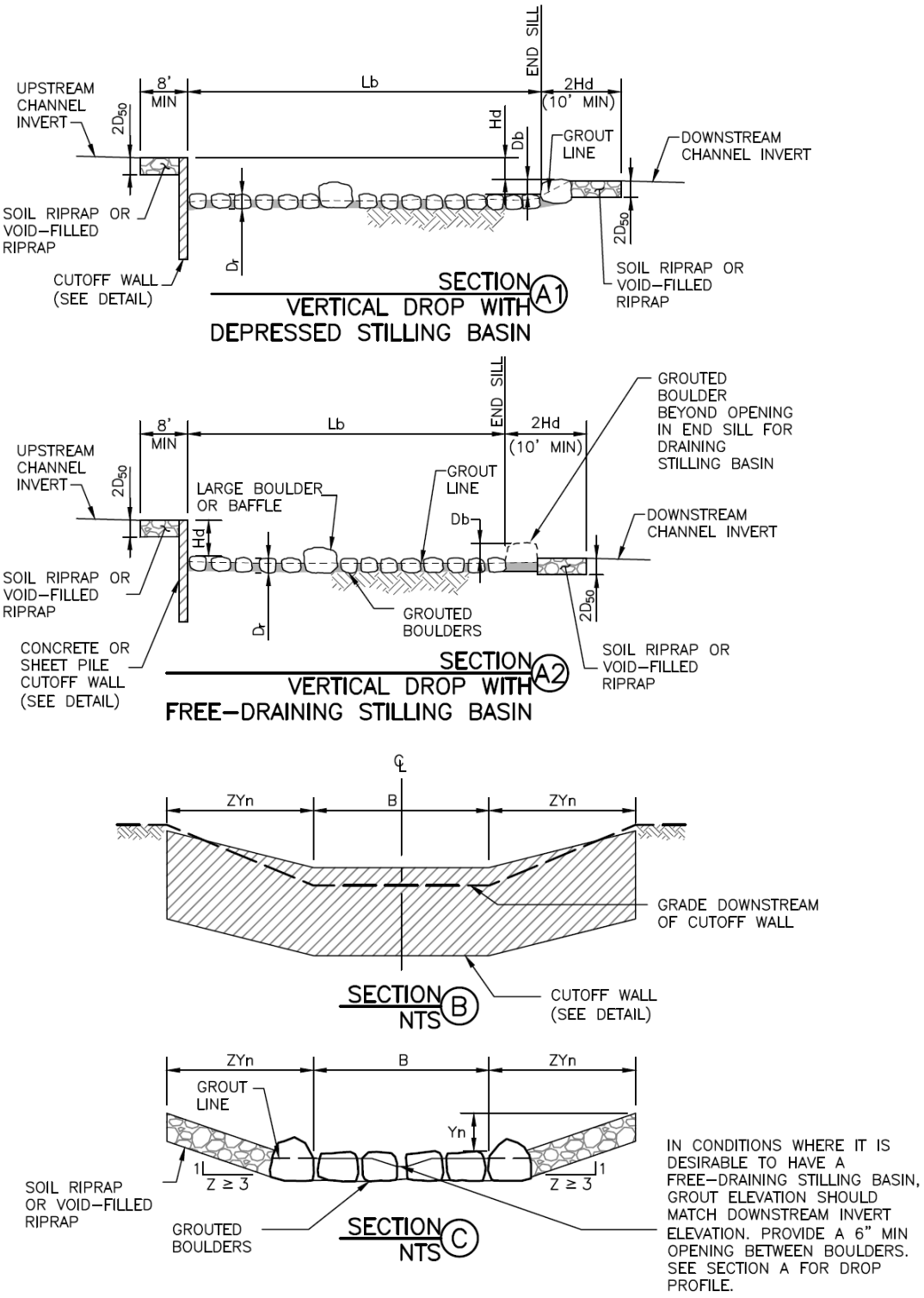


Figure 9-25. Example vertical drop structure sections

2.9 Low-flow Drop Structures and Check Structures

If a channel has not yet experienced significant erosion and degradation, but may degrade in the future, a number of options provide a level of reinforcement against future degradation. One approach is to install a standard drop structure and then backfill it to be mostly buried in the near term, but ready to handle additional grade difference as the channel invert lowers over time. Other approaches include:

- Low-flow Drop Structures. Low-flow drop structures are small structures designed to provide control points and establish stable bed slopes within the low-flow channel. Erosion of the low-flow channel, if left uncontrolled, can cause degradation and destabilization of the entire channel. Low-flow drop structures must be tied securely into the banks of the low-flow channel and take advantage of backwater from downstream drop structures to reduce the likelihood of circumventing, also known as flanking, or "end-around" erosion as flow converges back to the low-flow channel from the main channel overbanks below the drop structure. Low-flow drop structures in themselves do not address erosion potential in the overbank areas outside of the low-flow channel. See the criteria in the Open Channel chapter when evaluating the stability of the existing channel. Note that the low-flow channel is referred to as the bankfull channel in other parts of this manual.

- Check Structures with follow-up field observation program. Check structure construction typically consists of driving sheet pile to a 10-foot depth and capping it with concrete or filling an excavated narrow trench (12" minimum width) with concrete (if soil and groundwater conditions permit trenching to a depth of six feet). Only specify concrete check structures where soils permit excavation of a narrow trench. Never over-excavate to form concrete checks. Extend the walls laterally as necessary to contain the 5- to 10-year flow (depending on local criteria), but no less than 2 feet above the top of the low-flow channel banks. This will reduce the risk of side cutting. Space check structures so that there is no more than a 3-foot net drop from the crest of the check to the projected downstream invert based on the estimated long-term equilibrium slope. Figure 9-26 illustrates sheet piling and concrete check structures and a typical concrete cap for sheet piling check structures. Additional protection (e.g., soil riprap or void-filled riprap) downstream of the check structure may be appropriate based on scour potential. Consider soil type, longitudinal slope, and other site-specific considerations when evaluating scour potential.

  If a local government allows check structures, a follow-up field observation program is required to identify checks where erosion has exposed the face of the check structure, creating a significant drop in elevation from crest of the check to the elevation immediately downstream of the check. This vertical distance should not exceed 3 feet. Rehabilitative maintenance improvements may be necessary to install stable downstream erosion protection and convert the check to a drop structure (e.g., a grouted stepped boulder drop structure). Soil riprap placed downstream of the check structure can help as an interim condition to ensure the vertical distance does not exceed 3 feet. Vertical differences in excess of 3 feet present a fall hazard during dry weather and can increase potential for an overly retentive hydraulic during wet weather.

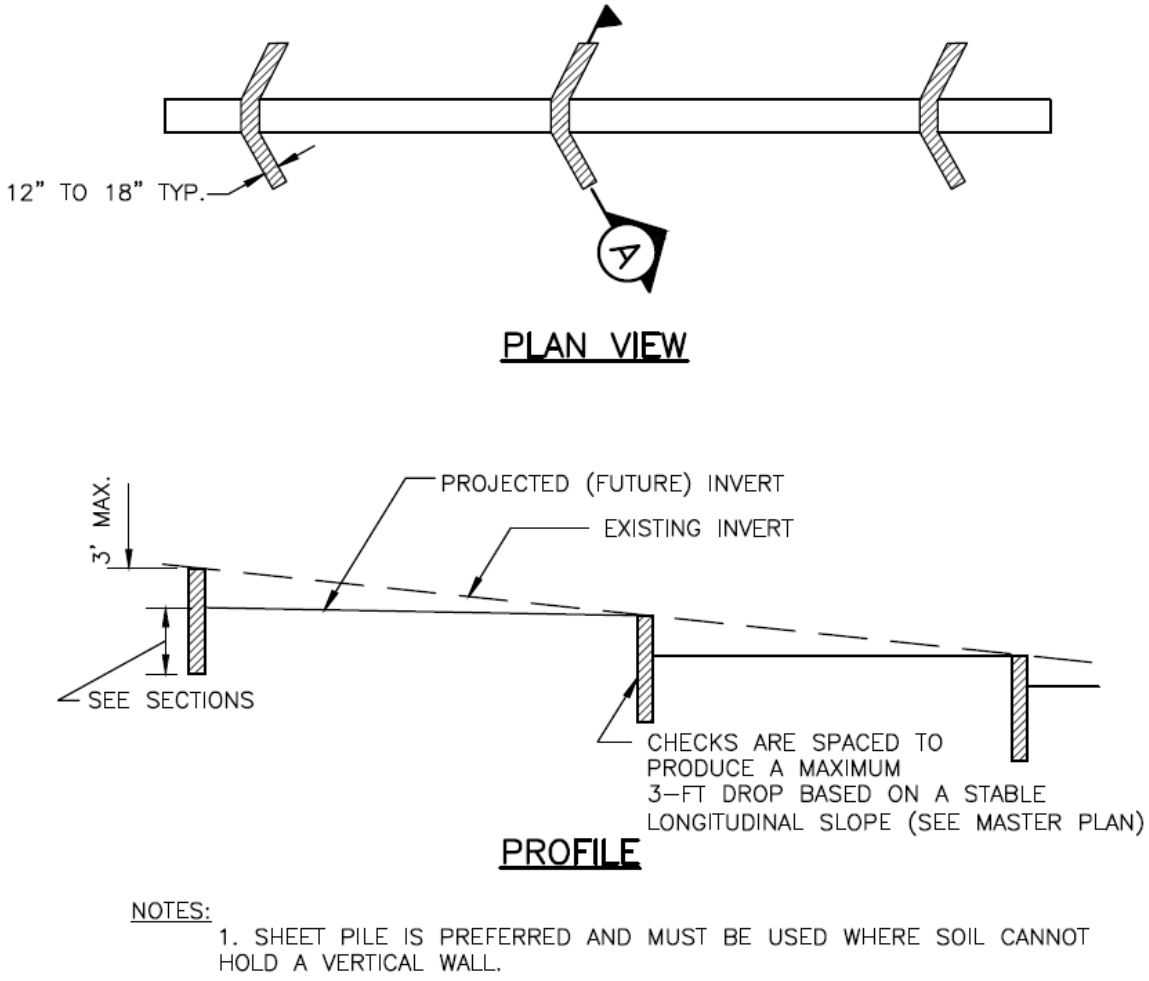
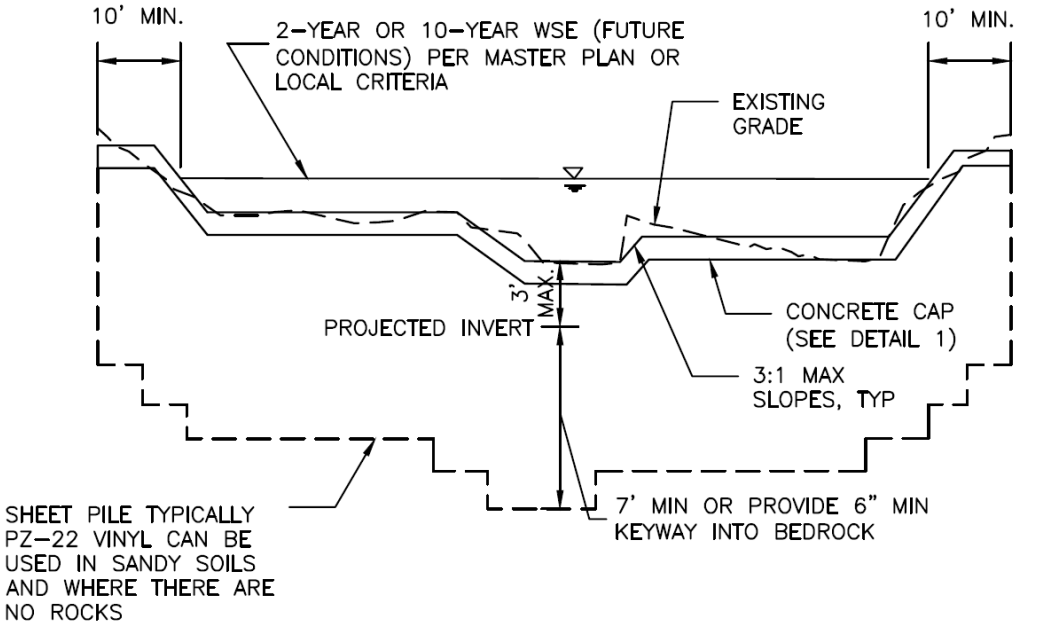
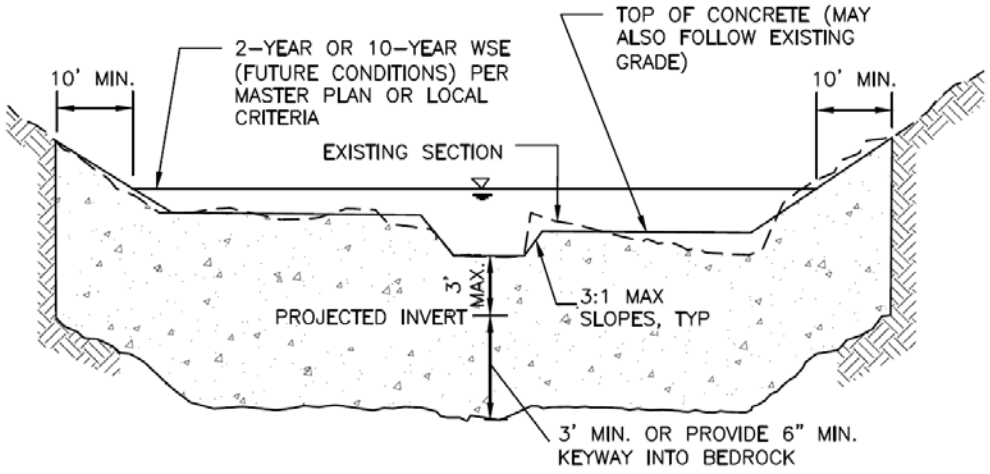


Figure 9-26. Check structure details (Part 1 of 3)



NOTE: THE STRUCTURE MAY BE COVERED WITH 6" OF SOIL OUTSIDE OF THE LOW FLOW AREA.

SECTION A1
SHEET PILE CHECK



NOTES:
1. TRENCH IN UNDISTURBED SOIL. FORM TOP 6" OF CHECK. DO NOT OVER EXCAVATE TO FORM WALLS OR CONSTRUCT A FOOTING.
2. THE STRUCTURE MAY BE COVERED WITH 6" OF SOIL OUTSIDE OF THE LOW FLOW AREA.
3. VIBRATE CONCRETE INTO TRENCH.

SECTION A2
CONCRETE CHECK

Figure 9-27. Check structure details (Part 2 of 3)

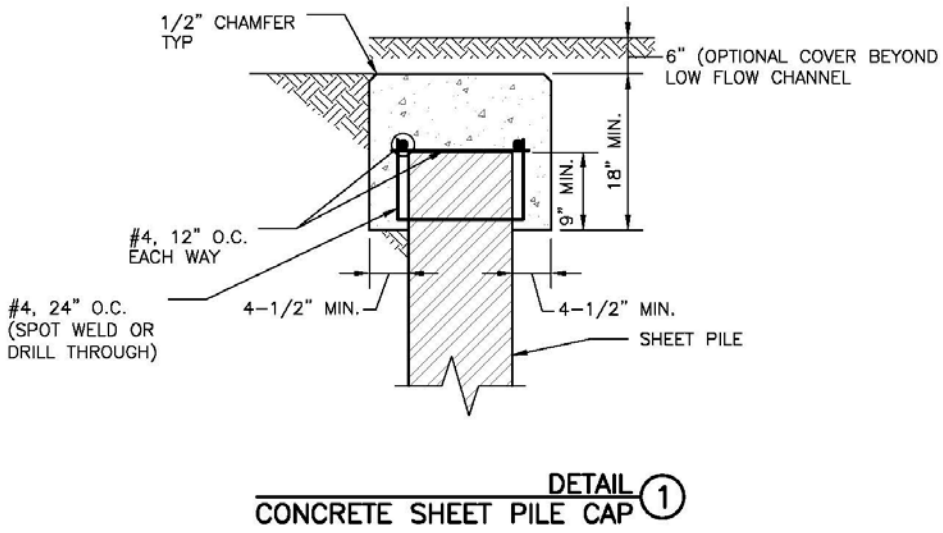


Figure 9-28. Check structure details (Part 3 of 3)

3.0 Pipe Outfalls and Rundowns

Pipe outlets represent a persistent problem due to concentrated discharges and turbulence of flow reaching this point of transition in an open channel. Too often, the designer focuses efforts on a culvert inlet and its sizing with outlet hydraulics receiving only passing attention. Appropriate pipe end treatment and downstream erosion protection at pipe outfalls is critical to protect the structural integrity of the pipe and to maintain the stability of the adjacent slope. Further discussion regarding appropriate treatment at pipe outfalls is included in the following sections.

Photograph 9-28. Pipe outfalls are recommended over rundowns due to the high failure rate of rundowns.

The use of rundowns to convey storm runoff down a channel bank is discouraged due to their high rate of failure and the resulting maintenance and repair burden. Instead, use a pipe to convey runoff to a point just above the channel invert (normally 1 foot for small receiving streams or ponds and up to 2 feet for large receiving channels).

3.1 Pipe End Treatment

Pipe end treatment consists of a flared end section, toe wall, headwall, wingwall or combination of treatments to protect the outfall from failure and provide a stable transition from hard to soft conveyance elements. Further discussion regarding these treatments follows.

Photograph 9-29. Pipe end failure resulting in loss of the flared end section

3.1.1 Flared-End Sections and Toe Walls

Flared end sections may be installed on both the inlet and outlet ends of culverts or storm drain systems. Erosion is likely at the outlet and possible at the inlet. Construction of a concrete toe wall (cutoff) is will protect the culvert from damage if inlet or outlet protection fails. At the outlet, provide scour protection including cutoff wall and use joint fasteners immediately upstream of the outlet. Protection at the upstream end can also help control seepage in the storm drain trench. See the Culverts chapter for discussion on inlet improvements.

Concrete toe walls include a footing and stem wall as shown in Figure 9-29 although the footing is optional for pipes 48 inches or less. Freezing depth should dictate the depth of the wall. The depth shown in the details represents freezing depth in the UDFCD region. Included is a design table for pipes 18 to 72 inches. The wall length shown allows an approximate 3(H):1(V) final ground slope from the flared-end section invert to the top outside edge of wall. Note that for large diameter flared-end sections, the wall lengths are quite large. It may be advantageous to use a combination headwall/wingwall approach or consider incorporating boulders for pipes larger than 36 inches in diameter. Always evaluate public safety including the need for pedestrian railing where a potential fall of 36 inches or more as possible. Along with the toe wall, install two joint fasteners between the flared end section and the last pipe section. Install these roughly at the ten o'clock and two o'clock positions and trim joint fastener threads flush with the interior bolts. Left untrimmed, these can catch debris and reduce pipe capacity. Joint fasteners are not necessary for flared end sections on the entrance of culverts or storm drains.

Figures 9-29 and 9-30 are applicable to both ends of a culvert or storm drain system. It is the design engineer's responsibility to assess the need for a cutoff wall. Factors to consider include:

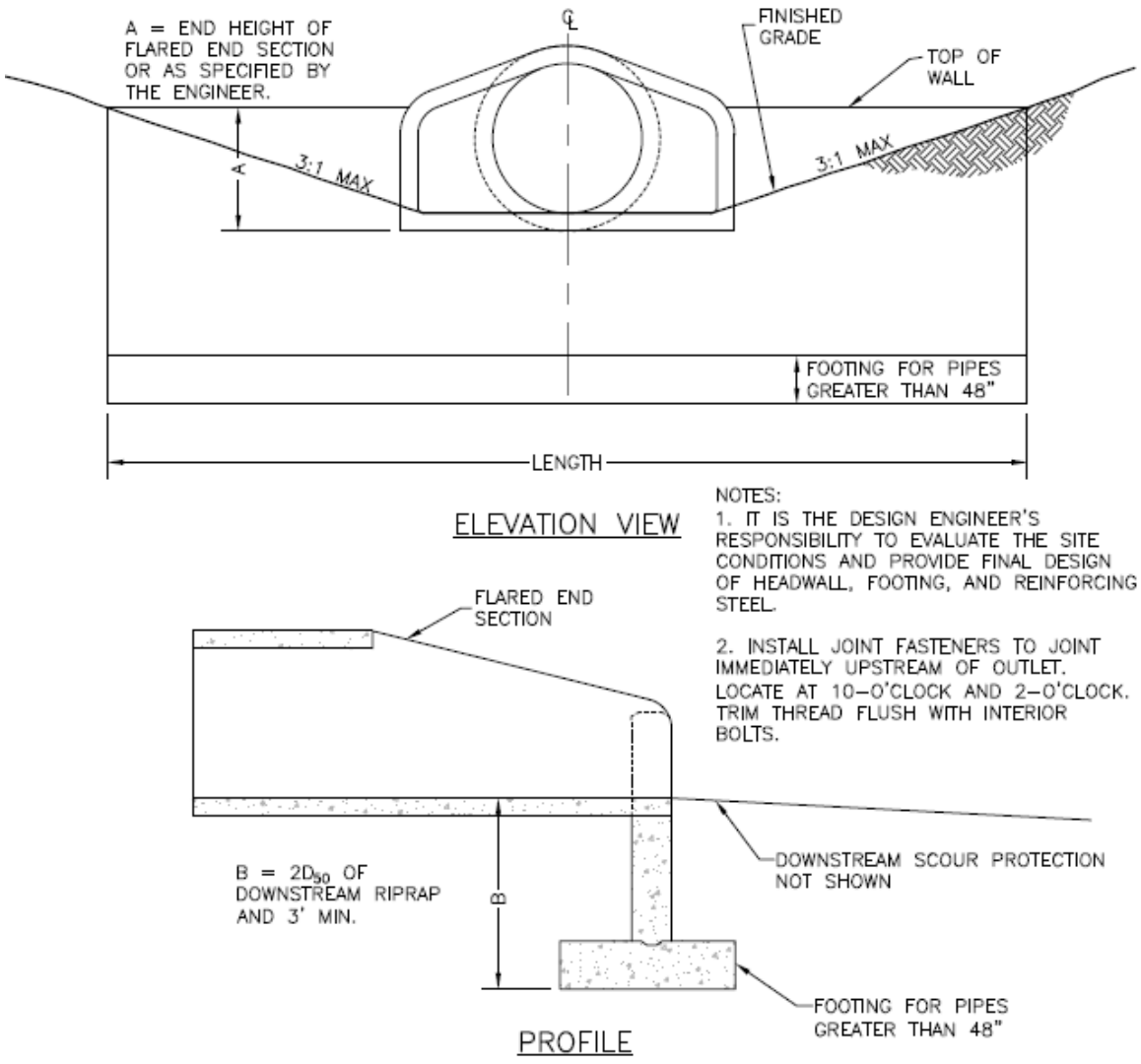
- The slope of the culvert or storm drain system is steep;
- The surrounding subsoils are granular or otherwise susceptible to erosion and/or piping;
- Potential for the roadway to wash out and the associated impact to public safety.

3.1.2 Concrete Headwall and Wingwalls

Concrete headwalls are an acceptable alternative to flared-end sections at pipe inlets and outlets. Figure 9-31 provides design guidance and a headwall design table for the design of a concrete headwall at a pipe inlet or outlet. When a 3(H):1(V) final ground slope from the pipe invert to the top outside edge of wall is used, the wall length can become quite long. Headwalls can be paired with wingwalls or boulders in order to reduce the overall headwall length. For 18" to 36" diameter pipes, headwalls can be paired with loosely placed boulders as shown in Figure 9-32. The addition of boulders can enhance the appearance of the end treatment and significantly reduce the wall length.

Storm drain outfalls into large river systems (e.g., the South Platte River) often require special consideration with respect to the channel bank geometry and base flow water surface elevation. Figure 9-33 provides general layout information for the construction of a headwall with wingwalls. It is the design engineer's responsibility to evaluate the site conditions and provide final design of headwall, wingwalls, footings, and reinforcing steel.

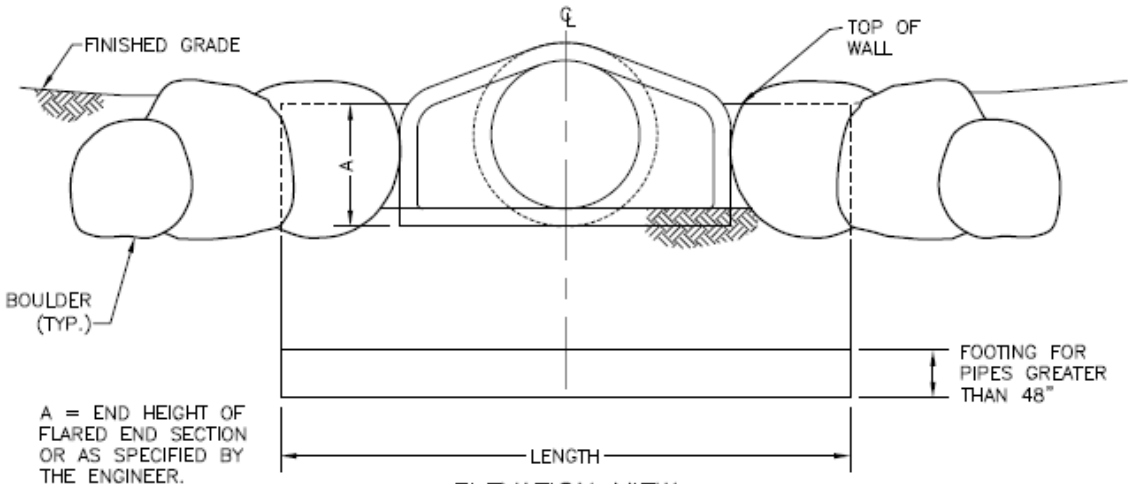
On large receiving streams, UDFCD encourages the use of wingwalls that are constructed perpendicular to the receiving channel centerline (or headwall), thereby reducing the impact to the channel overbanks. Further discussion regarding structure requirements for outfalls into large river systems is in Section 3.2.4.



HEADWALL DESIGN TABLE

PIPE SIZE	LENGTH, MIN
18"	7'–0"
24"	8'–0"
30"	10'–0"
36"	12'–6"
42"	15'–9"
48"	17'–6"
54"	19'–6"
60"	21'–6"
66"	22'–6"
72"	24'–0"

Figure 9-29. Flared end section (FES) headwall concept

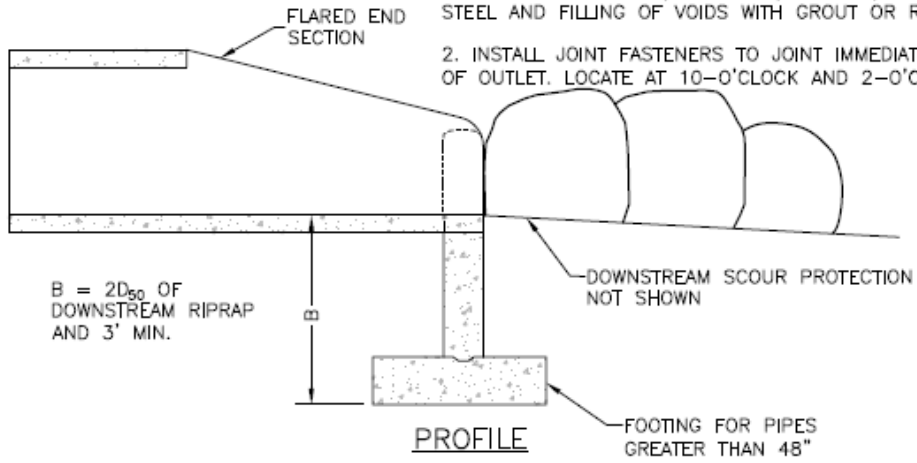


ELEVATION VIEW

NOTES:

1. IT IS THE DESIGN ENGINEER'S RESPONSIBILITY TO EVALUATE THE SITE CONDITIONS AND PROVIDE FINAL DESIGN OF BOULDER SIZES AND PLACEMENT, HEADWALL, FOOTING, REINFORCING STEEL AND FILLING OF VOIDS WITH GROUT OR ROCK.

2. INSTALL JOINT FASTENERS TO JOINT IMMEDIATELY UPSTREAM OF OUTLET. LOCATE AT 10–O'CLOCK AND 2–O'CLOCK. TRIM THREAD FLUSH WITH INTERIOR BOLTS.

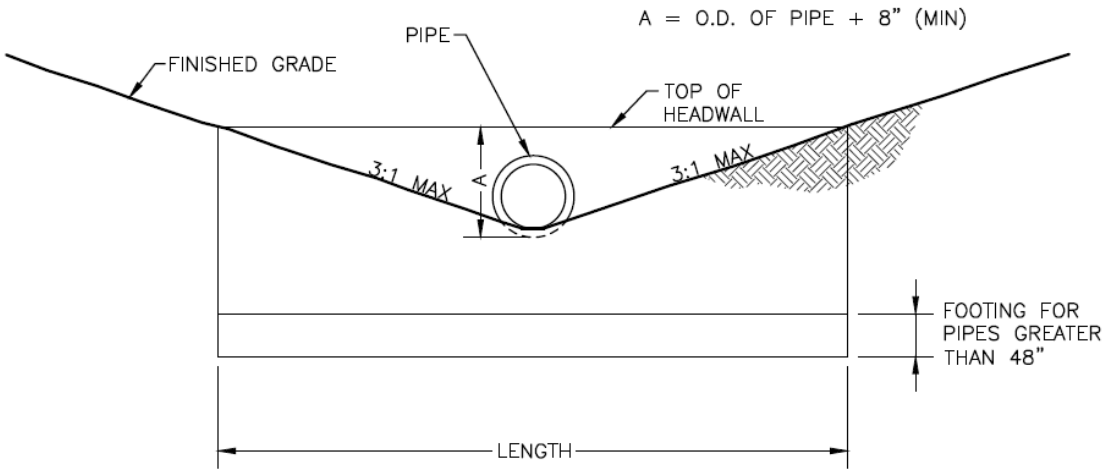


PROFILE

TOEWALL DESIGN TABLE

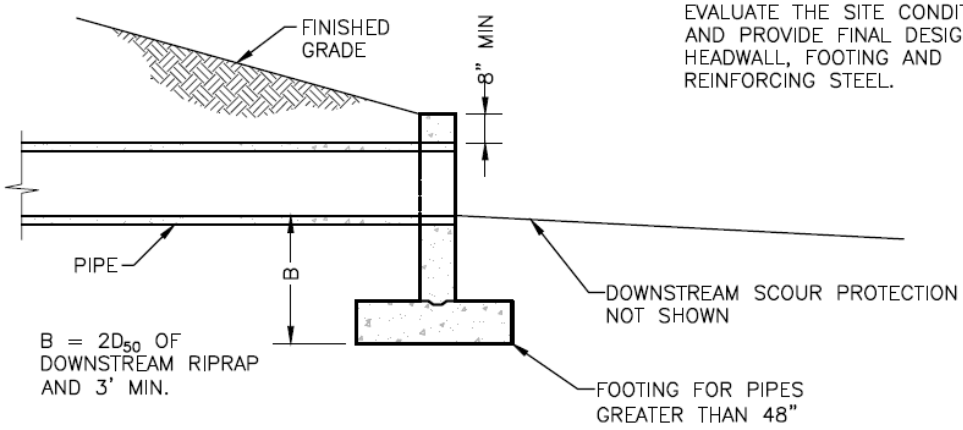
PIPE SIZE	LENGTH, MIN.
18"	7'–0"
24"	8'–0"
30"	10'–0"
36"	12'–0"
42"	12'–6"
48"	13'–0"
54"	13'–6"
60"	14'–0"
66"	14'–6"
72"	15'–0"

Figure 9-30. Flared end section (FES) headwall concept



ELEVATION VIEW

NOTE: IT IS THE DESIGN ENGINEER'S RESPONSIBILITY TO EVALUATE THE SITE CONDITIONS AND PROVIDE FINAL DESIGN OF HEADWALL, FOOTING AND REINFORCING STEEL.

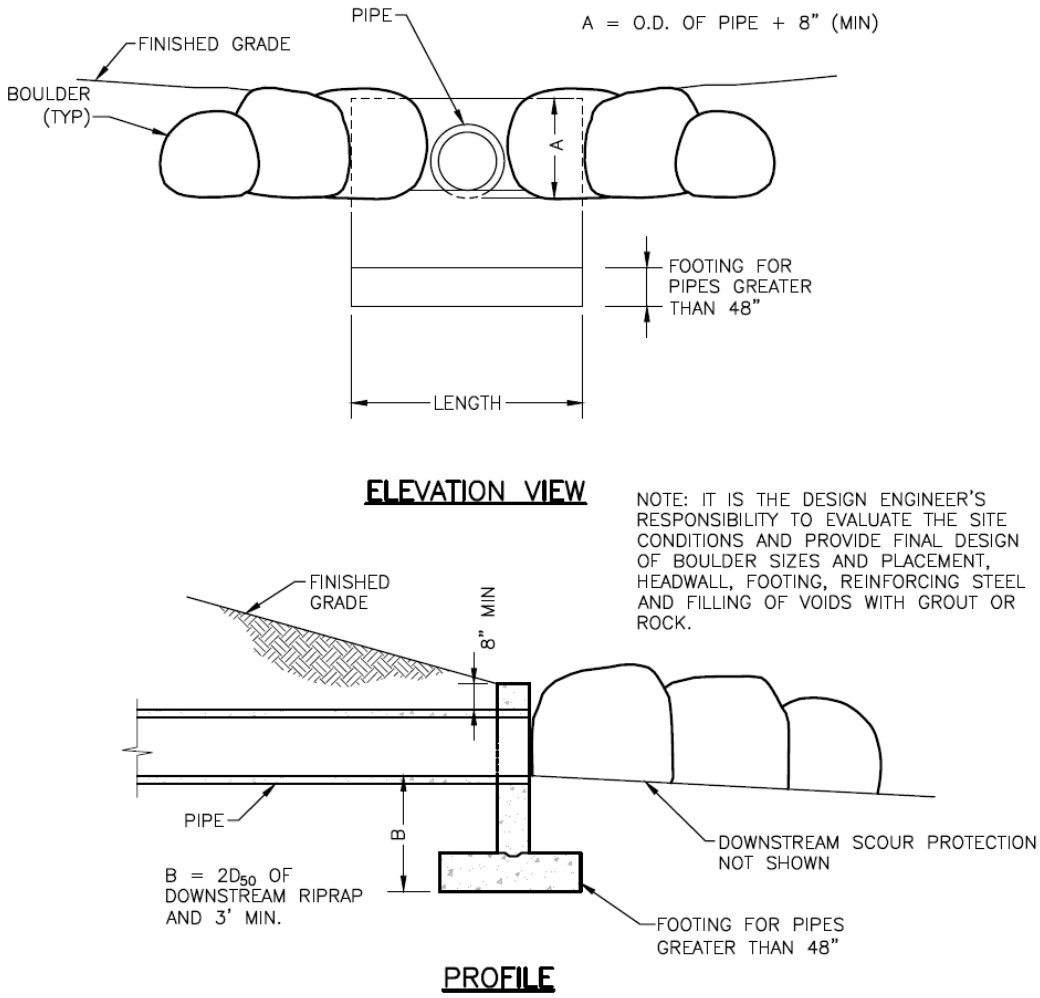


PROFILE

HEADWALL DESIGN TABLE

PIPE SIZE	LENGTH, MIN
18"	15'–9"
24"	19'–6"
30"	23'–4"
36"	27'–0"
42"	30'–9"
48"	34'–6"

Figure 9-31. Pipe headwall concept



HEADWALL DESIGN TABLE

PIPE SIZE	LENGTH, MIN
18"	7'–0"
24"	8'–0"
30"	8'–6"
36"	9'–0"
42"	9'–6"
48"	10'–0"

PIPE HEADWALL DETAIL (WITH BOULDERS)

Figure 9-32. Pipe headwall with boulders concept

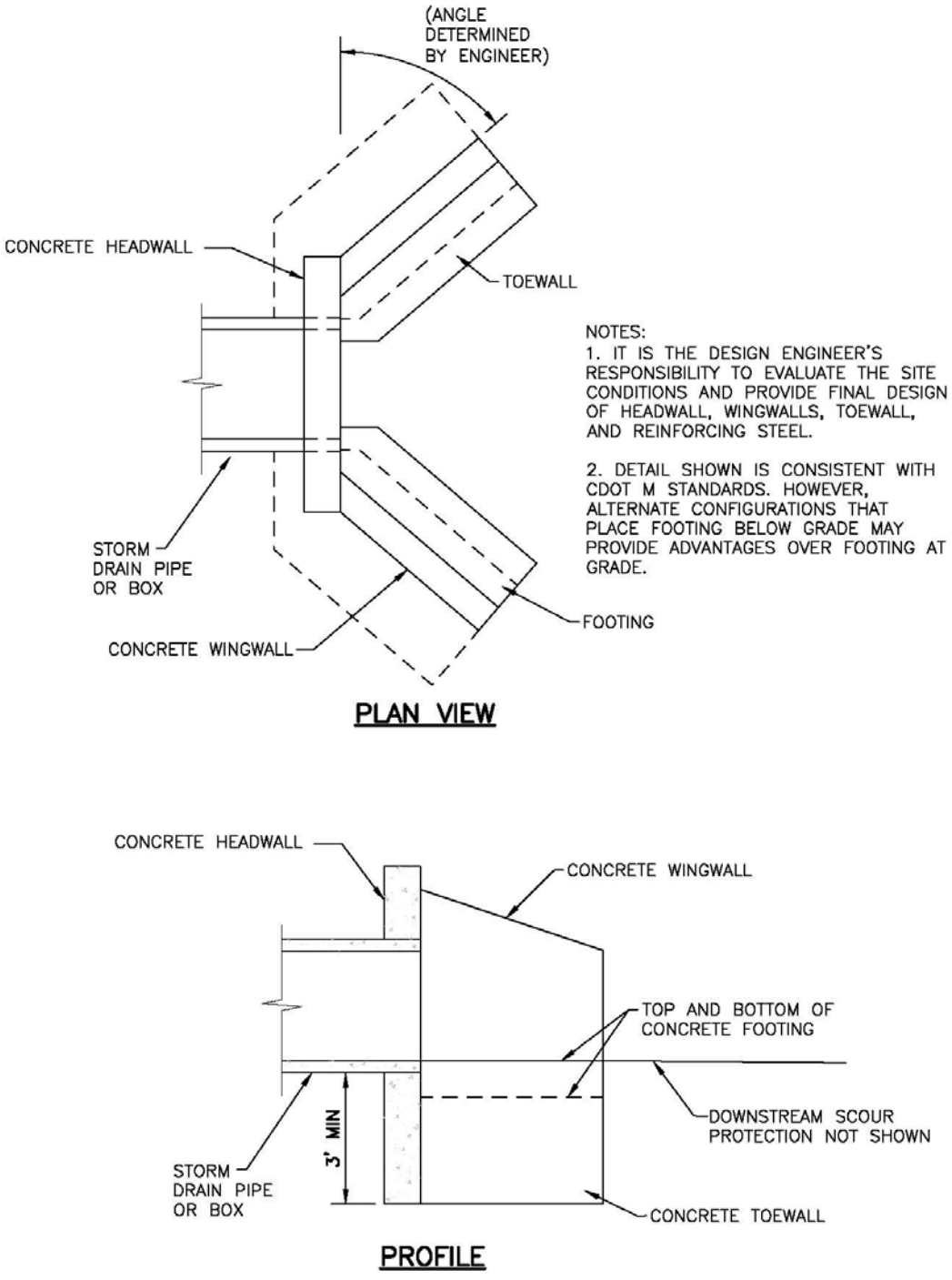


Figure 9-33. Pipe headwall/wingwall concept

3.2 Energy Dissipation and Erosion Protection

Local scour is typified by a scour hole produced at a pipe or culvert outlet. This is the result of high exit velocities, and the effects extend only a limited distance downstream. Coarse material scoured from the circular or elongated hole is deposited immediately downstream, often forming a low bar. Finer material moves farther downstream. The dimensions of the scour hole change due to sedimentation during low flows and the varying erosive effects of storm events. The scour hole is generally deepest during passage of the peak flow. Methods for predicting scour hole dimensions are found in the *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA 1983 and 2000).

Protection against scour at outlets ranges from limited riprap placement to complex and expensive energy dissipation devices. Pre-formed scour holes (approximating the configuration of naturally formed holes) dissipate energy while providing a protective lining to the streambed.

This section addresses energy dissipation and erosion control measures that can be used to minimize or eliminate local scour at a pipe outlet. The following measures are discussed:

- Riprap Apron
- Low Tailwater Basin
- Grouted Boulders
- Impact Basin

In general, all of these measures pose risks to the public. Discourage public access and minimize the risk of falls at these structures.

Scour and Stream Degradation

Scour is typically found at culvert outlets and other isolated transitional areas within a stream. Frequently, scour holes fill in with sediment over time only to appear again during infrequent high flows.

Degradation is a phenomenon that is independent of culvert performance. Natural causes can produce a lowering of the streambed over time. Contributing factors include the slope of the stream and the size and availability of the sediment load. Degradation can also be a result of other constructed features such as upstream detention or increased watershed imperviousness. The identification of a degrading stream is an essential part of the original site investigation. Discussion of this subject is in the *Open Channels* chapter.

3.2.1 Riprap Apron

This section addresses the use of riprap for erosion protection downstream of conduit and culvert outlets. Refer to the *Open Channels* chapter for additional information on applications for and placement of riprap. Those criteria will be useful in design of erosion protection for conduit outlets. When incorporating a drop into the outfall use Figure 9-40 or 9-41.

Rock Size
The procedure for determining the required riprap size downstream of a conduit outlet is in Section 3.2.3.

Configuration of Riprap Apron
Figure 9-34 illustrates typical riprap protection of culverts at conduit outlets.

Extent of Protection
The length of the riprap protection downstream from the outlet depends on the degree of protection desired. If it is necessary to prevent all erosion, the riprap must extend until the velocity decreases to an acceptable value. The acceptable major event velocity is set at 5 ft/sec for non-cohesive soils and at 7 ft/sec for erosion resistant soils. The rate at which the velocity of a jet from a conduit outlet decreases is not well known. The procedure recommended here assumes the rate of decrease in velocity is related to the angle of lateral expansion, θ, of the jet. The velocity is related to the expansion factor, $(1/(2\tan\theta))$, which can be determined directly using Figure 9-35 or Figure 9-36, by assuming that the expanding jet has a rectangular shape:

$$L_p = \left(\frac{1}{2\tan\theta}\right)\left(\frac{A_t}{Y_t} - W\right) \qquad \text{Equation 9-11}$$

Where:

L_p = length of protection (ft)

W = width of the conduit (ft, use diameter for circular conduits)

Y_t = tailwater depth (ft)

θ = the expansion angle of the culvert flow

and:

$$A_t = \frac{Q}{V} \qquad \text{Equation 9-12}$$

Where:

Q = design discharge (cfs)

V = the allowable non-eroding velocity in the downstream channel (ft/sec)

A_t = required area of flow at allowable velocity (ft^2)

In certain circumstances, Equation 9-11 may yield unreasonable results. Therefore, in no case should L_p be less than $3H$ or $3D$, nor does L_p need to be greater than $10H$ or $10D$ whenever the Froude parameter, $Q/WH^{1.5}$ or $Q/D^{2.5}$, is less than 8.0 or 6.0, respectively. Whenever the Froude parameter is greater than these maximums, increase the maximum L_p required by ¼ D_c or ¼ H for circular or rectangular (box) culverts, respectively, for each whole number by which the Froude parameter is greater than 8.0 or 6.0, respectively.

Once L_p has been determined, the width of the riprap protection at the furthest downstream point should be verified. This dimension is labeled "T" on Figure 9-34. The first step is to solve for θ using the results from Figure 9-35 or 9-36:

$$\theta = \tan^{-1}\left(\frac{1}{2(\text{ExpansionFactor})}\right) \qquad \text{Equation 9-13}$$

Where:

Expansion Factor = determined using Figure 9-35 or 9-36

T is then calculated using the following equation:

$$T = 2(L_p \tan\theta) + W \qquad \text{Equation 9-14}$$

Multiple Conduit Installations

The procedures outlined in this section can be used to design outlet erosion protection for multi-barrel culvert installations by replacing the multiple barrels with a single hydraulically equivalent hypothetical rectangular conduit. The dimensions of the equivalent conduit may be established as follows:

1. Distribute the total discharge, Q, among the individual conduits. Where all the conduits are hydraulically similar and identically situated, the flow can be assumed to be equally distributed; otherwise, the flow through each barrel must be computed.

2. Compute the Froude parameter $Q_i/D_{ci}^{2.5}$ (circular conduit) or $Q_i/W_iH_i^{1.5}$ (rectangular conduit), where the subscript i indicates the discharge and dimensions associated with an individual conduit.

3. If the installation includes dissimilar conduits, select the conduit with the largest value of the Froude parameter to determine the dimensions of the equivalent conduit.

4. Make the height of the equivalent conduit, H_{eq}, equal to the height, or diameter, of the selected individual conduit.

5. The width of the equivalent conduit, W_{eq}, is determined by equating the Froude parameter from the selected individual conduit with the Froude parameter associated with the equivalent conduit, $Q/W_iH_{eq}^{1.5}$.

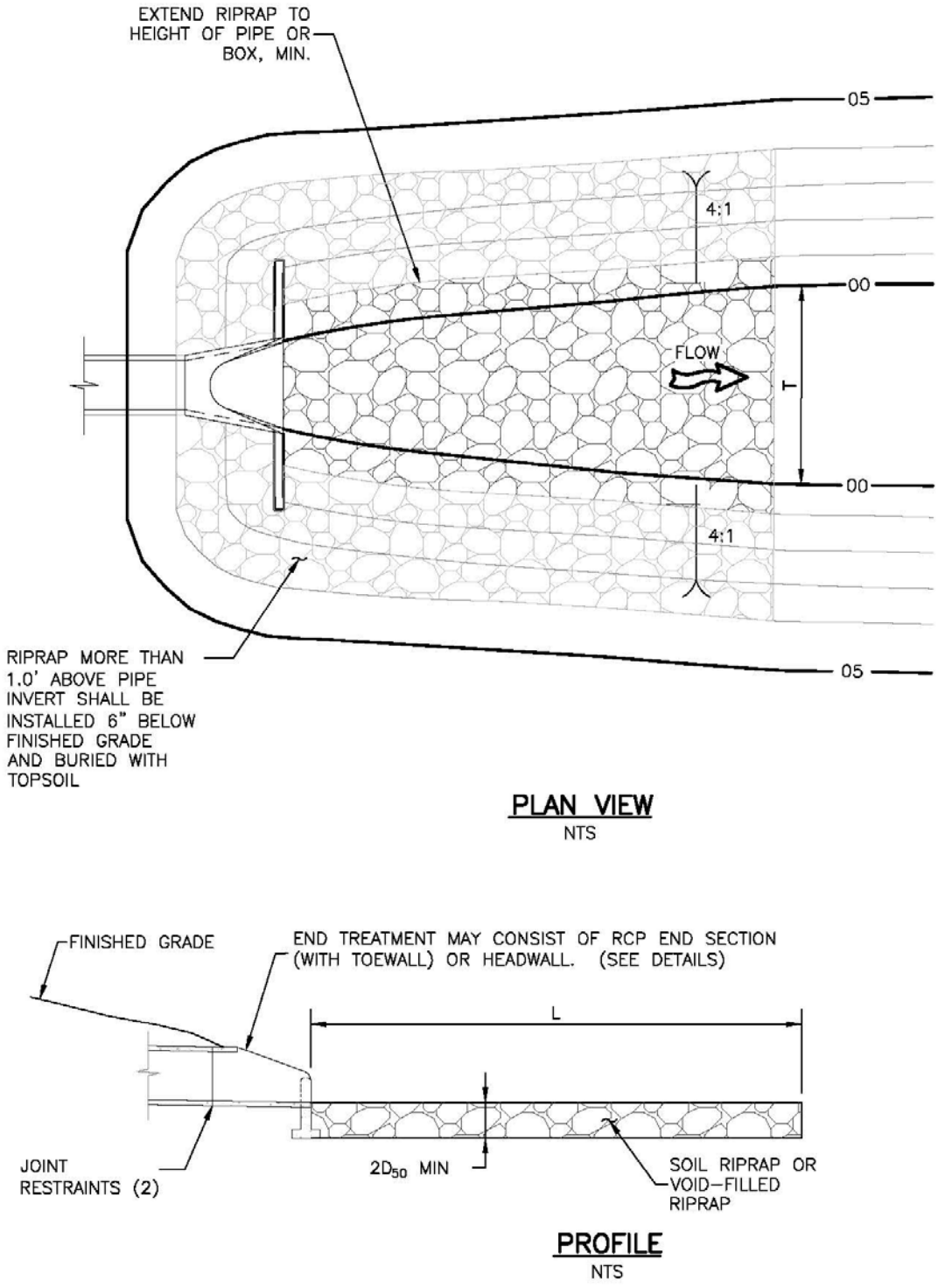


Figure 9-34. Riprap apron detail for culverts in-line with the channel

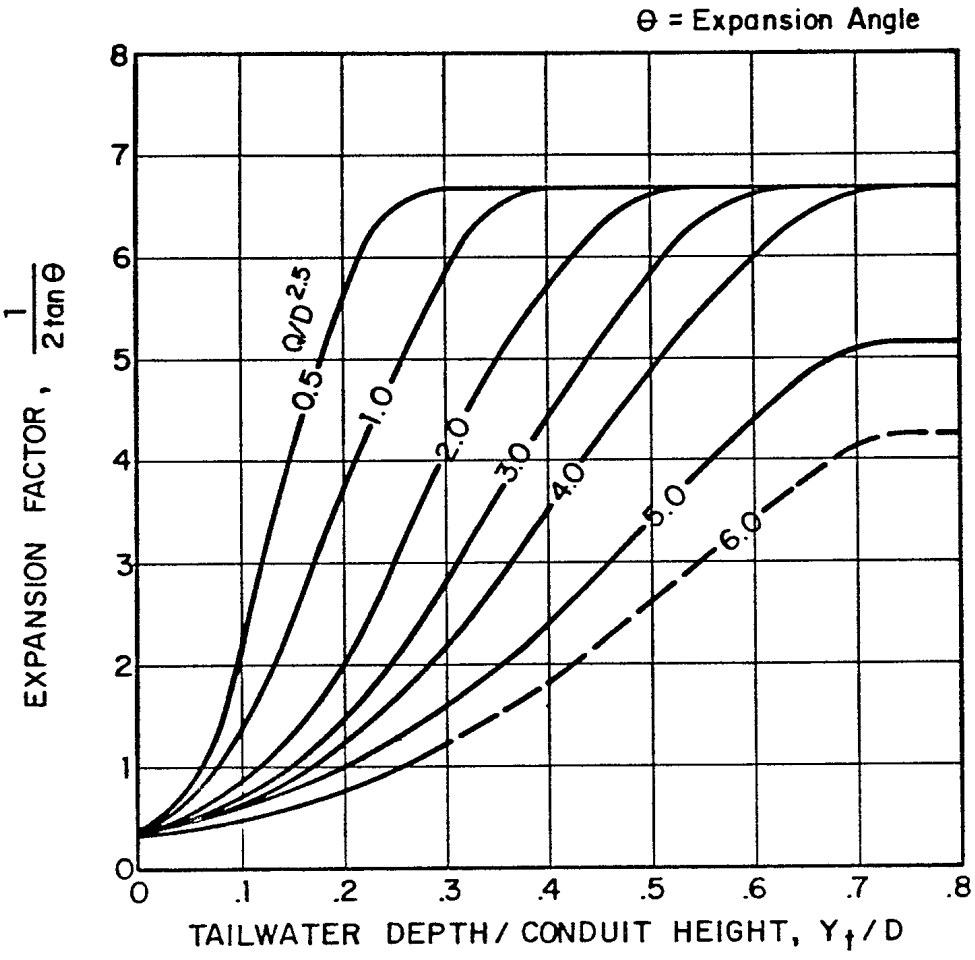


Figure 9-35. Expansion factor for circular conduits

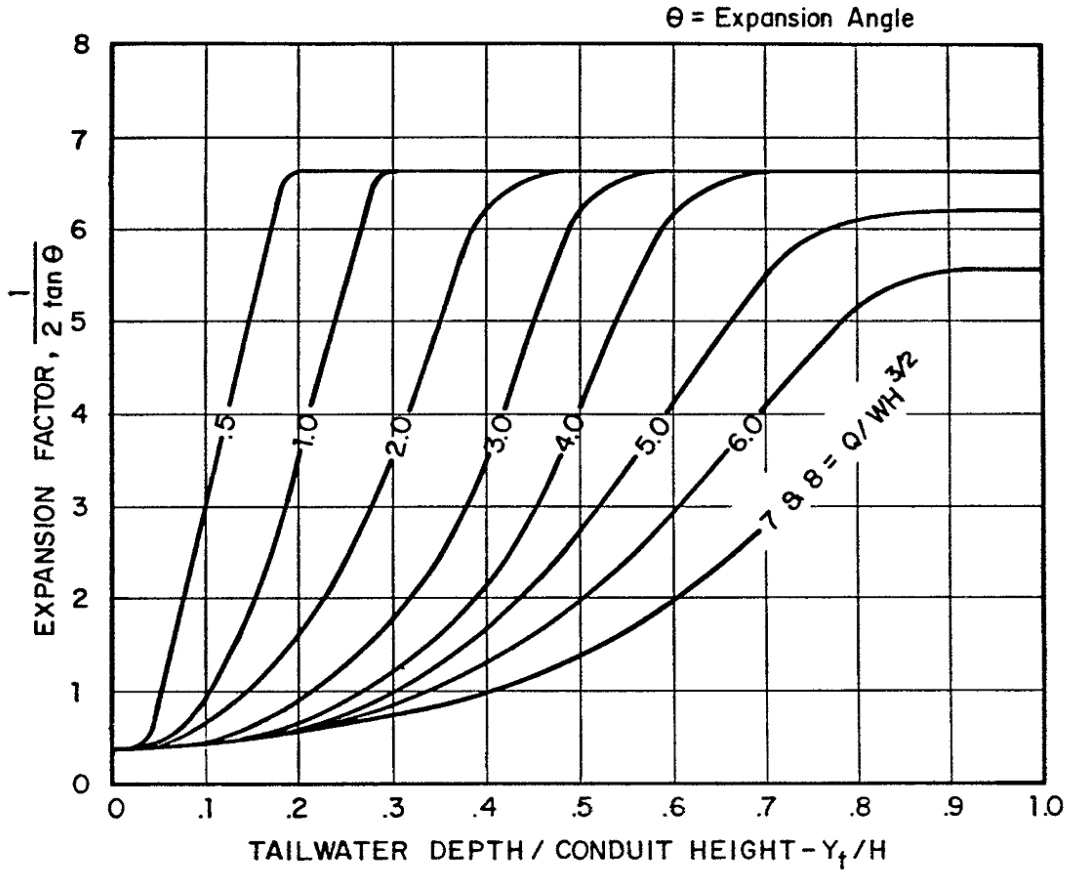


Figure 9-36. Expansion factor for rectangular conduits

3.2.2 Low Tailwater Basin

The design of low tailwater riprap basins is necessary when the receiving channel may have little or no flow or tailwater at time when the pipe or culvert is in operation. Figure 9-37 provides a plan and profile view of a typical low tailwater riprap basin.

By providing a low tailwater basin at the end of a storm drain conduit or culvert, the kinetic energy of the discharge dissipates under controlled conditions without causing scour at the channel bottom.

Low tailwater is defined as being equal to or less than ⅓ of the height of the storm drain, that is:

$$y_t \leq \frac{D}{3} \quad \text{or} \quad y_t \leq \frac{H}{3}$$

Where:

y_t = tailwater depth at design flow (feet)

D = diameter of circular pipe (feet)

H = height of rectangular pipe (feet)

Rock Size
The procedure for determining the required riprap size downstream of a conduit outlet is in Section 3.2.3.

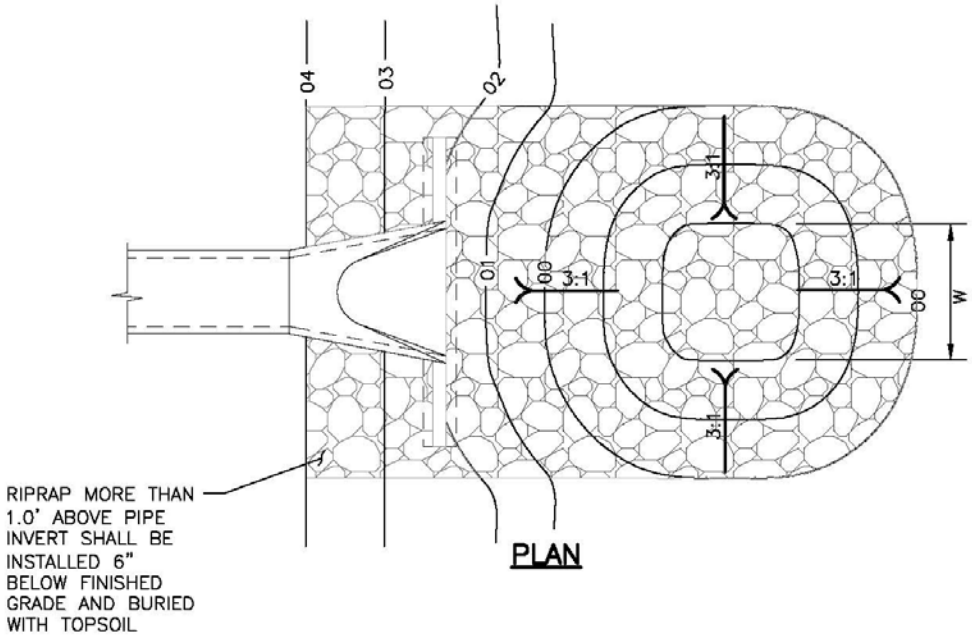
After selecting the riprap size, the minimum thickness of the riprap layer, T, in feet, in the basin is defined as:

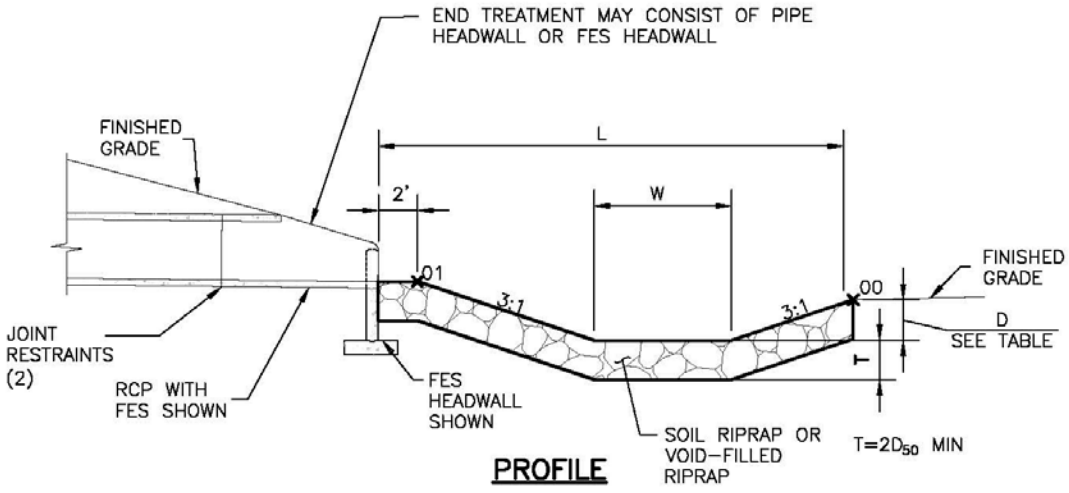
$$T = 2D_{50} \qquad \text{Equation 9-15}$$

Basin Geometry
Figure 9-37 includes a layout of a standard low tailwater riprap basin with the geometry parameters provided. The minimum length of the basin (L) and the width of the bottom of the basin (W1) are provided in a table at the bottom of Figure 9-37. All slopes in the low tailwater basin shall be 3(H):1(V), minimum.

Other Design Requirements
Extend riprap up the outlet embankment slope to the mid-pipe level, minimum. It is recommended that riprap that extends more than 1 foot above the outlet pipe invert be installed 6 inches below finished grade and buried with topsoil.

Provide pipe end treatment in the form of a pipe headwall or a flared-end section headwall. See Section 3.1 for options.





PIPE SIZE OR BOX HEIGHT	D	W*	L
18" – 24"	1'–0"	4'	15'
30" – 36"	1'–6"	6'	20'
42" – 48"	2'–0"	7'	24'
54" – 60"	2'–6"	8'	28'
66" – 72"	3'–0"	9'	32'

* IF OUTLET PIPE IS A BOX CULVERT WITH A WIDTH GREATER THAN W, THEN W = CULVERT WIDTH

Figure 9-37. Low tailwater riprap basin

3.2.3 Rock Sizing for Riprap Apron and Low Tailwater Basin

Scour resulting from highly turbulent, rapidly decelerating flow is a common problem at conduit outlets. The following section summarizes the method for sizing riprap protection for both riprap aprons (Section 3.2.1) and low tailwater basins (Section 3.2.2).

Use Figure 9-38 to determine the required rock size for circular conduits and Figure 9-39 for rectangular conduits. Figure 9-38 is valid for $Q/D_c^{2.5}$ of 6.0 or less and Figure 9-39 is valid for $Q/WH^{1.5}$ of 8.0 or less. The parameters in these two figures are:

1. $Q/D^{1.5}$ or $Q/WH^{0.5}$ in which Q is the design discharge in cfs, D_c is the diameter of a circular conduit in feet, and W and H are the width and height of a rectangular conduit in feet.

2. Y_t/D_c or Y_t/H in which Y_t is the tailwater depth in feet, D_c is the diameter of a circular conduit in feet, and H is the height of a rectangular conduit in feet. In cases where Y_t is unknown or a hydraulic jump is suspected downstream of the outlet, use $Y_t/D_t = Y_t/H = 0.40$ when using Figures 9-38 and 9-39.

3. The riprap size requirements in Figures 9-38 and 9-39 are based on the non-dimensional parametric Equations 9-16 and 9-17 (Steven, Simons, and Watts 1971 and Smith 1975).

Circular culvert:

$$d_{50} = \frac{0.023Q}{Y_t^{1.2} D_c^{0.3}} \qquad \text{Equation 9-16}$$

Rectangular culvert:

$$d_{50} = \frac{0.014H^{0.5}Q}{Y_t W} \qquad \text{Equation 9-17}$$

These rock size requirements assume that the flow in the culvert is subcritical. It is possible to use Equations 9-16 and 9-17 when the flow in the culvert is supercritical (and less than full) if the value of D_c or H is modified for use in Figures 9-38 and 9-39. Note that rock sizes referenced in these figures are defined in the *Open Channels* chapter. Whenever the flow is supercritical in the culvert, substitute D_a for D_c and H_a for H, in which D_a is defined as:

$$D_a = \frac{(D_c + Y_n)}{2} \qquad \text{Equation 9-18}$$

Where the maximum value of D_a shall not exceed D_c, and

$$H_a = \frac{(H + Y_n)}{2}$$ Equation 9-19

Where the maximum value of H_a shall not exceed H, and:

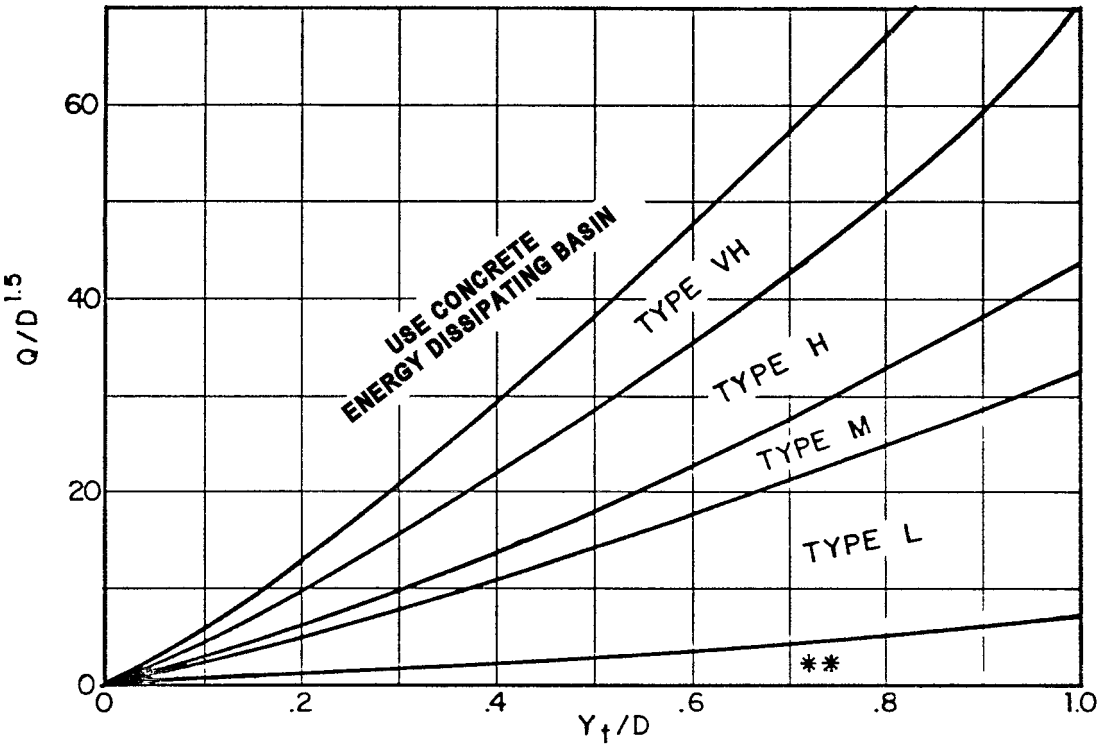
D_a = parameter to use in place of D in Figure 9-38 when flow is supercritical (ft)

D_c = diameter of circular culvert (ft)

H_a = parameter to use in place of H in Figure 9-39 when flow is supercritical (ft)

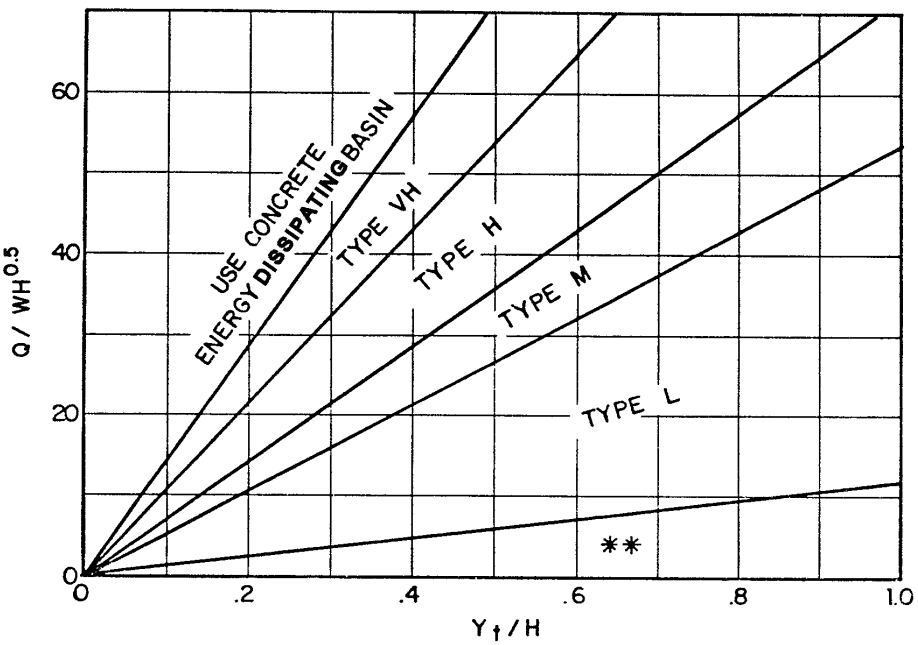
H = height of rectangular culvert (ft)

Y_n = normal depth of supercritical flow in the culvert (ft)



Use D_a instead of D whenever flow is supercritical in the barrel.
** Use Type L for a distance of 3D downstream.

Figure 9-38. Riprap erosion protection at circular conduit outlet (valid for Q/D2.5 ≤ 6.0)



Use H_a instead of H whenever culvert has supercritical flow in the barrel.
**Use Type L for a distance of 3H downstream.

Figure 9-39. Riprap erosion protection at rectangular conduit outlet (valid for Q/WH1.5 ≤ 8.0)

3.2.4 Outfalls and Rundowns

A grouted boulder outfall or "rundown" dissipates energy and provides erosion control protection. Grouted boulder outfalls are most commonly used in large rivers like the South Platte. Figure 9-40 provides a plan view and cross section for a standard grouted boulder rundown. See the grouted boulder drop profiles (A1, A2, and A3) in Figure 9-12 for site specific profile options, (i.e., depressed or free-draining basin for use with a stable downstream channel or with no basin for use in channels subject to degradation). Figure 9-41 provides a plan view of the same structure for use when the structure is in-line with the channel. Evaluate the following when designing a grouted boulder outfall or rundown:

- Minimize disturbance to channel bank
- Determine water surface elevation in receiving channel for base flow and design storm(s)
- Determine flow rate, velocity, depth, etc. of flow exiting the outfall pipe for the design storm(s)
- Evaluate permitting procedures and requirements for construction adjacent to large river system.

Use the criteria presented in Section 2.6 for grouted boulder drop structures as a reference for guidance in the design of a grouted boulder outfall. Those criteria for grout depth, side slopes, and boulder placement also apply to grouted boulder outfalls and rundowns.

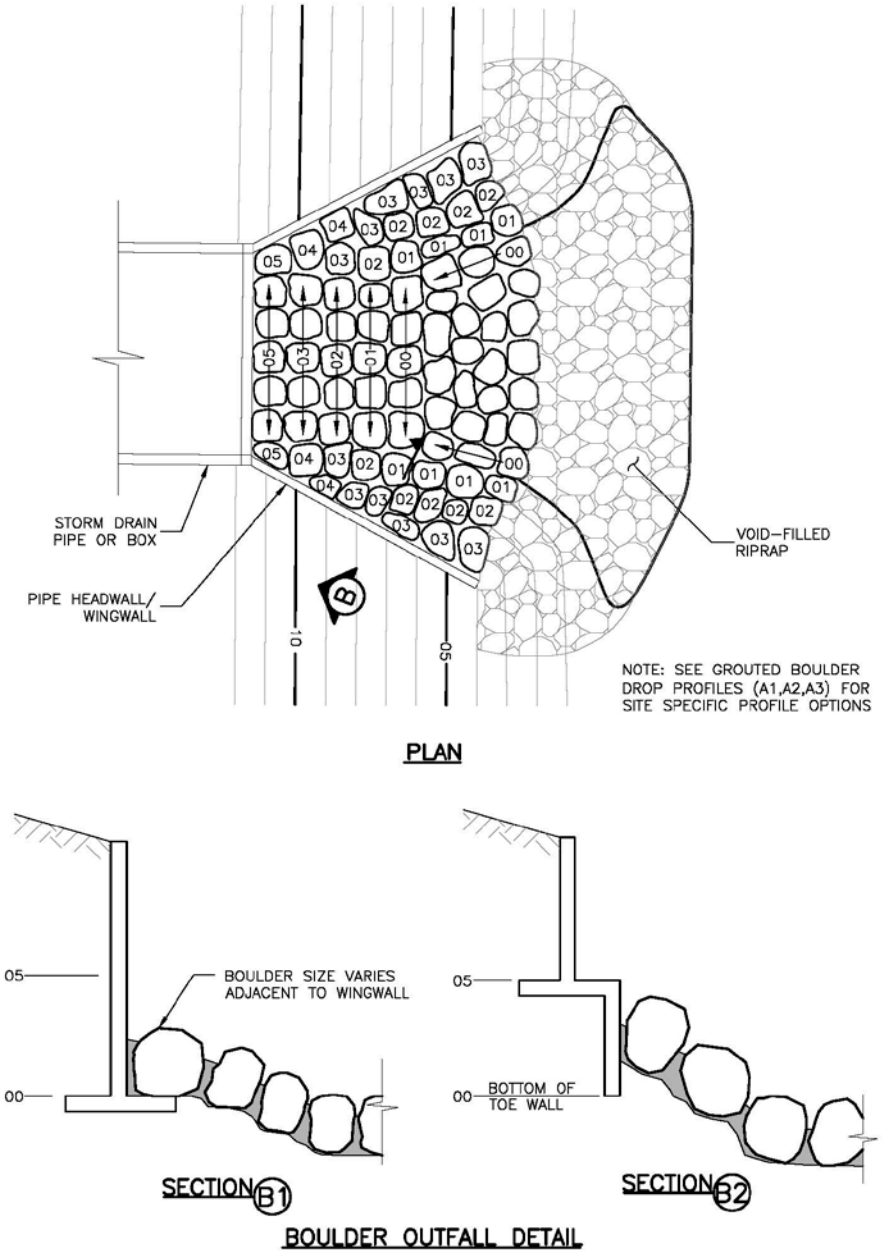


Figure 9-40. Boulder outfall detail

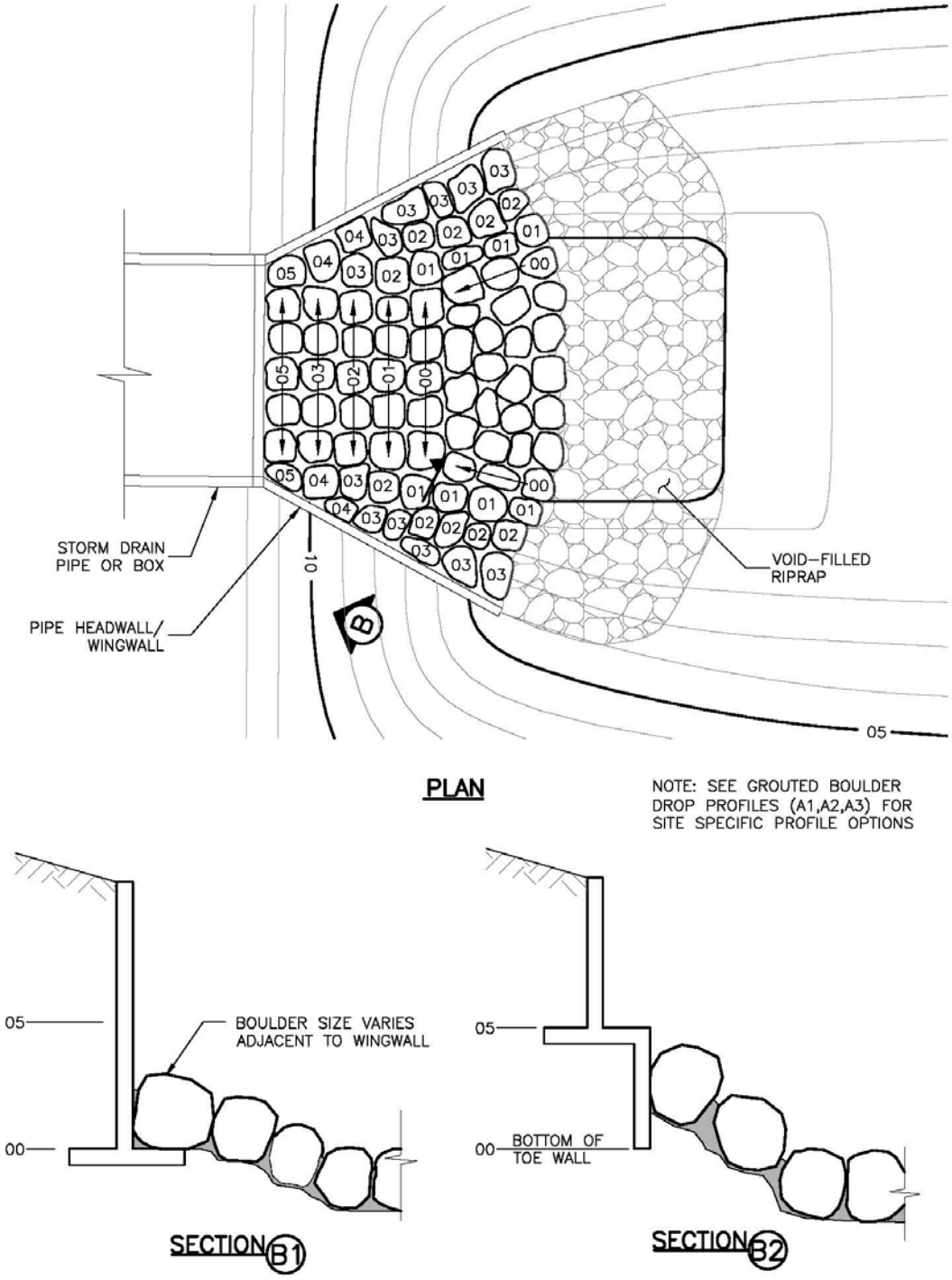


Figure 9-41. Boulder outfall detail (in-line with channel)

Energy dissipation or stilling basin structures are required to minimize scour damages caused by high exit velocities and turbulence at conduit outlets. Outlet structures can provide a high degree of energy dissipation and are generally effective even with relatively low tailwater control. Rock protection at conduit outlets, as discussed in Section 3.2.1, is appropriate where moderate outlet conditions exist; however, there are many situations where rock basins are impractical. Reinforced concrete outlet structures are suitable for a wide variety of site conditions. In some cases, they are more economical than larger rock basins, particularly when long-term costs are considered. The impact basin is an "all-emcompassing" structure that does not require a separate design for the pipe end treatment.

Any outlet structure must be designed to match the receiving stream conditions. The following steps include an analysis of the probable range of tailwater and bed conditions that can be anticipated including degradation, aggradation, and local scour.

Use of concrete is often more economical due to structure size or local availability of materials. Initial design selection should include consideration of a conduit outlet structure if any of the following situations exist:

- High-energy dissipation efficiency is required, where hydraulic conditions approach or exceed the limits for alternate designs (see the *Open Channels* chapter);
- Low tailwater control is anticipated; or
- Site conditions, such as public use areas, where plunge pools and standing water are unacceptable because of safety and appearance, or at locations where space limitations direct the use of a concrete structure.

Impact Basins for Small Outlets

Figures 9-43 and 9-44 provide design layout for circular outlets up to 48 inches in diameter. Unlike the Type VI impact basin used for large outlets, the modified basin does not require sizing for flow under velocities recommended in the *Streets, Inlets, and Storm Drains* chapter. However, use of this detail is limited to exit velocities of 18 feet per second or less. For larger conduits and higher exit velocities, use the Type VI impact basin.

Impact Basins for Large Outlets

Conduits with large cross-sectional areas are for significant discharges and often with high velocities requiring special hydraulic design at their outlets. Here, dam outlet and spillway terminal structure technology is appropriate (USBR 1987). Type II, III or VI (USBR nomenclature) stilling basins, submerged bucket with plunge basin energy dissipators and slotted-grating dissipators can be considered when appropriate to the site conditions. For instance, a plunge basin may have applicability where discharge is to a retention pond or a lake. Alternate designs of pipe exit energy dissipators provided in this chapter can be matched to a variety of pipe sizes, pipe outlet physical configurations, and hydraulic conditions.

Most design standards for an impact stilling basin are based on the USBR Type VI basin, often called "impact dissipater" or conduit "outlet stilling basin." This basin is a relatively small structure that is very efficient in dissipating energy without the need of tailwater. The original hydraulic design reference (Biechley 1971) is based on model studies. Additional structural design details are provided by Aisenbrey, et al. 1974; and Peterka 1984.

The Type VI basin was originally designed to operate continuously at the design flow rate. However, it is applicable for use under the varied flow conditions of stormwater runoff. The USBR Type VI Impact Basin design configuration is shown in Figure 9-43, which consists of an open concrete box attached directly to the conduit outlet. The width, *W*, is a function of the Froude number and can be determined using Figure 9-46. The sidewalls are high enough to contain most of the splashing during high flows and slope down to form a transition to the receiving channel. The inlet pipe is vertically aligned with an overhanging L-shaped baffle such that the pipe invert is not lower than the bottom of the baffle. The end check height is equal to the height under the baffle to produce tailwater in the basin. UDFCD modified this USBR structure to provide a means of draining the structure to improve maintenance conditions and avoid development of mosquito habitat. Low-flow modifications have not been fully tested to date. Avoid compromising the overall hydraulic performance of the structure.

Multiple Conduit Entry to an Impact Basin

Where two or more conduits of different sizes outlet in close proximity to each other, a composite structure can be constructed to eliminate common walls. This can be somewhat awkward since each basin "cell" must be designed as an individual basin with different height, width, etc. Where feasible, a more economical approach is to combine storm drains at a manhole or vault and bring a single, combined pipe to the outlet structure.

When using the modified Type VI impact basin for two side-by-side pipes of the same size, the two pipes may discharge into a single basin. In this scenario, increase the width of the basin by a factor of 1.5. When the flow is different for the two conduits, the width of the basin is based on the pipe carrying the higher flow. For the modified impact basin shown in 9-43, add 1/2 D space between the pipes and to each outside pipe edge when two pipes discharge into the basin to determine the width of the headwall and extent the width of the impact wall to match the outside edges of the two pipes. The effect of mixing and turbulence of the combined flows in the basin was not modeled.

The remaining structure dimensions are based on the design width of a separate basin *W*. If the two pipes have different flow, the combined structure is based on the higher Froude number. Install handrails, access control grating, or a hinged rack around the open basin areas where safety is a concern.

General Design Procedure for Type VI Impact Basin

1. Calculate the Froude number. Determine the design hydraulic cross-sectional area inside the pipe at the outlet. Determine the effective flow velocity, *V*, at the same location in the pipe. Assume the depth of flow (D), is equal to the square root of the flow area inside the pipe at the outlet.

$$\text{Froude number} = \frac{V}{(gD)^{1/2}}$$

2. Place the entrance pipe horizontally at least one pipe diameter equivalent length upstream from the outlet. For pipe slopes greater than 15 degrees, the horizontal length should be a minimum of two pipe diameters.

3. Determine the basin width, *W*, by entering the Froude number and effective flow depth into Figure 9-40. The remaining dimensions are proportional to the basin width according to Figure 9-39. No not oversize the basin width. Larger basins become less effective as the inflow can pass under the baffle.

4. Design structure wall thickness, steel reinforcement, and anchor walls (underneath the floor) using accepted structural engineering methods. Note the baffle thickness, t_b, is a suggested minimum. It is not a hydraulic parameter and is not a substitute for structural analysis. Hydraulic forces on the overhanging baffle may be approximated by determining the hydraulic jet force at the outlet:

   $F_j = 1.94\ V_{out}\ Q$ (force in pounds) Equation 9-20
   Q = maximum design discharge (cfs)
   V_{out} = velocity of the outlet jet (ft/sec)

Provide type "M" soil riprap or void-filled riprap in the receiving channel from the end check to a minimum distance equal to the basin width.

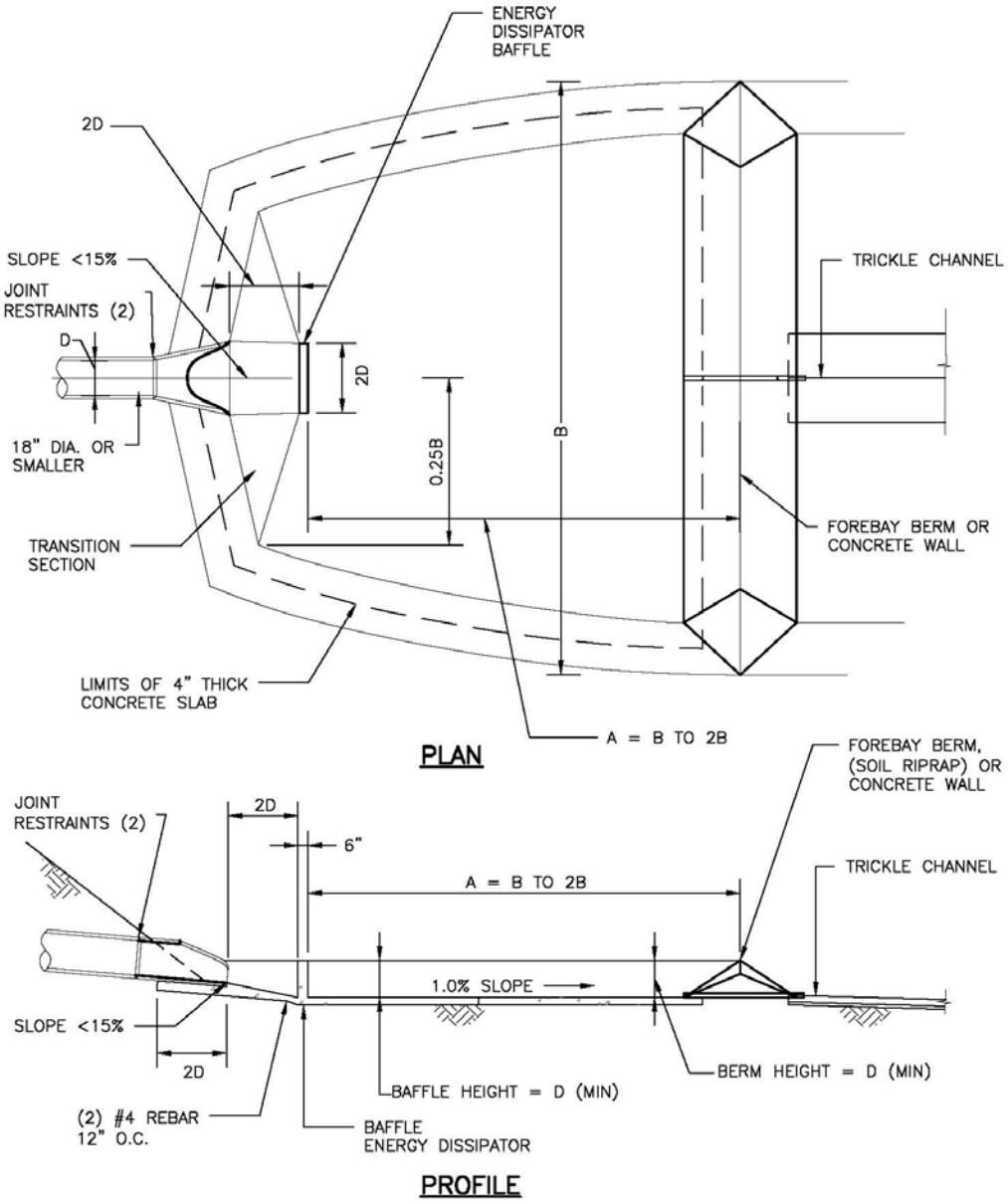


Figure 9-42. Impact stilling basin for pipes smaller than 18" in diameter

(Source: City and County of Denver 2006)

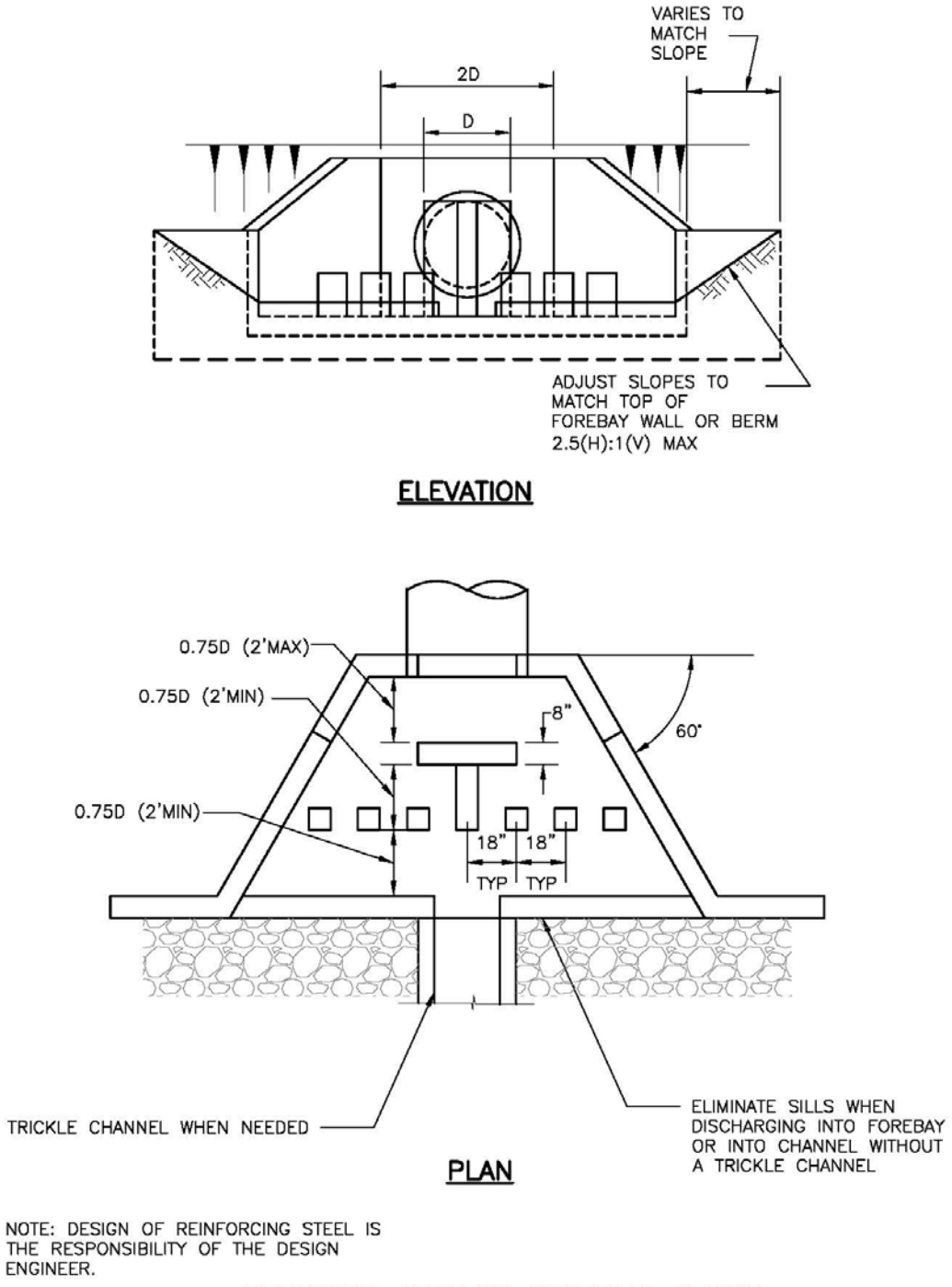


Figure 9-43. Modified impact stilling basin for conduits 18” to 48” in diameter (Part 1 of 2)

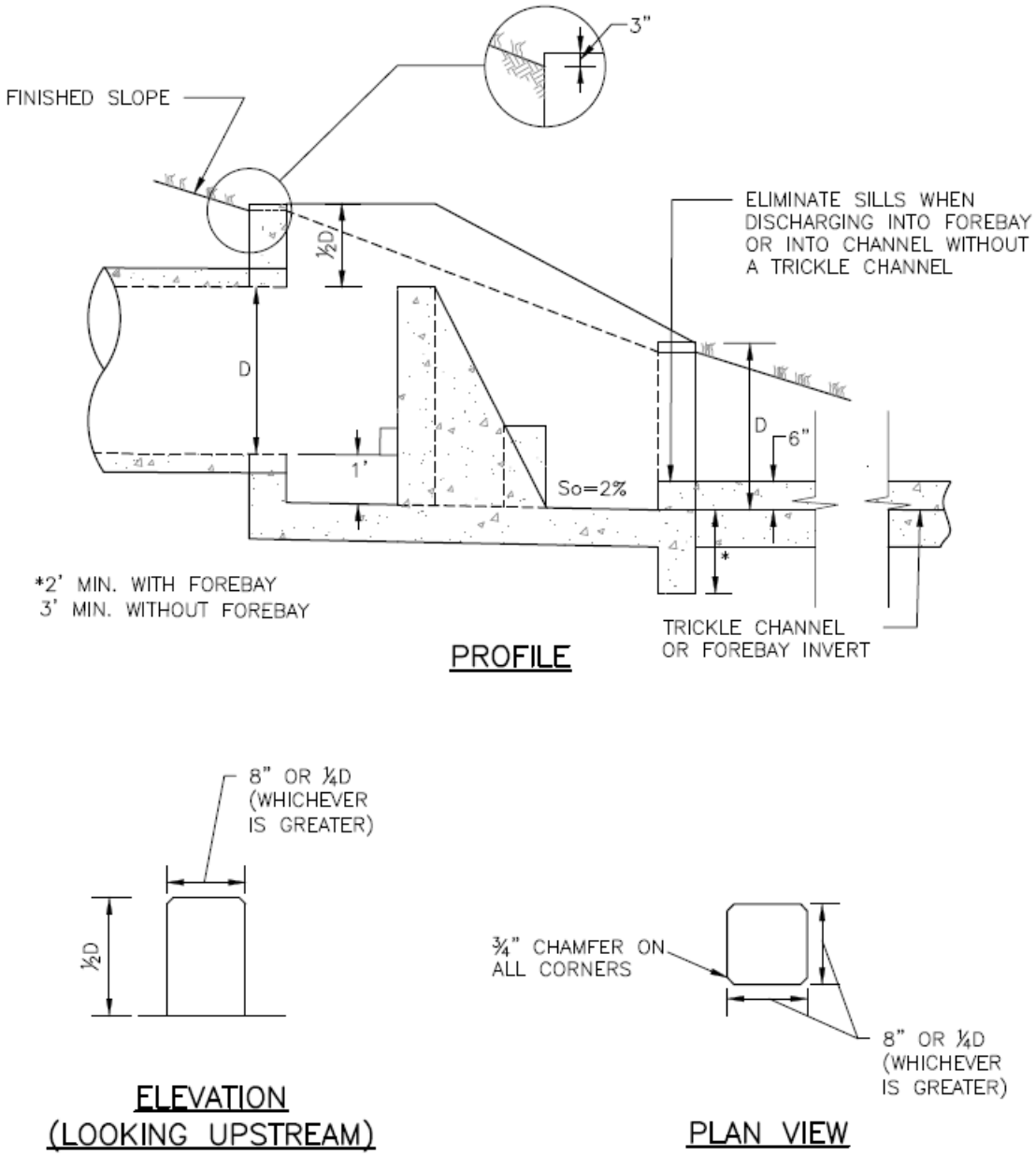


Figure 9-44. Modified impact stilling basin for conduits 18" to 48" in diameter (Part 2 of 2)

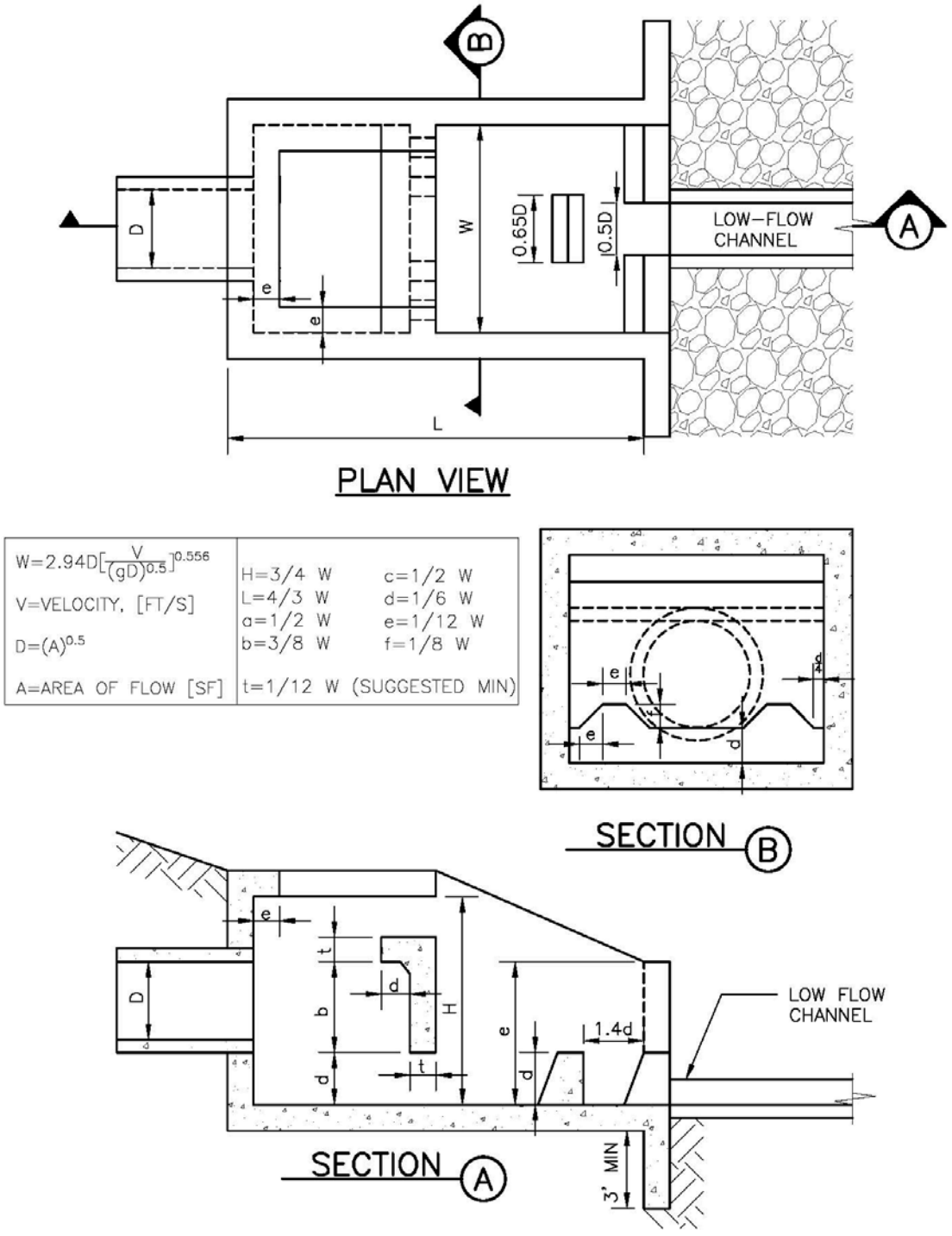
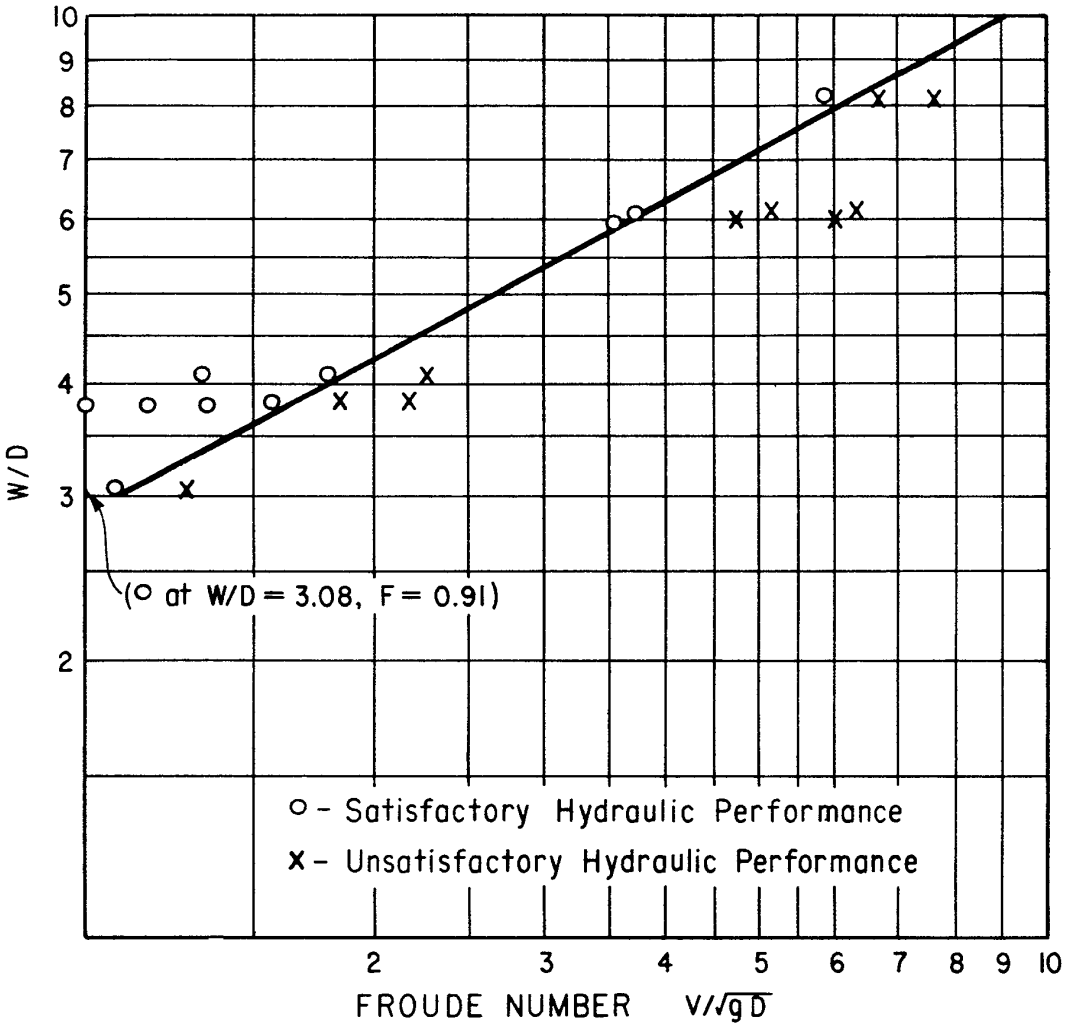


Figure 9-45. UDFCD modified USBR type VI impacts stilling basin (general design dimensions)



"W" is the inside width of the basin.
"D" represents the depth of flow entering the basin and is the square root of the flow area at the conduit outlet.
"V" is the velocity of the incoming flow.
The tailwater depth is uncontrolled.

Figure 9-46. Basin width diagram for the USBR type VI impact stilling basin

3.2.5 Rundowns

Rundowns are used to convey storm runoff from the bank of a channel to the invert of an open channel. Rundowns can also convey runoff from streets and parking lots into channels or storage facilities. The use of rundowns is discouraged due to their high rate of failure and resulting unsightly structures that become a maintenance burden. The preferred alternative is to spread flows over the embankment using a level spreader. See the Grass Buffer Fact Sheet located in Chapter 4 of Volume 3 for guidance on level spreaders. If the flow is too great to be distributed and conveyed down the slope of an open channel, use a pipe to convey flows closer to the invert of the stream or use a drop structure. For both of these options, provide adequate erosion protection at the downstream end.

In the case when a rundown is the only viable option, use the following design criteria.

Design Flow
The rundown should be designed to carry the full design flow of the tributary area upstream (see *Runoff* chapter), or 1 cfs (assuming critical depth) with freeboard, whichever is greater.

Cross Section
Construct the rundown with grouted boulder invert and edge treatment. The top of edge treatment should be flush with proposed grade. Ensure a minimum of 1 foot of freeboard from the calculated design flow depth from the invert to the top of the grouted boulders. Do not use riprap or soil riprap rundowns as they frequently fail.

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Appendix A. Force Analysis for Grade Control Structures

Each component of a drop structure has forces acting upon it that require evaluation. This section describes the general forces, with the exception of forces on riprap for which the reader is referred to Isbash 1936; Oliver 1967; Smith 1975; Smith and Strung 1967; Stevens 1976; Taggart 1984; Abt 1986 and 1987; WittIer and Abt 1988; Maynord and Ruff 1987; Richardson 1988; and LSA 1986 and 1989. It is worth noting that the boulders are subject to all of the usual forces plus the hydrodynamic forces of interflow through voids and related pressure fluctuations. A complete presentation of forces acting on riprap and boulders is not presented herein. Forces are described here, as they would apply to sloping grouted boulder and reinforced concrete drop structures.

The various criteria for structural slab thicknesses given for each type of drop structure have generally taken these forces into consideration. It is the user's responsibility to determine the forces involved.

Five location points are of concern. Point 1 is downstream of the toe, at a location far enough downstream to be beyond the point where the deflection (turning) force of the surface flow occurs. Point 2 is at the toe where the turning force is encountered. Point 3 is variable in location to reflect alternative drain locations. When a horizontal drain is used, Point 3 is at a location where the drain intercepts the subgrade of the structure. Point 4 is approximately 50% of the distance along the drop face. Point 5 is at a point underneath the grout layer at the crest and downstream of the cutoff wall.

Point 3 is usually the critical pressure location, regardless of the drain orientation. In some cases, Point 1 may also experience a low safety factor when shallow supercritical flow occurs, such as when the jump washes downstream.

Seepage uplift is often an important force controlling structure stability. Weep drains, the weight of the structure, and the water on top of the structure counteract uplift. The weight of water is a function of the depth of flow. Thus, greater roughness will produce deeper flow resulting in greater weight.

Shear Stress

The normal shear stress equation is transformed for unit width and the actual water surface profile by substituting S_e, the energy grade line slope for S_o, the slope of the drop face.

$$\tau = \gamma y S_e \qquad \text{Equation A-1}$$

Where:

τ = shear stress (lbs/ft^2)

γ = specific weight of water (lbs/ft^3)

y = depth of water at analysis point (ft)

Buoyant Weight of Structure

Each design should take into consideration the volume of grout and rock or reinforced concrete and the density of each. In the case of reinforced concrete, 150 pounds per cubic foot can be used as the specific weight (or 88 pounds per cubic foot net buoyant weight). Specific weight of rock is variable depending on the nature of the material.

Impact, Drag and Hydrodynamic Lift Forces
Water flowing over the drop will directly impact any abrupt rock faces or concrete structure projections into the flow. Technically, this is considered as a type of drag force, which can be estimated by equations found in various references. Impact force caused by debris or rock is more difficult to estimate because of the unknown size, mass, and time elapsed while contact is made. Therefore, it is recommended that a conservative approach be taken with regard to calculating water impact (drag force), which generally will cover other types of impact force. Specialty situations, where impact force may be significant, must be considered on an individual basis. In addition, boulders and riprap are subject to hydrodynamic lift forces (Urbonas 1968) that are caused by high velocities over the top of the stones and the zones of separation they create, resulting in significant reduction in pressure on the top while hydrostatic pressure remains unchanged at the stone's bottom.

Turning Force
A turning force impacts the basin as a function of slope change. Essentially, this is a positive force countering uplift and causes no great stress in the grouted rock or reinforced concrete. This force can be estimated as the momentum force of the projected jet area of water flowing down the slope onto the horizontal base and calculating the force required to turn the jet.

Friction
With net vertical weight, it follows that there would be a horizontal force resisting motion. If a friction coefficient of 0.5 is used and multiplied by the net weight, the friction force to resist sliding can be estimated.

Frost Heave
This value is not typically computed for the smaller drop structures anticipated herein. However, the designer should not allow frost heave to damage the structure and, therefore, frost heave should be avoided and/or mitigated. In reinforced concrete, frost blankets, structural reinforcing, and anchors are sometimes utilized for cases where frost heave is a problem. If gravel blankets are used, then the seepage and transmission of pressure fluctuations from the hydraulic jump are critical.

Seepage Uplift Pressure
As explained previously, uplift pressure and seepage relief considerations are critical to structural stability and usually of greater concern than the forces described above. There can be troublesome pressure differentials from either the upstream or downstream direction when there is shallow supercritical flow on the drop face or in the basin. One may consider an upstream cutoff to mitigate this problem. Weep locations with proper seepage control may be provided. For high drop structures (i.e., > 6 feet), more than one row of weep holes may be necessary.

A prudent approach is to use a flow net or other type of computerized seepage analysis to estimate seepage pressures and flows under a structure.

Dynamic Pressure Fluctuations
Laboratory testing (Toso 1986; Bowers and Toso 1988) has documented that the severe turbulence in a hydraulic jump can pose special problems often ignored in hydraulic structures. This turbulence can cause significant positive and negative pressure fluctuations along a structure. The key parameter is the coefficient of maximum pressure fluctuation, $C_{p\text{-}max,}$ which is in terms of the velocity head of the supercritical flow just upstream of the jump:

$$C_{p-\max} = \frac{\Delta P}{\left(\frac{V_u^2}{2g}\right)} \qquad \text{Equation A-2}$$

Where:

ΔP = pressure deviation (fluctuation) from mean (ft)
V_u = incident velocity (just upstream of jump) (ft/sec)
g = acceleration of gravity (ft/sec^2)

Effectively, C_P is a function of the Froude number of the supercritical flow. The parameter varies as a function of X, which is the downstream distance from the beginning of the jump to the point of interest.

Dynamic Pressure Fluctuation Example

A good example of this is when an entire sloping face of a drop is underlain by a gravel seepage blanket. The gravel could be drained to the bottom of the basin or other locations where the jump will occur. In such a case, the positive pressure fluctuations could be transmitted directly to the area under the sloping face, which then could destabilize the structure since there would not be sufficient weight of water over the structure in the area of shallow supercritical flow.

Table 9-6 presents recommended $C_{p\text{-}max}$ positive pressure values for various configurations. When the Froude number for the design case is lower than those indicated, the lowest value indicated should be used (do not reduce on a linear relationship) for any quick calculations. The values can be tempered by reviewing the C_p graphs, a few of which are given in Figures A-1 and A-2. Note that the graphs are not maximum values but are the mean fluctuation of pressure. The standard deviation of the fluctuations is also indicated, from which the recommended $C_{p\text{-}max}$ values were derived.

Figure A-1 illustrates positive and negative pressure fluctuations in the coefficient, C_p, with respect to the location where the jump begins at the toe. Figure A-2 presents the positive pressure fluctuation coefficient where the jump begins on the face.

For the typical basin layouts given and where the drains are at the toe and connect directly to the supercritical flow, these pressure fluctuations should not be of great concern. However, when drains discharge to the jump zone and could transfer pressure fluctuations to areas under supercritical flow, pressure fluctuations are of concern.

Table 9-6. Nominal limit of maximum pressure fluctuations within the hydraulic jump (Toso 1986)

Jump Condition	Froude Number	Suggested Maximum C_p
0° slope, developed inflow (boundary layer has reached surface)	3.0	1.0
30° slope, toe of jump at base of chute[1]	3.8	0.7
30° slope, toe of jump on chute[1]	3.3	0.8

[1] Velocity head increased by elevation difference between toe of jump and basin floor, namely, depth at the drop toe.

Overall Analysis

All of the above forces can be resolved into vertical and horizontal components. The horizontal components are generally small (generally less than 1 psi) and capable of being resisted by the weight of the grout, rock, and reinforced concrete. When problems occur, they are generally the result of a net vertical instability.

The overall (detailed) analysis should include reviews of the specific points along the drop structure and the overall drop structure geotechnical and structural stability. All steps of this detailed analysis are not necessary for design of drop structures along modest capacity grass-lined channels, provided that the design is developed using the guidelines and configurations presented in the following simplified analysis approach section and that other USDCM criteria are met. The critical design factors are seepage cutoff and relief and pressure fluctuations associated with the hydraulic jump that can create upward forces greater than the weight of water and structure over the point of interest. Underflow can easily lift a major slab of rock and grout and, depending upon the exposure, the surface flow could cause further weakening, undermining, or displacement. Generally, a 30-pound net downward safety allowance should be provided, and 60 pounds is preferred. An underdrain is generally needed to prevent hydrostatic uplift on the stones.

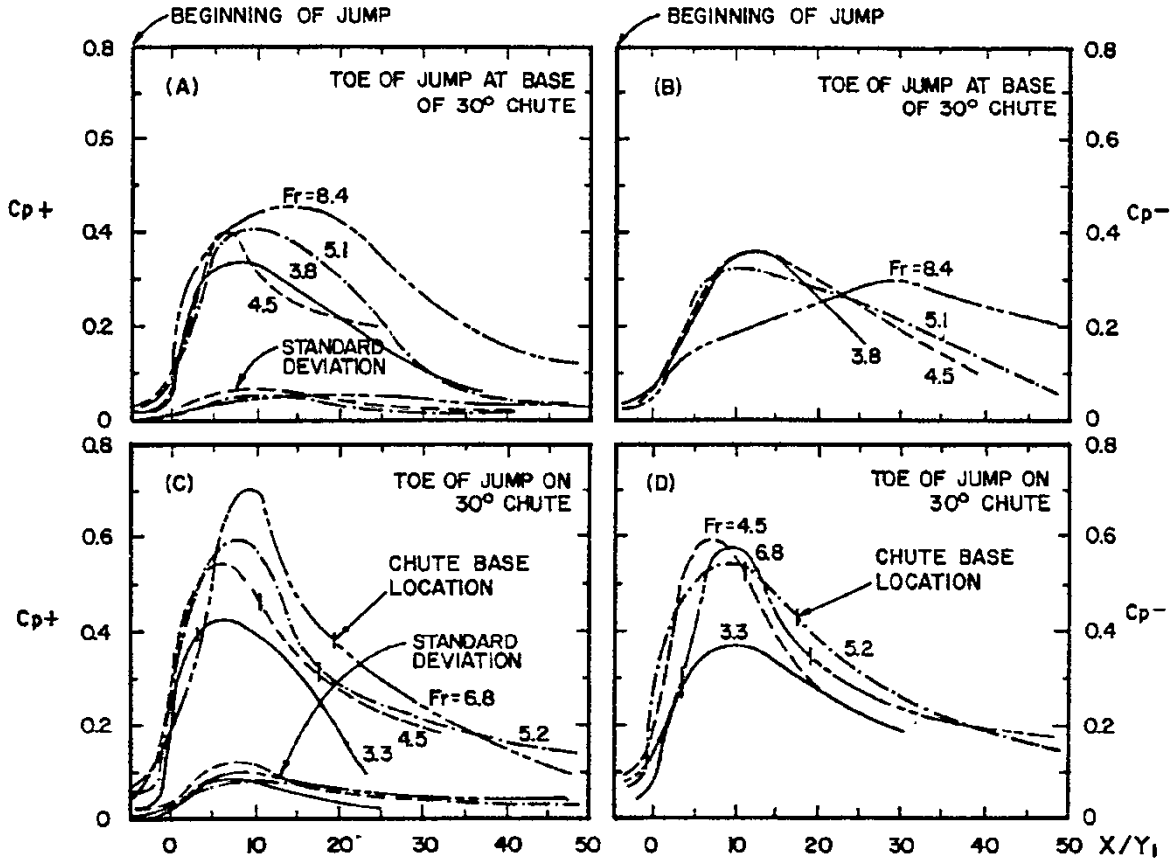

Figure A-1. Coefficient of pressure fluctuation, Cp, at hydraulic jump

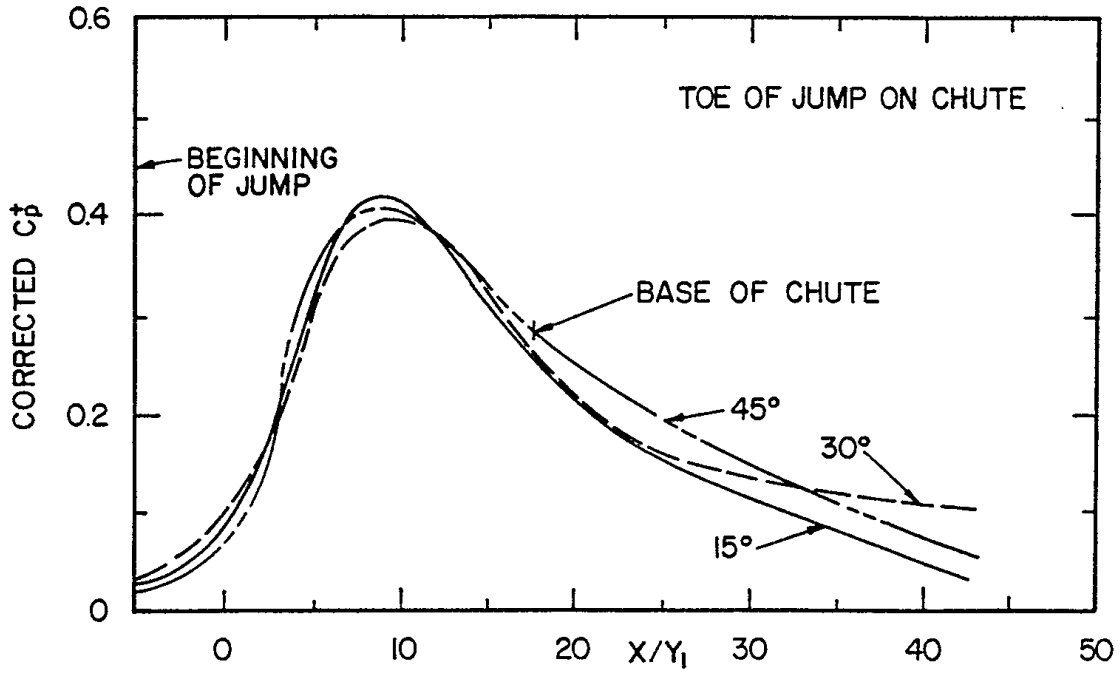

Figure A-2. Coefficient of pressure fluctuation, Cp, normalized for consideration of slope and jump beginning slope

Chapter 10
Stream Access and Recreational Channels

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1.0 Introduction and Overview

When channels are readily accessible to the public, public safety must be a primary design objective. The term "recreational channels" refers to all open channels that are readily accessible to the public. The planning, design, and construction of recreational channels should provide safe public access and use to all accessible areas. Unintended entry into the water by the public should also be considered during the planning and design phase. This chapter is relevant to virtually all open channels in urban areas and is largely focused on safety.

This chapter provides criteria and guidance for design of special structures, such as drop structures and pedestrian crossings, as well as larger scale considerations such as egress and signage for the length of a reach. It covers design of shared use paths, equestrian trails, low-flow crossings, underpasses, cross drainage and other considerations specific to paths adjacent to streams. This chapter also provides criteria for recreation channels that are also considered to be "boatable."

Boatable channels represent a subset of recreational channels. Channels should be planned and designed to address public safety issues related to this use when they are considered to be boatable or this use is planned for the future or when the channel is classified by the Colorado Water Quality Control Commission as having existing or potential "primary contact use."

Some boatable channel criteria may also be appropriate for recreational channels where boating does not typically occur. The degree of this consideration will depend on issues such as:

- Level of activity around the water's edge both for current conditions and anticipated future uses,
- Frequency and range of flows within the recreational channel, and
- Potential consequences of accidentally falling into the water (low water and high water conditions).

2.0 Public Safety Project Review

As an increasing number of design professionals and developers promote the natural and beneficial functions of the floodplain, encouraging passive recreation in the floodplain and drawing people toward the water's edge, public safety becomes even more critical. This chapter focuses largely on to public safety issues, providing detailed criteria in Sections 3.0 and 4.0 for areas designed for some level of use by the public. This section, including the inset on the next page, is intended to identify when a comprehensive public safety review for a project is recommended and to guide the engineer and owner on key public safety issues. The safety criteria provided in the inset are additional to criteria provided in Sections 3.0 and 4.0 of this chapter. The *Public Safety Guidance for Urban Stormwater Facilities* (ASCE 2014) is also a good resource for public safety.

Although the engineer should consider public safety throughout the design process, the following siting and design components should trigger a comprehensive project review for public safety:

- Projects in densely populated areas and with populations that may require specific site requirements (e.g., high populations of children or elderly);
- Projects adjacent to schools, playgrounds, or within a public park;
- Projects designed with the intent to draw the public toward water,
- Drop structures taller than 3 feet from crest to stilling basin floor,
- Vertical drop structures of any height,
- Walls (including boulder walls and channel edging) exceeding 3 feet,
- Channel side slopes steeper than 4:1,
- Detention basins and outlet structures,
- Retention ponds and outlet structures,
- Inlets to storm drains and long culverts,
- Below grade paths, and
- Low-flow crossings.

The following considerations may be helpful when conducting this review:

- At what locations and with what frequency might a person become trapped by flood water?
- At what locations could signage be beneficial to public safety?
- What dry weather and wet weather risks exist in the project area?
- What locations present potential fall hazards during dry weather, wet weather, or when snow or ice is present?
- Do maintenance personnel have safe access to all required areas?
- How will channel degradation impact safety associated with various elements of the project?

Public safety criteria found elsewhere in the Urban Storm Drainage Criteria Manual (USDCM):

From the Open Channels Chapter:

Channel side slopes steeper than 2.5H:1V are considered unacceptable under any circumstances because of stability, safety, and maintenance considerations.

From the Hydraulic Structures Chapter:

Drop faces should have a longitudinal slope no steeper than 4(H):1(V). The formation of overly retentive hydraulics is a major drowning safety concern when constructing drop structures. Longitudinal slope, roughness and drop structure shape all impact the potential for dangerous conditions.

When designing [underground conveyance] systems with flared-end sections that are larger than 36 inches in diameter, pedestrian railing may be warranted if public access will occur. If this is the case, railing can be more easily mounted to a combination headwall/wingwall.

It is important to note that vertical [drop] structures can cause dangerous hydraulic conditions, including keeper waves, during wet weather and are generally discouraged. In addition, vertical drop structures are to be avoided due to impingement energy, related maintenance and turbulent hydraulic potential (ASCE and WEF 1992).

Vertical drops are not appropriate where fish passage is needed, design flow (over the length of the drop) exceeds 500 cfs or a unit discharge of 35 cfs/ft, net drop height is greater than 2 feet, or the stream is used for boating or there are other concerns related to in-channel safety.

From the Culverts and Bridges Chapter:

Based on UDFCD investigations of culvert and storm drain deaths, safety grating should be required when any of the following conditions are or will be true:

- It is not possible to "see daylight" from one end of the culvert to the other,
- The culvert is less than 42 inches, or
- Conditions within the culvert (bends, obstructions, vertical drops) or at the outlet are likely to trap or injure a person.

From the Storage Chapter:

The use of retaining walls within detention basins is generally discouraged due to the potential increase in long-term maintenance access and costs as well as concerns regarding the safety of the general public and maintenance personnel. Where walls are used, limit the length of the retaining walls to no more than 50 percent of the basin perimeter. Also, consider potential fall hazards associated with pedestrians, cyclists, and vehicles in determining the appropriate treatment between a sidewalk, path, or roadway and the top of the wall. Considerations include distance from the public to the wall, curvature of the path or roadway, single or terraced walls, and volume of traffic.

Potential solutions include dense vegetation, seat walls, perimeter fencing, safety railing and guardrail. In some cases walls less than 2 feet will warrant a hard vertical barrier; in other cases a 3 foot wall may be the point at which this barrier is appropriate. Check requirements of the local jurisdiction. UDFCD recommends providing a hard vertical barrier in any location where walls exceed 3 feet.

It should also be noted that retention ponds pose a greater risk to the public compared to detention basins and should be evaluated for unintentional entry by the public.

3.0 Shared-Use Paths Adjacent to Streams

This section provides guidance for shared use paths and equestrian trails, low-flow crossings, underpasses, cross drainage, and other considerations specific to paths adjacent to streams. Paths are an integral part of recreational channels, providing access for the public and channel maintenance. Paths are typically also part of the active conveyance area for the channel during a flood. When available, adhere to local jurisdiction shared-use path design criteria in addition to this section. The AASHTO Guide for Development of Bicycle Facilities is also an excellent reference and guidance and conformance to these criteria is frequently required for federally funded projects. Where criteria conflict, adhere first to local jurisdiction criteria, then this manual, followed by the AASHTO guide (when appropriate).

Additional Resources for Path Design

- AASHTO Guide for the Development of Bicycle Facilities
- National Trails Training Partnership website
- NACTO Urban Bicycle Design Guide
- www.bicyclinginfo.org
- Iowa Water Trails Toolkit, Iowa Department of Natural Resources FHWA Designing Sidewalks and Trails for Access
- FHWA Evaluation of Safety, Design, and Operation of Shared-Use Paths
- Architectural Barriers Act (ABA) Accessibility Standards
- Americans with Disability Act (ADA) Standards for Accessible Design

3.1 Path Use

Paths are often constructed along streams to provide access for maintenance vehicles. However, if public access is provided to the path, it should be assumed that the path will be used by the public. For this reason, it is important to design paths with the health, safety, and welfare of the public as a primary design objective. It is also important to evaluate when it is appropriate for a path to conform to accessibility criteria. Accessibility is a requirement for all paths described in this section with few exceptions (e.g., a gated section of path not intended for any public use). Depending on the design, users may include bicyclists, pedestrians, runners, equestrians, dog walkers, people with baby carriages, people in wheelchairs, skate boarders, and others. Not all paths will be designed for all of these users, but the following can be considered when determining type of use of the path:

- Does this segment of path fit into an existing master plan where use has been determined?
- What connections are made with the path? Who are the likely users?
- How can the path best provide continuity between its connection points? Alternating segments (in regard to intended use, material, or geometry) should be minimized.

Determining the expected types of path users expected will help in establishing geometry, selecting construction materials and techniques, and understanding safety considerations.

3.2 Frequency of Inundation

Photograph 10-1. Frequently inundated channels pose a high threat to public safety, especially in a walled channel where water can rise rapidly and egress is limited.

The frequency of inundation is one of the most important considerations for the design of a path adjacent to a stream. This criterion directly affects safety and maintenance and frequently impacts cost, conveyance capacity, and the users' path experience. Less frequent inundation is better from a safety and maintenance perspective. The public safety threat is especially high in channels susceptible to flash flooding and where egress from the channel section is limited (e.g., walled channels). Frequently inundated paths also require more frequent maintenance due to sediment deposit on the path surface and erosion at the path edges.

Photograph 10-2. Sediment frequently accumulates under crossings. Frequently inundated paths collect sediment and are maintenance-intensive.

Removal of sediment after runoff events typically involves collection and disposal of sediments. Washing the sediment back into the channel would violate typical MS4 permit requirements. Additionally, sediment deposition between the channel and the path can impede drainage away from the path and result in water or ice on the path. Paths constructed with new channel or roadway improvements should be constructed above the 5-year water surface elevation or higher. For highly used paths an elevation above the 10-year water surface elevation is preferred.

For a retrofit project, the same standards should be met when practical; however, existing conditions may not allow this for the entire length of the path. In this case UDFCD strongly recommends that the design elevation remain above the 2-year water surface elevation at all locations. Changes in channel section can occur over time resulting in the increased frequency of overtopping in the future. For this reason, it is also good practice to set the surface of the path a minimum of two feet above the estimated base flow elevation. When existing conditions do not allow for a path elevation meeting either of these two criteria, consider alternative alignments.

Exceptions to the above criteria may be appropriate in the area of a low-flow stream crossing where the crossing could be designed to pass up to a 2-year event before overtopping. This should be evaluated on a case-by-case basis taking into consideration frequency of use and the importance of the crossing as a path connection component. Benefits of constructing a low-flow crossing include conserving flood capacity for higher flows, improving user experience by bringing the user in closer contact with the stream, and potentially eliminating railing that could otherwise catch debris, become a maintenance issue, and further impact the floodplain. However, low-flow crossings have attendant safety risks of their own. See Section 3.6 for additional guidance on stream crossings.

Underpasses, where users frequently seek shelter in a storm event, present a more critical case for public safety as it relates to frequency of inundation. If the geometry of the surrounding area and configuration of the underpass combine to allow the user to see the water and seek higher ground, more frequent inundation may be acceptable. See Section 3.4 for additional guidance on underpasses.

Frequency of inundation criteria for paths is summarized in Table 10-1. Further discussion specific to path underpasses and stream crossings is provided in Sections 3.4 and 3.5.

Table 10-1. Frequency of inundation criteria summary

Path Type	Recommended Elevation (when practicable) (water surface elevation)	Minimum Elevation (water surface elevation)	Other Considerations
Stream Crossings	2 to 5-year	2-year	
Bridge Underpass	5-year	2-year	
Culvert Underpasses less than 100 feet in length	5-year	2-year	The user should be able to see when water is rising and climb to safety.
Culvert Underpasses greater than 100 feet in length	10-year	5-year	The culvert should be straight. The user should be able to see when water is rising and climb to safety.
All Other Locations (New)	10-year	5-year	Elevating the path to the 10-year WSE is preferred.
All Other Locations (Retrofit)	5-year	2-year	Where practicable also elevate the path two feet above the baseflow.

3.3 Path Geometry

3.3.1 Typical Sections

The minimum recommended width for a path that facilitates light maintenance vehicles is ten feet. A reduced width typically results in edge damage from maintenance vehicles. This is also consistent with AASHTO's width recommendations for two-directional shared-use paths. In many cases it may be desirable to increase the width to 12 or even 14 feet to accommodate conflict points or when high volumes of users are anticipated. In very high-use areas multiple treads allow separation of uses that might conflict. An example of this is where the South Platte River path meets that of Cherry Creek. Within Confluence Park, users on foot and those on wheels are split on either side of the water. In the extremely high use area of Confluence Park where different users are not separated, the path is widened to 14 feet and all railing includes rub rails (see photo 10-22). Rub rails on bridges are horizontal members that help mitigate injury to cyclists crashing into them.

Trail Conflict Points

Trail conflict points include underpasses, trail intersections, blind corners, areas with steep grade and other locations where an accident between users is more likely to occur.

These areas require special consideration. Depending on the scenario, the following could be added to reduce the probability of or resulting damage from an incident:

- Railing
- Yellow Striping (indicating separation between two-directional users)
- Increased trail width
- Signage
- Wide-angle Mirrors
- Signals Lights

On each side of the path the adjacent grade (shoulder) should be no steeper than 6(H):1(V) for a minimum width of two feet. This is regardless of the edge treatment and provides a place for the user to safely move off the path and also protects the path from potential damage due to adjacent sloughing grade. Sloughing grade adjacent to the path can eventually undermine the path or cause a rumble strip to become separated from the path. It is best to provide a section in the construction drawings that shows the shoulder and specifically calls out for backfilling the sides of the path. When the site does not allow for a shoulder, a thickened edge (see Figure 10-1) can protect the path from being undermined and allow maintenance personnel time to identify and repair the problem.

Photograph 10-3. Signing and striping help segregate bicyclists and pedestrians at Confluence Park where the two treads are separated by the creek.

In some cases (see Table 10-2), a safety rail parallel to the path is recommended. Rails are appropriate where a dangerous condition would otherwise exist. Common locations include steep side slopes, vertical walls, steep longitudinal slopes, bends, areas where cross drainages create isolated hazards, and where combinations of the above circumstances exist.

3.3.2 Use of Rails, Curb Rails, and Rumble Strips

Rails, curb rails, rumble strips, increased path width, changes in texture and/or color, signage and striping are all tools that can be used to improve path safety and heighten user awareness of a new or changing condition. For the purpose of these criteria the term "edge treatment" refers to rails, curb rails, and rumble strips. All above-grade stream crossings should include an edge treatment. For all edge treatments, increase the width of the path (in addition to the width of the approaching path) to allow for placement of the treatment. See Figure 10-2 for rumble strip details. When using rails (curb rails or full rails), provide a minimum of one foot clear beyond the edge of the approaching path to the rail. See Table 10-2 for a summary of recommendations and Figures 10-2 through 10-8 for plan views and sections.

Photograph 10-4: Rumble strips warn the user of the path edge without reducing capacity for flood flows. Photo Courtesy Architerra Group.

Use of full rails (typically 42 inches when bicyclists are anticipated and 54 inches when the path provides equestrian passage) can cause adverse flooding conditions and should only be used when a curb rail or rumble strip does not provide an acceptably safe condition for the user. When rails are used, the hydraulic model should consider the full area of the rail to be clogged with debris. Based on the experience of UDFCD, "break-away" rails which are designed to collapse during high flow, are often ineffective over time and should not be relied on for floodplain analysis (i.e., they too should be modeled as fully blocked).

Photograph 10-5. Most of the "break-away" rails on this crossing failed to break despite the capacity lost to debris.

Photograph 10-6. Curb rails are typically no higher than 12 inches and can be constructed from a variety of materials.

Table 10-2. Edge treatment criteria summary

Path Type	Difference in elevation from path surface to adjacent grade (design[1])	Edge Treatment
Paths perpendicular to the stream or in an underpass	Up to 36 inches	Rumble strip or curb rail
	up to 54 inches	Curb rail[2]
	Greater than 54 inches	Full rail[3] (typically 3'-6" inches for shared use and 4'-6" for equestrian)
Paths parallel to the stream and not in an underpass	Up to 36 inches	Rumble strip
	Greater than 36 inches or adjacent slope steeper than 3:1[3]	Full rail[3] (typically 42 inches for shared use and 54 inches for equestrian)

[1] Values provided assume that differences in elevation following construction may potentially increase in some areas by up to 20% due to stream degradation.
[2] Model flooding effects with rail fully clogged.
[3] Span 100-year floodplain (preferred) or model flooding effects with rail fully clogged.
[4] Adjacent slope refers to slope adjacent to the 2-foot shoulder.

Photograph 10-7. Horizontal members are placed on the users' side of the posts. This is an important consideration for both shared- use paths and equestrian trails in that it reduces the chance of snagging clothing, a bike pedal or a stirrup.

Photograph 10-8. At Confluence Park a rub rail was included as part of the rail design. This, in addition to the 14-foot path width, improves safety in this high-use area.

Considerations for Designing Safety Rails

- Minimize the likelihood of the rail catching debris. This is a maintenance issue and, if not maintained, can reduce capacity in the stream and cause flooding or damage to the safety rail
- Place horizontal members on the users' side of the posts. This provides a safer surface, less likely to catch clothing, a bike pedal, or a stirrup.
- Provide a rail height of at least 42 inches when cyclists are anticipated and 54 inches when the trail provides equestrian passage.
- Consider snow removal either by designing the rail to allow movement of snow through the bottom of the rail (without creating a safety hazard for small children) or by planning for snow storage in an alternate location.

Photograph 10-9. Striping used sparingly can be effective in alerting the user of a safety concern. In this photo, it is used where the path approaches a crossing.

Photograph 10-10. Along this section of the South Platte River, the combination of a steep longitudinal slope, a cross drainage structure, and a steep slope from the path to the water warranted both a safety rail and striping.

3.3.3 Path Overtopping Protection

Provide adequate protection to avoid damage caused when flows overtop the path. As a path turns perpendicular to the stream, or anywhere significant overland flows are likely to cross the path (e.g., downstream of side-channel spillways or at undersized culvert crossings), scour can occur along the downstream edge. This causes the path to act like a drop structure. Flows across the path accelerate, potentially damaging the upstream edge of the path, while scour downstream can eventually undermine the path (see Photo 10-11). For these reasons, a thickened edge on both the upstream and downstream sides of a path approaching a low crossing is recommended. The edge should extend a minimum of two feet below the surface of the path (see Figure 10-1). Soil riprap placed adjacent to the path can be used to provide additional protection.

Photograph 10-11. A soil cement path approaching a crossing on Sand Creek is undermined on the downstream side due to overtopping. Overtopping protection was not adequate to stop scour damage before losing a section of the path.

The length of the overtopping protection is site specific. If the bank of the channel is well defined, protection should extend from the crossing into the bank. If the bank is not well defined, extend the protection to a point where the path is more parallel with the stream than it is perpendicular. In either case, the length of overtopping protection typically does not need to extend higher than the 10-year surface elevation.

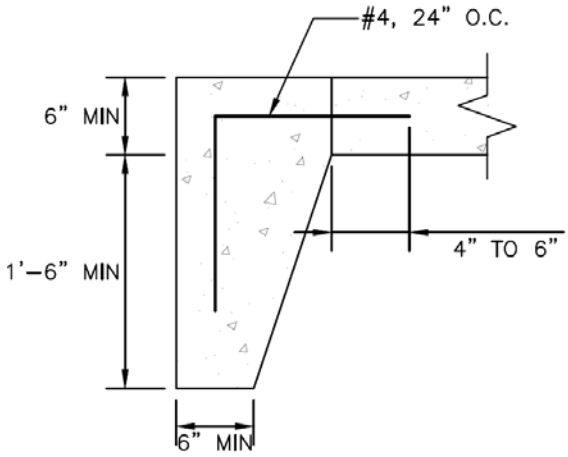


Figure 10-1. Thickened edge detail

3.3.4 Vertical Clearance in an Underpass

Maximizing vertical clearance improves the users' experience on the path. It increases light in underpasses and helps open the area so users do not feel trapped by the walls of a structure. However, increasing vertical clearance can also increase frequency of inundation because often the top elevation of the structure is fixed by the profile of existing utilities or the roadway crossing the stream (i.e., the path must be lowered to increase vertical clearance). In cases where the desired vertical clearance cannot be met without lowering the path to an elevation below the 2-year water surface elevation (at a minimum), the vertical clearance must either be reduced to the minimum allowable clearance in Table 10-3 or an alternative crossing (e.g., at-grade) considered. Ramps up to an at-grade crossing provide a good alternative for the path user (where feasible) and also serve as an escape route during a flash flood.

Table 10-3 provides minimum values for vertical clearance for various types of paths. Minimum values may be lower than those published by local communities within the UDFCD boundary. They are based on the minimum reasonable value for the respective use listed. Always check local criteria and conform to their vertical clearance requirements.

Table 10-3. Path geometry criteria summary

Path Type	Minimum Width (feet)	Minimum Width for High Use or Conflict Areas[3] (feet)	Minimum Vertical Clearance for Consideration[1] (feet)	Typical Minimum Vertical Clearance[2,4] (feet)	Preferred Vertical Clearence[4] (feet)	Typical Materials[5]
Maintenance Only	10	12	8	8	10	Concrete, Reinforced Grass
Hiking trail Only	n/a	n/a	6.67	8	10	Compacted Soil, Crusher Fines[3,] Proprietary Materials
Shared-Use with Bicyclists	10	12 to 14	8	8 to 9	10	Concrete or Proprietary Material
Equestrian	1.5 to 2.5	8	10	10	12 to 14	Grass or Compacted Soil

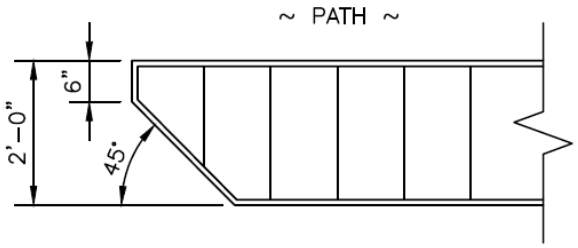
1 Represents the minimum clearance that should be considered.
2 Represents typical minimum criteria common to reviewing agencies and owners.
3 Also recommended where a rail or wall is placed on both sides of the path.
4 Based on review of path criteria for several agencies nationwide. Values will vary based on community.
5 Not intended to be limiting.

3.3.5 Sight Distance

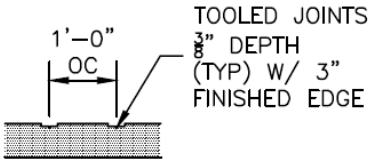
In order to avoid a crash, a cyclist must have time to identify potential conflicts and react accordingly. For all hard paths, or where bicyclists are otherwise anticipated, refer to tables and charts provided in *AASHTO Guide for the Development of Bicycle Facilities* to calculate the appropriate sight distances.

Photograph 10-12. Despite striping and signage, bicyclists frequently speed through the University Boulevard underpass along the Cherry Creek path.

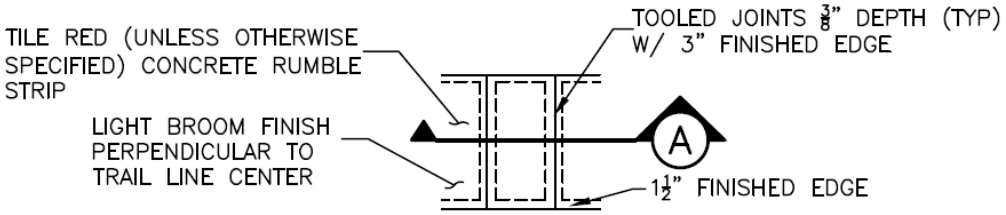
Photograph 10-13. Understanding the popularity of the Cherry Creek path, designers worked to make the underpass at University safe for bicyclists and pedestrians while working within the limitations of the existing site. Land was purchased to create a suitable turning radius at this 90 degree bend. This provides bicyclists with additional time to react to the unexpected.



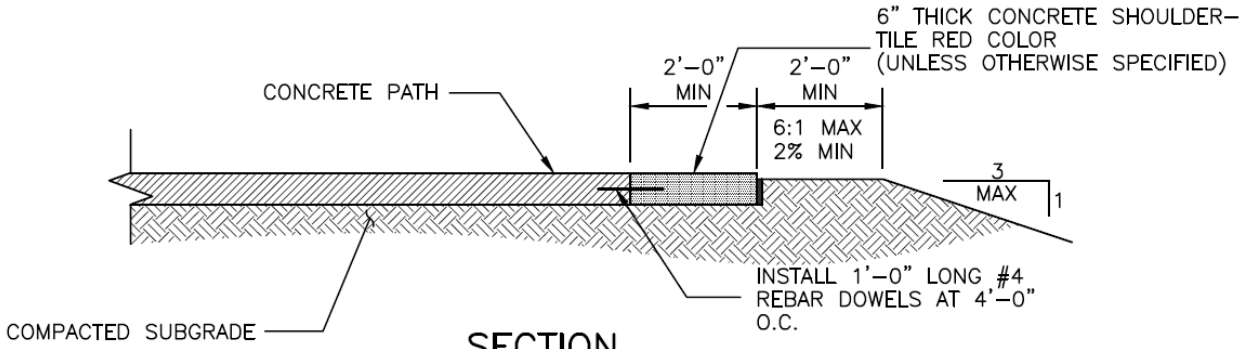
TYPICAL RETURN PLAN



SECTION A



TYPICAL SCORING PLAN



SECTION

RUMBLE STRIP

Figure 10-2. Rumble strip detail

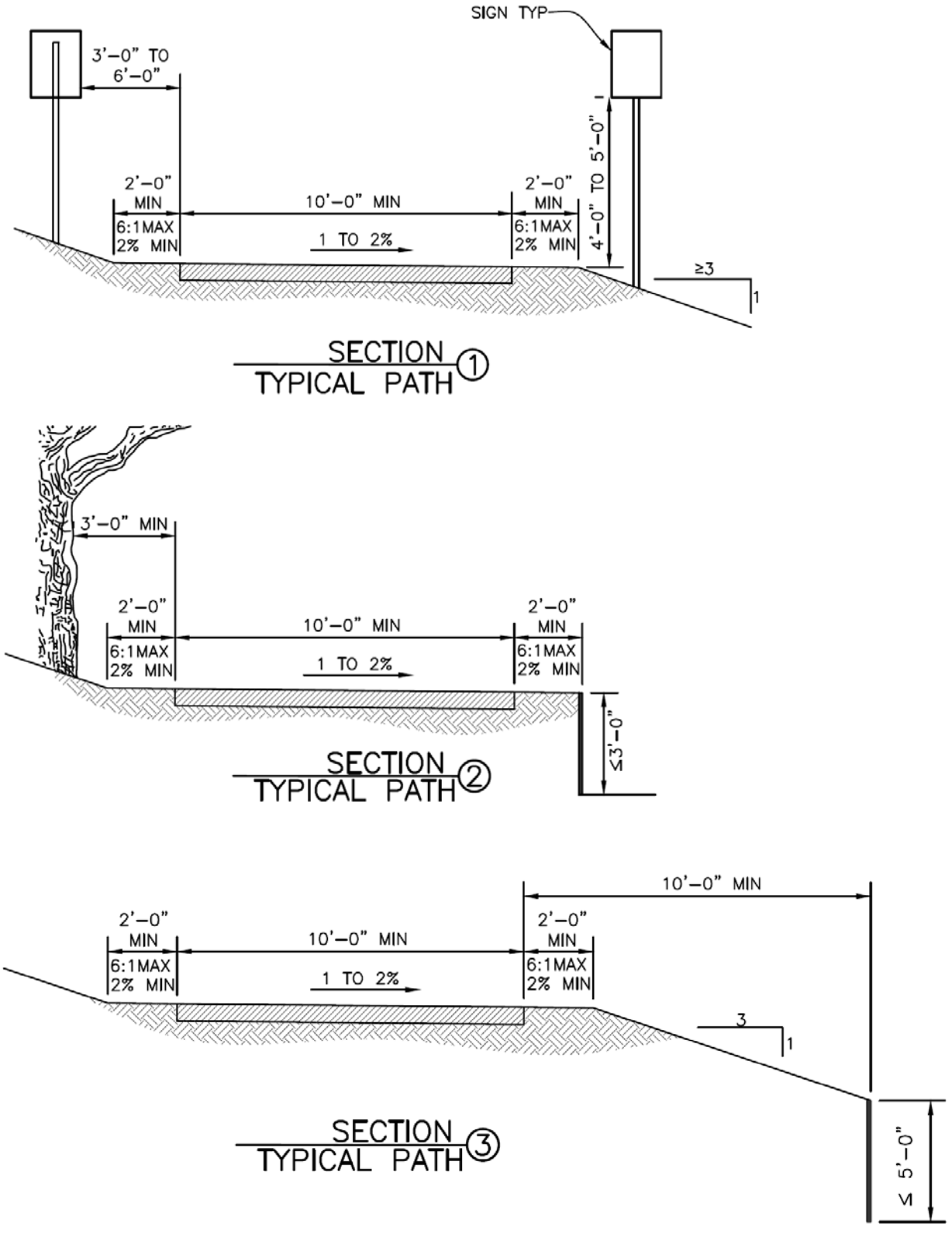


Figure 10-3. Typical path sections 1, 2, and 3.

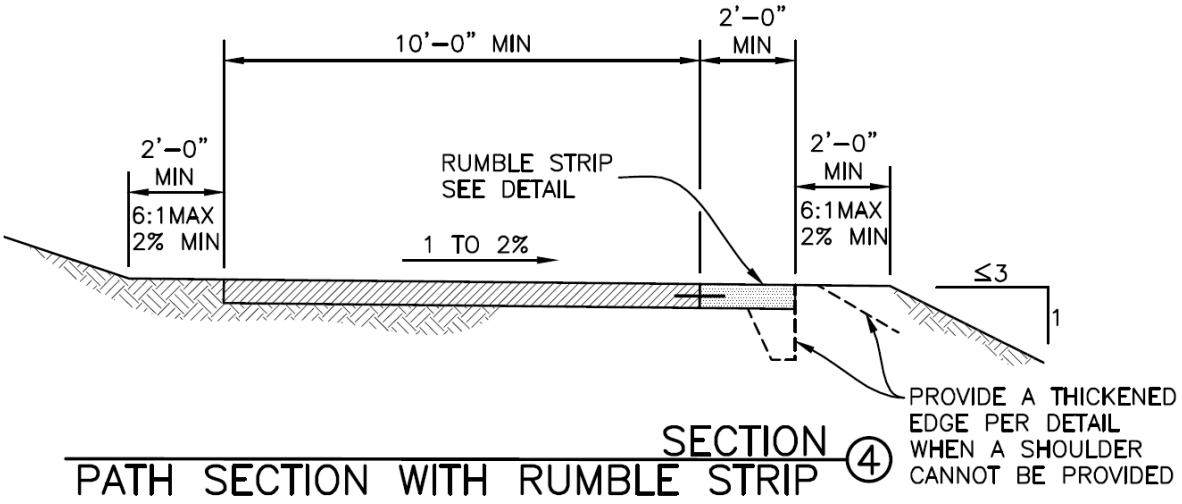


Figure 10-4. Path section with rumble strip

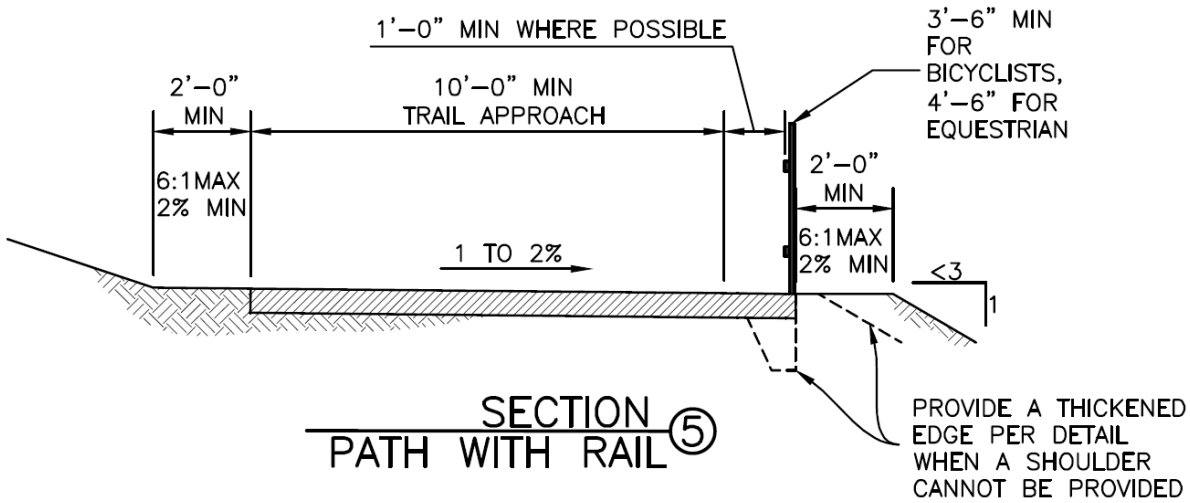


Figure 10-5. Path section with rail

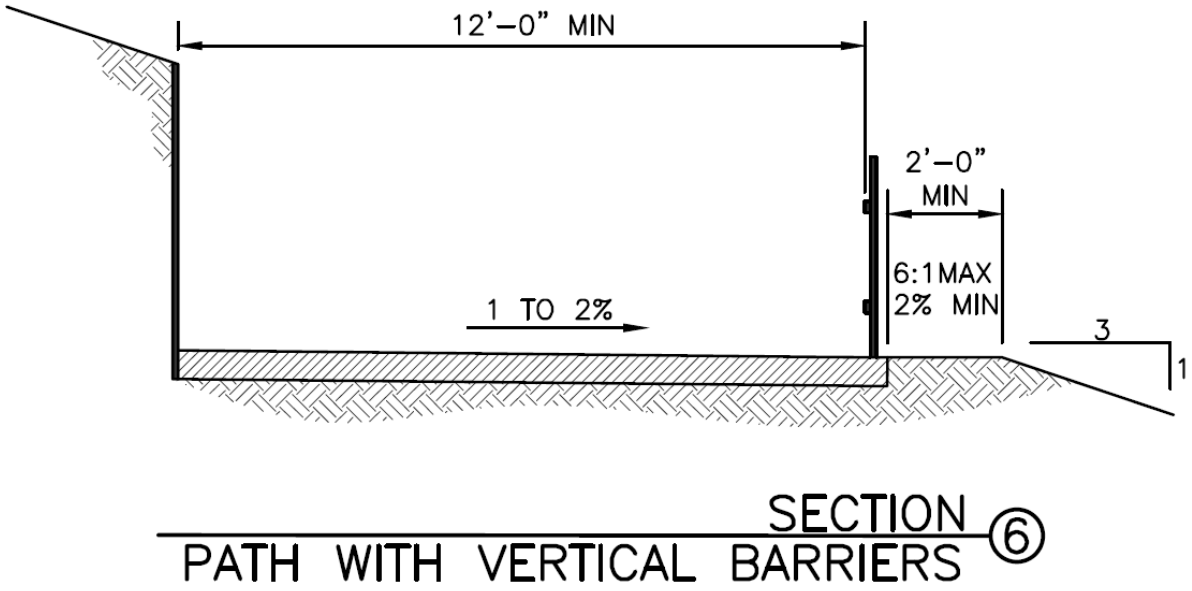


Figure 10-6. Path section with vertical barriers on both sides

3.4 Path Drainage

To avoid nuisance drainage problems, the path should have a cross slope toward the channel. The slope should not exceed two percent to meet accessibility requirements. Typically a cross slope of at least one percent coupled with a longitudinal slope provides adequate drainage. The bench on each side of the path should also be sloped a minimum of 2% to provide adequate drainage and should not exceed a slope of 6(H):1(V).

3.4.1 Cross Drainage

Where outfalls intersect the path, provide culverts below the path to provide conveyance for frequent events. This will minimize disruption of path use and icing. For small outfalls located below the path, a level spreader, in combination with a riparian buffer may also be used to spread low-flows, improve water quality, and benefit vegetation. See the *Grass Swales* Fact Sheet in Chapter 4 of Volume 3 for more information on level spreaders. Similarly, other linear BMPs could also be used to reduce stormwater on the path. Where constraints exist, a chase may be used to keep frequent flows off the path. Be aware that chases tend to clog with leaves, trash, and other debris and require frequent maintenance to function properly. They can also become damaged during snow plow operations and can result in more frequent icing than piped conveyance. Additionally, metal chases should not be used on equestrian paths.

3.4.2 Pumped Systems

In some locations, where an underpass is at a low point in the path, pump systems have been installed to drain the sump when water overtops the path. Electromechanical systems can be unreliable however, especially when needed most. Pumped systems can also require frequent and costly maintenance and may trigger requirements for water quality monitoring under an individual permit from the State. For all of these reasons UDFCD strongly discourages the use of pumped systems except as a last resort.

3.4.3 Paths Adjacent to Walls

Consider discharge from weep holes. This can cause unexpected icing on the path after a warm day followed by a cold night. Where possible, it may be appropriate to collect this flow and convey it under the path.

3.5 Path Underpasses

At roadway crossings, there are generally three alternatives for path connections: path underpasses, at-grade crossings, and pedestrian bridges. The type of crossing selected effects user safety, user experience, animal passage, and cost. The scope of this manual focuses on underpasses. At-grade crossings and pedestrian bridges are not specific to streams and are covered in detail by other path design manuals.

Underpasses are the preferred alternative when the structure and roadway profile allow for the design to meet both vertical clearance and frequency of inundation criteria. Underpasses include (in order of preference) bridges, single span culverts,

Underpass Safety

Underpasses are often used for shelter during inclement weather. The following should be included where possible.

- Visibility of rising water from any location within the underpass
- Ability to climb to a higher elevation.
- Signage discouraging use of the underpass as a shelter and warning of potential flash flood. This signage should be placed inside the culvert or under the bridge. UDFCD encourages use of the sign shown in Photo 10-17 as a regional standard.

and multiple cell culverts. When both vertical clearance and frequency of inundation criteria cannot be met, other alternatives (i.e., at-grade crossings and pedestrian bridges) should be explored.

3.5.1 Path Underpass through a Bridge

Bridges with path crossings below are preferred over culverts because they provide the user with a wider field of vision and bring the user closer to the stream. This improves the experience for the path user, and from a safety perspective, is especially important along flashy streams, where being able to see water rising and climb to higher ground during a flash flood could save a life.

Bridges tend to be favored over culverts by the US Army Corps of Engineers (USACE) as they provide better wildlife passage and sometimes result in less impact to wetlands.

Photograph 10-14. This bridge offers safe passage, providing the user with a view of potentially rising water and the path beyond the structure. Additionally, the slope from the path to the roadway offers the user a passable route to higher ground in case of flash flooding.

3.5.2 Path Underpass in a Culvert

Underpasses in a culvert are less desirable than bridges especially when the use of multi-cell culverts separates the user from the water. This creates a scenario where the user may not be aware that water is rising in other culverts and a potential flashflood threat exists. When a bridge cannot be provided, the design should include a connection to street level on both sides. This will ensure maintenance access and improve safety. A culvert underpass presents a location where users may seek shelter during rain or hail, placing them in danger from flooding. Provide signage inside each end of the culvert to discourage users from seeking shelter within the structure. UDFCD recommends the sign provided in Photo 10-17 to promote consistency throughout the region.

The confined space within culvert underpasses can frighten horses, making them problematic for equestrian paths.

Photograph 10-15. This single-cell three sided box culvert offers safe passage, providing the user with a view of potentially rising water and the path beyond the structure.

Photograph 10-16. Multi-cell culverts can be uninviting, especially if the user is not able to see the other end.

3.5.3 Floodwalls

A wall placed between the stream and the path to allow use of the path while flows exceed that of the path surface is a type of floodwall. The use of floodwalls to meet frequency of inundation criteria is discouraged. Floodwalls require a high level of maintenance with both sediment removal and nuisance drainage issues.

3.5.4 Culvert Geometry

Within any underpass, the path section should allow for pedestrians to safely move off the path if another user speeds by. For this reason, a shoulder is recommended on each side of the path (see Figure 10-3). This can be an extension of the path section or can be surfaced differently as long as it provides a stable surface (e.g., a rumble strip).

The length and geometry of the culvert also affect safety. The length should be minimized to enable the user to evacuate quickly. Long culverts (over 100 feet) should be elevated to the 5-year water surface elevation (at a minimum) and should be straight to increase visibility and natural light. Culverts in excess of 200 feet are strongly discouraged. Reducing the length may require increasing the size of the wing walls, raising the elevation of the path, and/or acquiring land and placing the culvert at an alternate location. When the culvert design length exceeds 200 feet consider an alternative crossing for the path, e.g. at-grade.

Photograph 10-17. Place cautionary signage inside the structure where it is most likely to be seen by someone using the culvert for shelter.

See the Path Geometry section and Table 10-3 for vertical clearance recommendations. Also consider the vertical alignment immediately upstream and downstream of the culvert as it relates to maintenance access and drainage. Ensure passage of maintenance vehicles through the culvert. This may require a vertical curve or shifting a grade break further away from the culvert. Where practical, drain water away from each end of the culvert in an effort to minimize flow on the path inside the culvert.

3.5.5 Lighting

The *AASHTO Guide for the Development of Bicycle Facilities* recommends average maintained horizontal illumination levels of 5 lux to 22 lux. Even relatively short culverts can require lights. Look for opportunities to increase natural lighting. This is especially important for long culverts (over 100 feet). Divided roadways sometimes allow for natural light to be brought in through a median. Bends reduce visibility and natural light in long culverts and should be avoided to the extent practicable.

Photograph 10-18. A skylight between C-470 travel lanes brings natural light into the Willow Creek path underpass. Note also sediment deposition on path, typical of a long culvert with a mild slope. Photo courtesy City of Lone Tree.

3.5.6 Underpass Drainage

Drainage within the culvert is often problematic as well as maintenance-intensive. As shown in Photo 10-18, a long culvert constructed on a mild slope will deposit sediment on the path surface. The long flow path can exacerbate nuisance drainage issues and cause icing. When the design relies on inlets within the culvert, maintenance requirements should be specified to minimize problems due to clogging.

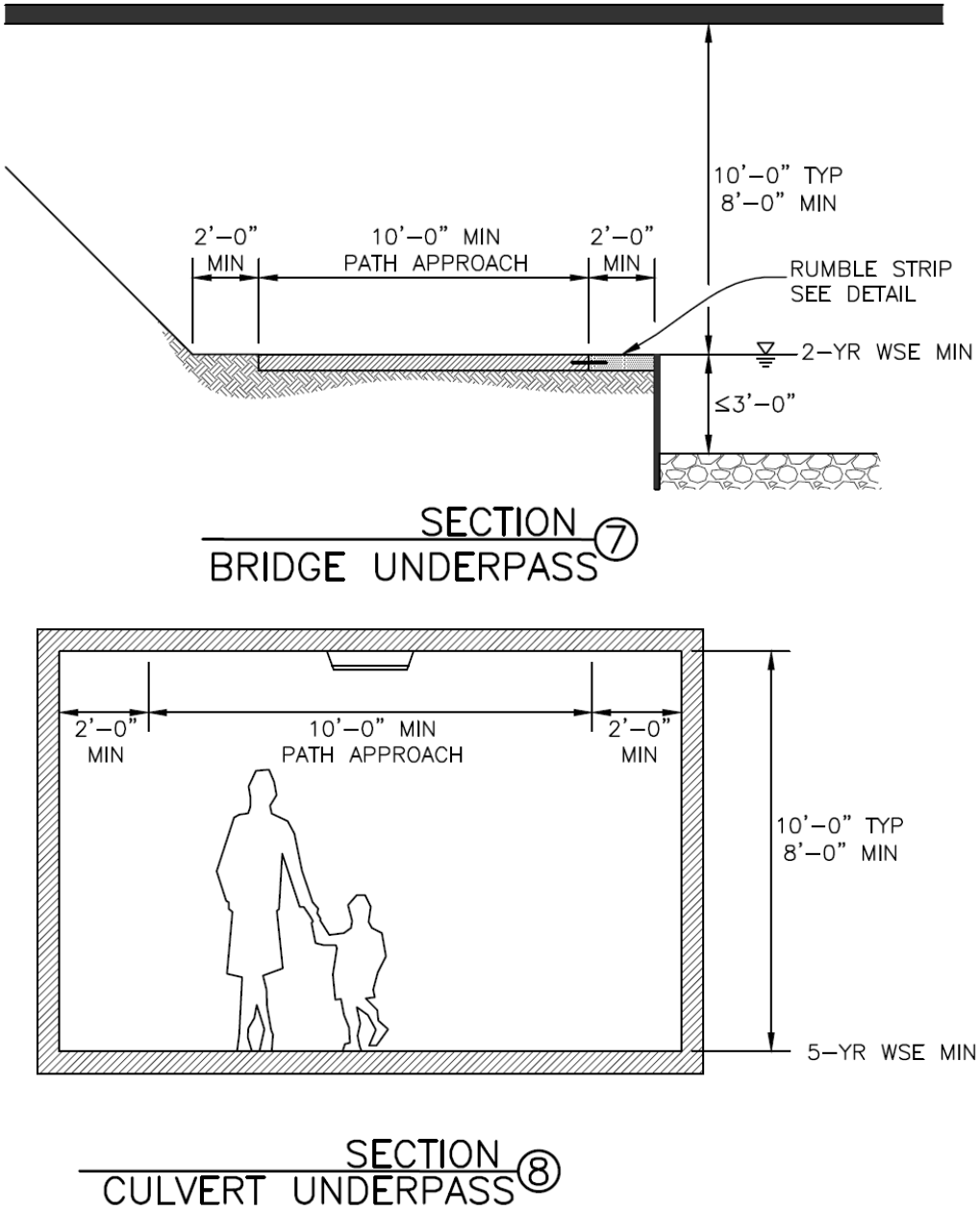


Figure 10-7. Path underpass sections

3.6 Stream Crossings

This section generally pertains to path crossings within the floodplain and includes structures that may be designed to overtop as frequently as during a 2-year event. These structures are sometimes referred to as low-flow crossings, low water crossings, or pedestrian crossings. These criteria are also intended for golf cart bridges, equestrian crossings, boardwalks, and any other similar structures with the exception of a temporary construction crossing. Discussion on larger crossings can be found in Chapter 8, *Hydraulic Structures*.

Photograph 10-19. A cast-in-place concrete culvert crossing with rumble strips. Photo Courtesy Architerra Group.

All stream path crossings need to be evaluated as part of the proposed hydraulic model and must be constructed to withstand forces associated with the 100-year flood event as well as wear and tear from frequent inundation without structural damage. Crossings should not include components that might break from the structure and cause debris blockage downstream. This can cause flooding and/or damage to downstream structures. All crossings should have a maintenance plan to address periodic and post-runoff debris and sediment removal. The designer should consider debris collection and blockage at the crossing and minimize potential for this while providing adequate safety components as described in this manual.

Photograph 10-20. This Cherry Creek crossing was split into three segments to accommodate the long span. Curb rails were used and the path was kept low to minimize impediment to flood flows. Photo Courtesy Muller Engineering.

3.6.1 Crossing Type and Materials

The two most common types of path crossings in the UDFCD region are bridges and cast-in-place concrete culverts. Bridges can be constructed in-place or prefabricated and can be concrete, wood, steel, or a combination of materials. Bridges, designed to span the main channel and sometimes other environmentally sensitive areas within the floodplain, can provide the benefit of reduced disruption when the project does not otherwise include disturbance of the channel. Concrete culverts can often be constructed without rails or with curb rails and provide a structure that has little impact to the water surface elevation of major events in the stream. Three-sided box culverts offer the added environmental benefit of a continuous streambed.

Photograph 10-21. A Bear Creek cast-in-place concrete culvert crossing with rumble strips and a crossing with rails in the distance.

3.6.2 Placement

When the placement of a crossing is flexible, (i.e., not dictated by existing constraints), the designer can add more thoughtfully considered user experience and potential future geomorphic changes to the requisite safety considerations. As discussed in Section 3.2, elevation of the path as it relates to frequency of inundation is an important consideration as the invert of the channel can change over time. Locating a crossing just upstream of a grade stabilization structure (check or drop structure) or incorporating a crossing into a grade stabilization structure, offers a stable channel invert at the crossing. This means the channel invert should not increase, causing more frequent inundation and related maintenance and loss of use issues, and that it also should not decrease, causing a potentially dangerous condition for the user. Depending on the design, locating a crossing downstream of a drop structure may offer the same benefit and also benefit user experience, bringing the user in contact with the sight and sound of the water flowing over the drop.

Photograph 10-22. A pedestrian bridge crossing with rails at Confluence Park.

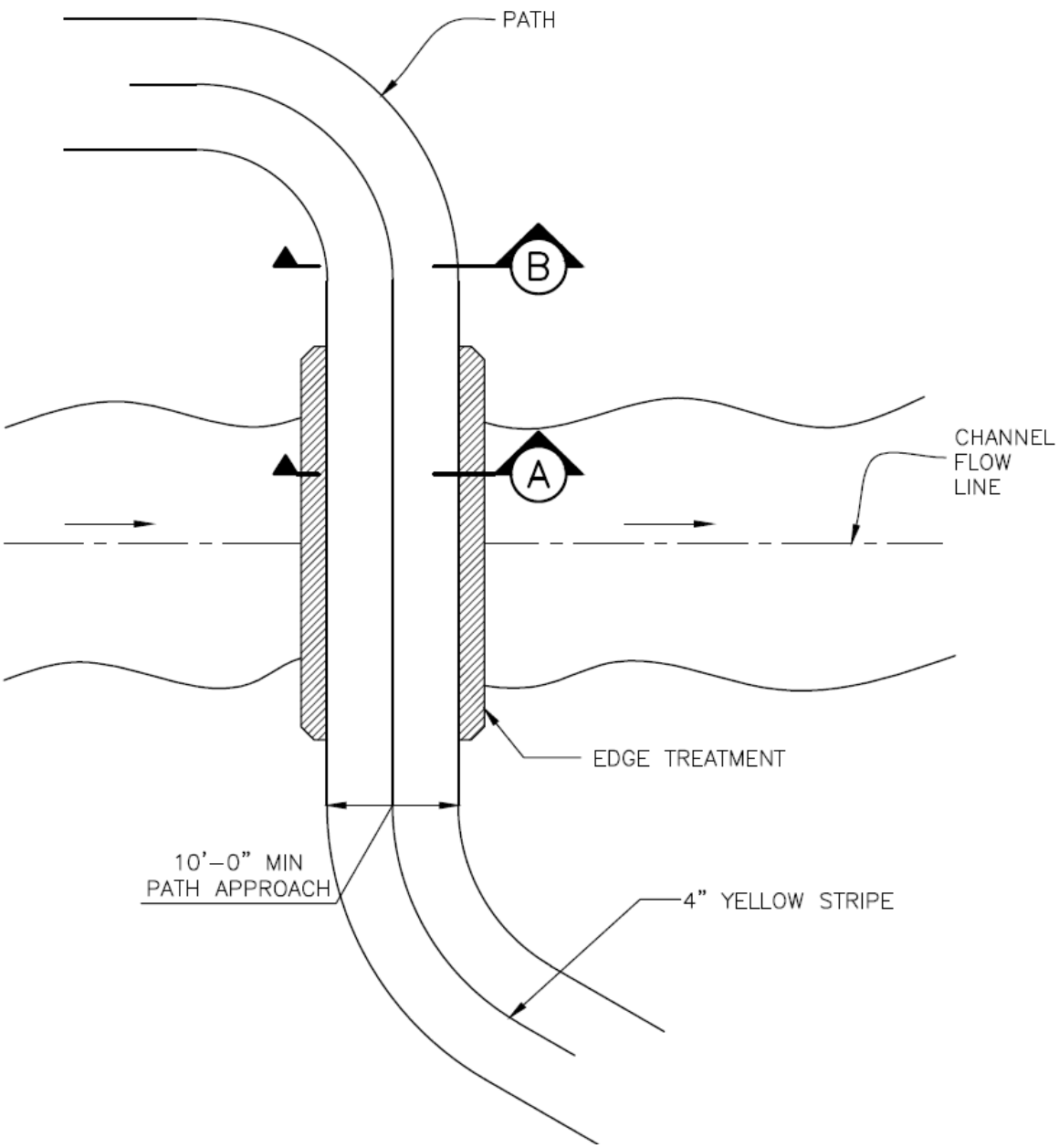
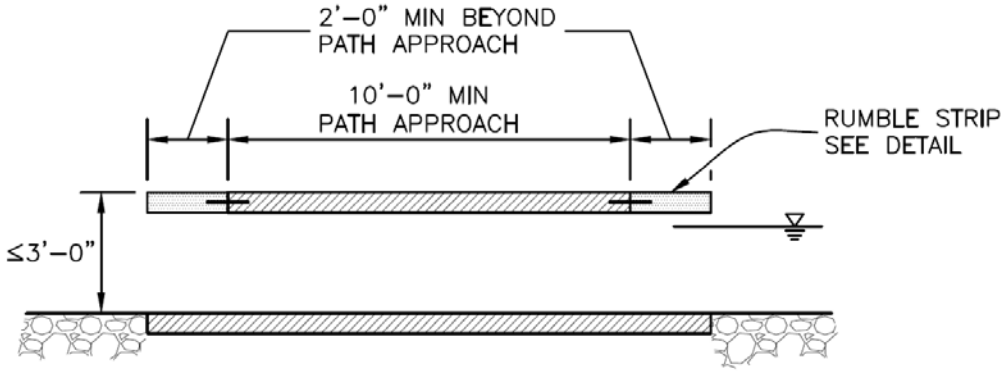
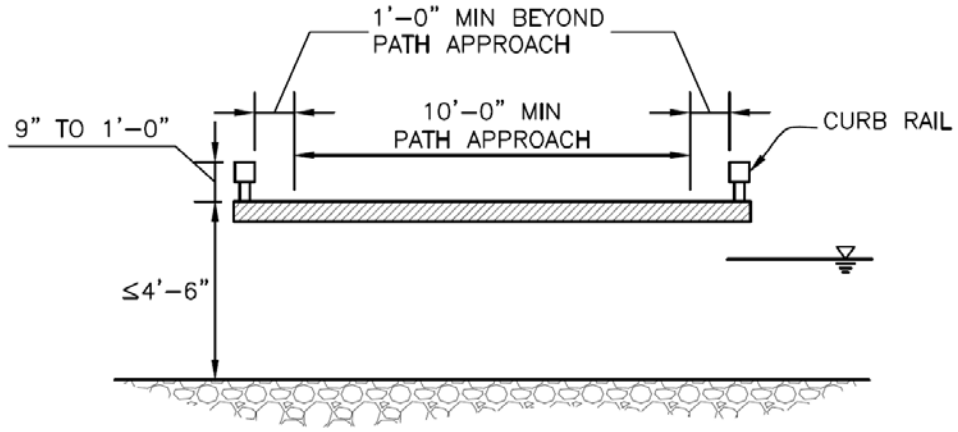


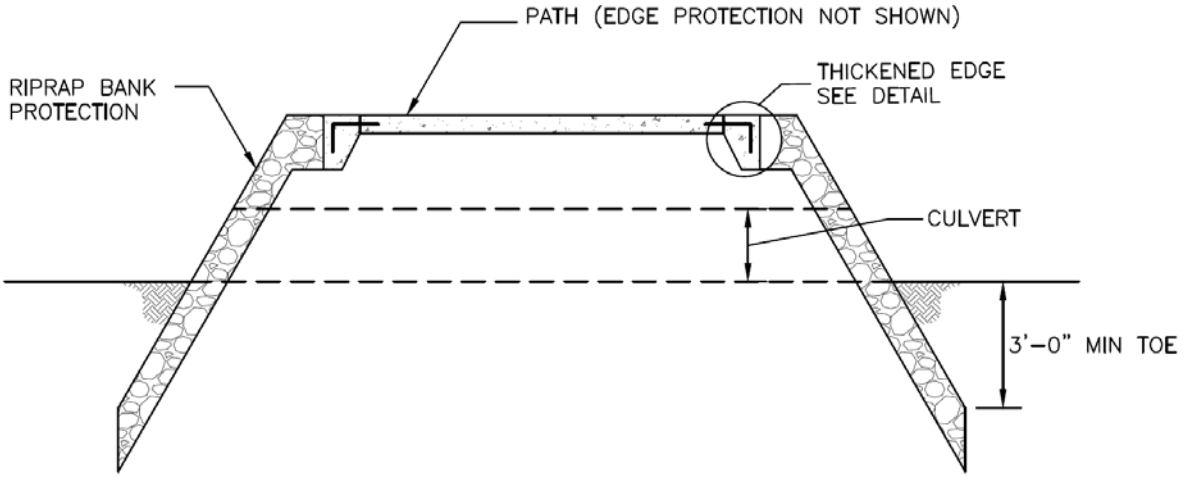
Figure 10-8. Typical low-flow crossing



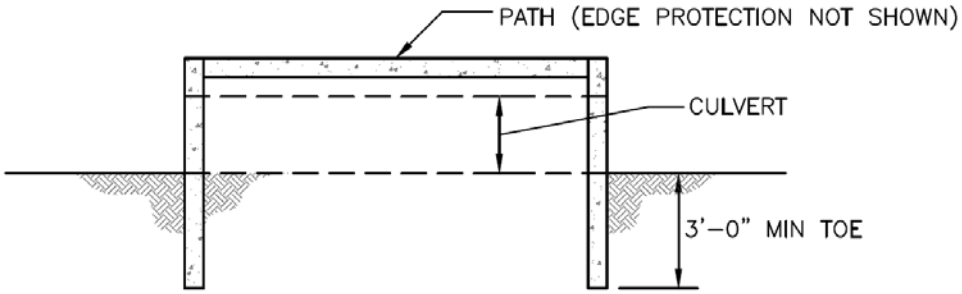
SECTION A1
CROSSING WITH RUMBLE STRIP



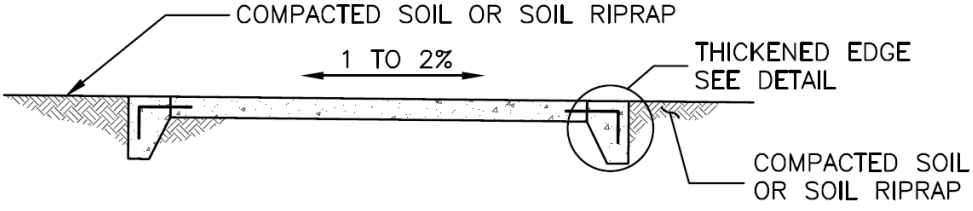
SECTION A2
CROSSING WITH CURB RAIL



SECTION A3
CROSSING WITH CULVERT AND RIPRAP



SECTION A4
CROSSING WITH CULVERT AND HEADWALL



SECTION B
OVERTOPPING PROTECTION

3.6.3 Equestrian Crossings

Horses are not always compatible with other types of path users and a separate tread for equestrian use, where practicable, is a good idea. This is especially true at crossings and underpasses where an animal may experience additional anxiety due to other users. When this is the case, equestrian crossings consist of a stabilized section of the stream marked for equestrian use. Equestrian crossings should consider safety for the horse. The smooth face of a horseshoe can cause a slip on a smooth hard surface such as concrete or metal especially when placed on a slope. Placement of an equestrian crossing is best where typical flows will be two feet or less and the channel is relatively straight. Equestrian crossings can be constructed by filling cellular confinement material with crushed rock. Use of geosynthetic materials (e.g., cellular confinement systems), in general, offers the desired surface for the animal while also providing the stability needed in areas of the path that are frequently wet (including crossings). Methods such as plating the channel with riprap (pushing riprap onto the channel bottom) and constructing a textured concrete (e.g., tooled joints similar to a rumble strip) crossing, such as the one shown in Photo 10-23, have also been used in the Denver Metropolitan area.

Smooth and hard surfaces become more dangerous on a slope. The Federal Highway Administration recommends that paths that have hard surfaces and slopes steeper than five percent need to be treated (e.g., terraced such as the crossing shown in Photo 10-24) to increase traction.

Photograph 10-23. An equestrian crossing parallels a separate multi-use crossing. Photo courtesy Arapahoe Park and Recreation District.

Photograph 10-24. Timber steps filled with roadbase are constructed to provide traction approaching a water crossing. Photo courtesy Arapahoe Park and Recreation District.

3.7 Material Selection

UDFCD has used several surfacing techniques for paths, including stabilized rock, reinforced grass, crusher fines, asphalt, concrete, and other proprietary surfaces. The following sections provide considerations for each.

3.7.1 Stabilized Rock and Reinforced Grass Paths

Stabilized rock and reinforced grass paths are generally used for "maintenance only" paths. To avoid rutting, compact both the subgrade and rock and use a rock that is well graded. Road base works well in this application. As with all path materials, backfilling the edges after construction is recommended to help hold the material in place and reduce chance of injury.

Photograph 10-25. This stabilized rock trail was constructed for maintenance.

Photograph 10-26. Reinforced grass pavement shortly after construction.

3.7.2 Crusher Fines

Crusher fines are not recommended below the 10-year water surface elevation or where the longitudinal slope exceeds 5%. Crusher fines typically wash out when stream flow (or concentrated cross drainage) flow over the path. Provide a weed barrier over the subgrade when using crusher fines.

Photograph 10-27. Geotextile is all that is left of this crusher fines trail that washed out on Goldsmith Gulch.

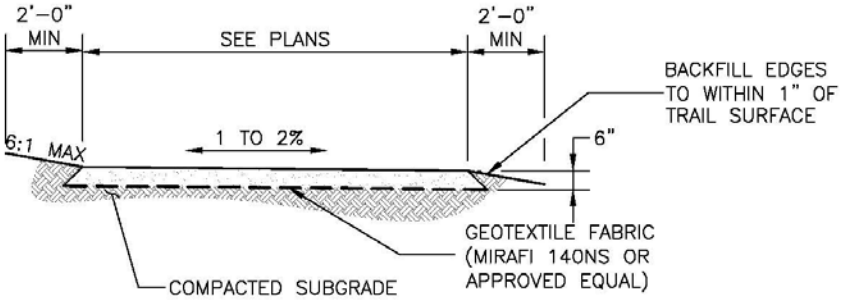


Figure 10-9. Crusher fines path section

3.7.3 Asphalt

UDFCD no longer uses asphalt for path construction due to maintenance issues. Problems with this material near the stream include vegetation, both with tree roots damaging the pavement and with weed growth through the pavement. Cracking, especially near the edges of the pavement was also a significant issue. If used for this purpose an herbicide should be applied on the subgrade prior to placement.

3.7.4 Concrete

Concrete is the most common path material for shared-use paths. A 6-inch depth section of fiber-reinforced concrete on top of compacted subgrade is generally adequate depending on soil conditions and the types of vehicles anticipated. The concrete should be finished to provide a safe surface for the user. Broom finish is typical.

Control joints should be placed 10 to 12 feet on center. Hand-tooled joints are highly discouraged as they often catch debris. Provide expansion joints at all cold joints and locations where the path abuts another structure, (e.g., a low-flow culvert crossing or bridge abutment).

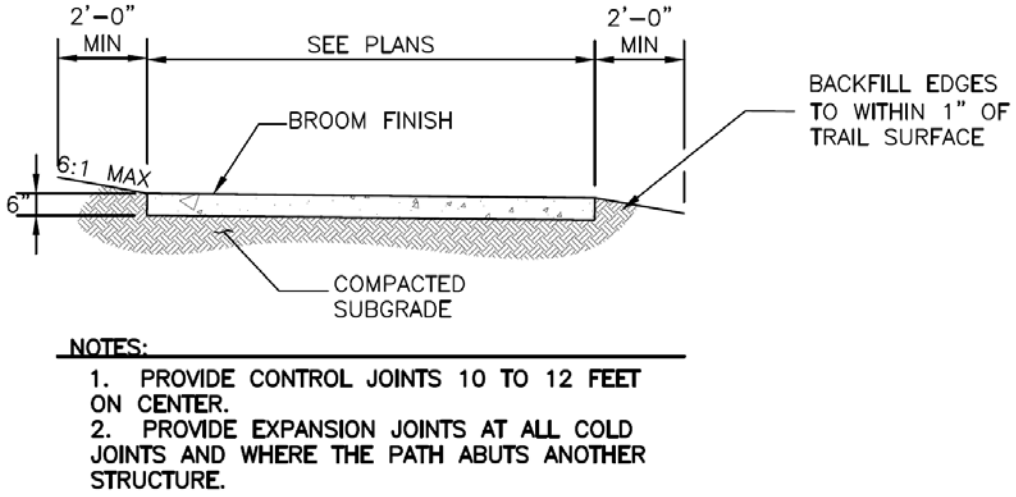


Figure 10-10. Concrete path section

3.7.5 Proprietary Surfaces

Proprietary surfaces expand the range of alternatives available for the surface of the path and sometimes offer qualities not found in conventional surfacing. Use of proprietary surfaces on UDFCD-maintained streams is generally allowable when the surface provides a structurally sound, maintainable surface that allows for frequent inundation without requiring repair.

Photograph 10-28. StaLok® paving material, a proprietary surface consisting of resin bound gravel, has replaced failed portions of the crusher fines Goldsmith Gulch path.

4.0 In-Channel Safety

Planning, design and construction of channels and related structures such as low-head dams, drop structures, bridges and armoring, mandate a standard of care consistent with common-sense safety concerns for the public that responsibly uses the rivers and waterways.

This chapter focuses on the safety of public users in or near the water in recreational channels. The term "in-channel users" refers to people that are in the water. Swift Water Rescue manuals often refer to this as the "Hot Zone". In-channel users include recreational enthusiasts in river craft such as rafts and kayaks, tubers, anglers, waders, and swimmers. In-channel users also include personnel maintaining or operating various structures and facilities in and sometimes adjacent to channels. Observers or others within a recreational channel that accidentally fall into the water are also considered in-channel users. The area where such incidents can occur is referred to as the "Warm Zone" in Swift Water Training and has been typically identified as within 10 to 15 feet of the edge of the water.

While the identification and nomenclature of zones used in Swift Water Rescue are used in this chapter, note that issues and criteria related to these zones in Swift Water Rescue manuals and training may be different than used in this chapter. Discussions within this chapter refer to planning and design issues in and around water in recreational channels and are not related solely to "rescue" or "swift water" conditions, i.e. rapids.

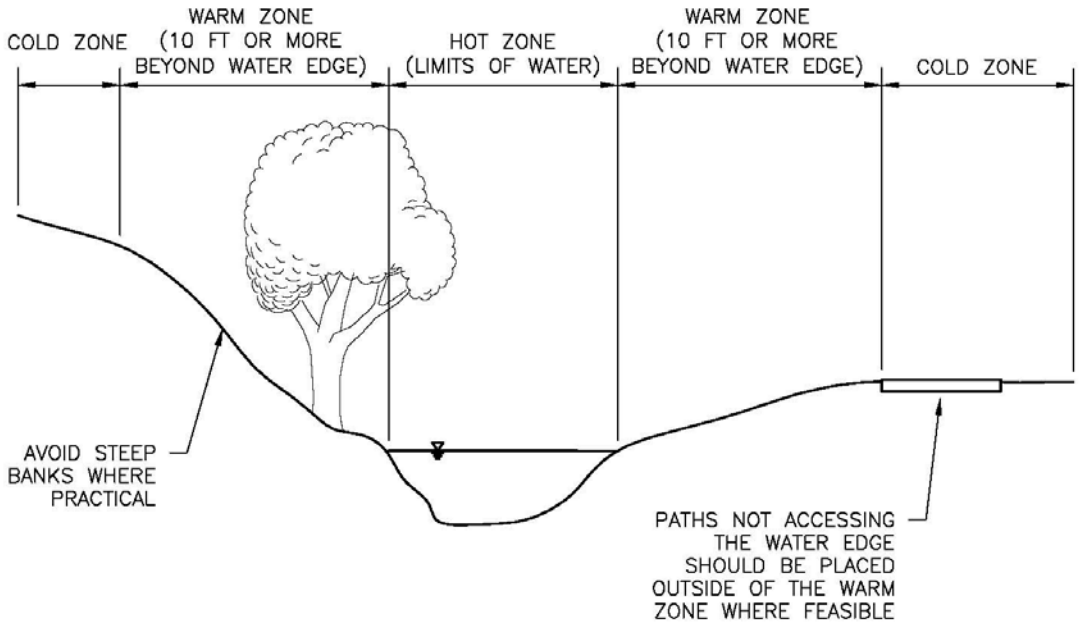


Figure 10-11. Zones of operation

In general, personal safety risks related to in-channel users include drowning, injury, and infection. These risks are primarily attributed to:

- An overly-retentive hydraulic jump (sometimes referred to as "submerged hydraulic," "keeper," or "drowning machine");
- Impacts, blunt trauma, cuts, and abrasion;
- Ingestion of pathogens in water:
- Hypothermia;
- Infection from cuts and abrasions;
- Foot or extremity entrapment;
- Pinning or entrapment against or in an obstruction;

These risks are greatly increased if proper equipment is not correctly used by the in-channel user.

Channels and rapids, with or without man-made structures are inherently hazardous. There are inherent and unavoidable risks related to recreating in and around channels. A primary objective in the planning, design, and construction of structures is that:

Structures should be designed and constructed so that they are predictable and without hidden or unobvious hazards to responsible users. (Charlie Walbridge, Safety Chairman, American Whitewater).

4.1 Recreational and Boatable Channels

4.1.1 Recreational Channels

Photograph 10-29. These rafters are running the largest and most turbulent hydraulic features ever constructed. However this feature has been successfully run by tens of thousands of recreationalist and is hailed by safety expert Charlie Walbridge. Photo courtesy of Thanis McLaughlin

The design, planning, and construction of recreational channels should take into consideration the potential for unintended entry into the water. Therefore, some planning and design considerations outlined in the Boatable Channels section (Section 4.1.2) may need to be addressed in the planning and design of all urban channels. The degree of this consideration will depend on issues such as the volume of traffic around the water's edge, adherence to the criteria presented in Section 3.0 of this chapter, frequency and flow rate, the presence of railings, and the resulting consequences of accidentally falling into the water. Safety considerations during dry conditions related to public access to the bottom of the channel should also be made.

Design and planning considerations for recreational channels should consider bank conditions and

conditions within the Warm Zone. Design channel banks to avoid hidden safety issues (e.g., tripping hazards) that could cause unintended entry into the water and provide egress for those who may accidentally fall into the water.

Safety considerations related to the presence of flowing water during flooding in the Cold Zone may also need to be made. Some of these issues are discussed in Section 3.0, Paths Adjacent to Streams.

4.1.2 Boatable Channels

Boatable channels are considered a sub-set of recreational channels. Planning and design considerations within boatable channels include but are not limited to: drop structures; whitewater recreational areas or other recreational whitewater features; bridge piers; all types of bank armoring; woody vegetation; debris and debris accumulation; jetties; bendway weirs; fish passages; intake structures; etc.

The design of these features and structures must avoid the development of overly-retentive hydraulic jumps, sharp edges, foot entrapments, restricted egress, and address other dangers listed in Section 4.3. Within this manual, the term “drop structures” includes grade control structures, low-head dams, boatable passage structures or chutes, recreational features which form holes or waves, and others described herein. Some of these considerations, albeit to a reduced level, may need to be addressed in recreational channels that are not considered boatable.

Photograph 10-30. Recreational users in personal water craft at Confluence Park and most other constructed features are more common than experienced boaters. Photo courtesy of Rick McLaughlin.

Photograph 10-31. Recreational whitewater features in rivers are used by both children and adults. Appropriate use of a river and proper gear can be encouraged through recreational and educational programs. Photo courtesy of Thanis McLaughlin.

4.2 Glossary of Related Terms

The following glossary is intended to improve consistency and accuracy in communications with the river recreating community. The reader should note that the definitions of all terms are not universally recognized within this specialized industry.

Term or Abbreviation	Meaning
Aggradation	Aggradation involves the raising of the channel bed elevation through sedimentation, an increase in width/depth ratio, and often a corresponding decrease in channel capacity.
Bed Load	Coarse sediment transported along the bottom of the river by saltation (hopping), sliding, rolling,etc.
Benthic Macro-invertebrates	Benthic Macroinvertebrates are small animals living among the sediments and stones on the bottom of streams, rivers and lakes. Insects comprise the largest diversity of these organisms and include mayflies, stoneflies, caddisflies, beetles, midges, crane flies, dragonflies, and others. Other members of the benthic macro invertebrate community are snails, clams, aquatic worms, and crayfish. They are extremely important in the food chain of aquatic environments as they are important players in the processing and cycling of nutrients and are major food sources for fish and other aquatic animals
Counter Weir	A counter weir is a secondary drop structure or armored channel section downstream of a drop structure, pool, or hydraulic disturbance. It is usually smaller than the upstream drop structure and maintains the elevation of the tailwater experienced by the upstream drop structure or other hydraulic disturbance. An end sill, as described in the *Hydraulic Structures* chapter, could also be used for this purpose. They are often placed at the downstream limit of the Recovery Pool.
Drop Structure	A constructed feature or structure in a channel that creates a downward step in the water surface and a resulting hydraulic jump downstream of the structure. These can typically have a hydraulic drop of one-half to eight feet. These structures can be used for a number of purposes including diversions, recreation, and stream stability. They can also be called grade control structures, diversions, low-head dams, weirs, or just drops. They are typically constructed of grouted boulders or sculpted concrete with additional concrete or sheet pile cutoff walls. Regarding recreational whitewater, a drop structure is a physical feature that forms a “wave” or "hole", boat chute, whitewater park or whitewater feature.
Eddies	Eddies are usually formed downstream of an obstruction or curvature in a river or channel. Eddies swirl on the horizontal surface of the water. Typically, they are areas where the downward movement of water is partially or fully arrested and currents flow in an upstream direction – if slow enough, a nice place to rest or to make one's way upstream.
Freestyle	Competitive event where boaters perform tricks on a “breaking wave” or “hole”.

Hole(s)	A "hole" is formed when the supercritical jet on the downstream face of an obstruction within the channel is directed toward the invert within the formation of the hydraulic jump. This causes the surface water and the upper portion of the water column to flow back upstream toward the obstruction. A strong breaking wave (see below) is often confused with a hole. It differs from a hole in that the supercritical jet is lifted and directed within the upper portion of the water column within the initial formation of the hydraulic jump. The distinction between a hole and a breaking wave however is not consistently made within the whitewater community. In hydraulic design terms, it is a particular formation of a hydraulic jump (see below). In the design of man-made whitewater or other structures within a river or waterway, it is usually created by a drop structure or structure(s) that create a significant constriction in the channel. Holes in recreational structures are typically designed for entertainment and skill-building, places where paddlers use the features to perform various moves. Poorly designed holes can be dangerous. They can dramatically aerate the water, possibly to the point where they lose the capacity to carry watercraft. In overly-retentive holes or "keepers" (see below) a boater may become stuck in the recirculating water. Some of the most dangerous types of holes are formed by low-head dams (weirs), ledges, and similar types of obstruction. Low-head dams or other structures that form a uniform hydraulic with no irregular or weak point are particularly dangerous. Low-head dams are insidiously dangerous because their danger cannot be easily recognized by people who have not studied whitewater.
Hydraulic	The term "hydraulic" refers to a hydraulic jump and is river recreationalist jargon sometimes used when referring to a "hole" or "wave." It could also be used to describe a hydraulic formation known as a supercritical shock wave.
Hydraulic Drop	Sometimes referred to as just "drop". The vertical distance between the upstream and downstream water surface elevation. This can be applied to a single feature or to multiple features within a river reach or whitewater course.
Hydraulic Jump	A hydraulic transitional formation that occurs between supercritical and subcritical flow. This occurs downstream of a constriction or Drop Structure when the fast flow collides with the slower moving flow in a downstream pool. It is commonly referred to by river recreationalists as a "hole", "wave", or "hydraulic".
Keeper	See Overly-Retentive Hydraulic.
Overly-Retentive Hydraulic	A hydraulic condition –technically a specific form or a hydraulic jump –that can occur downstream of a natural or man-made feature (such as a low-head dam). This condition tends to trap boaters, swimmers, or other floating objects for an extended length of time. This condition can also be called a submerged hydraulic, keeper, reverse roller, drowning machine or a variety of negative descriptors followed by the term "hole" or "hydraulic".
Play Boating	Recreational boating primarily for surfing and performing "tricks" on breaking waves or in holes. These are typically whitewater kayaks and canoes. This type

	of recreational use can also include surfing, standup paddle boarding, and body boarding.
Pillows	Pillows are formed when a large flow of water runs into a large obstruction, causing water to "pile up" or "boil" against the face of the obstruction. Pillows are also known as Pressure Waves.
Portages or Portage Paths	Portages or portage paths are land routes used by in-river users to bypass or avoid dams, drop structures, or other in-channel obstructions. Portages can also serve as "detours" around sections of water that in-river users choose not to run.
Put-in	A put-in is a formalized area that facilitates access of in-river users and their craft to enter the water. They are often located at the downstream end of a portage path or upstream of a reach of river that is commonly used by recreationalists.
Recovery Pool or Zone	A recovery zone or pool is a slow moving reach of the river immediately downstream of a drop structure, series of drop structures, or other challenging hydraulic feature that allows for recovery by recreational users.
Slalom	Competitive event where boaters negotiate gates suspended over the river for the fastest time.
Strainers	Strainers can be deadly obstacles within a boatable channel. Water passes through but solid objects like boats or people do not, similar to a kitchen strainer used to drain spaghetti or clean vegetables. A fallen tree or branch is the most common type.
Structural Failure	Movement of rock or structures that: 1) is unanticipated or 2) results in a condition that negatively impacts safety. Also see Tuning or Adjustments.
Submerged Hydraulic Jump	See Overly-Retentive Hydraulic
Take-out	A take-out is a formalized area where in-river users can exit the river with their craft. They are often located at the upstream end of a portage path or at the downstream end of a reach of river that is commonly used by recreationalists.
Tailwater	Tailwater is the downstream depth of the water in a channel relative to a particular feature or structure. Tailwater has a significant impact on the performance of a drop structure and the resulting hydraulic jump.
Tuning or Adjustments	Due to the complex nature of hydraulics and the use of irregular boulders, some adjustments to rock or structure is usually required after the initial construction and the river is observed to flow through the features. This is usually conducted at the direction of the designer shortly after the initial construction or after the first year or two of operations. Also see Structural Failure.
Wave(s)	Waves found in most man-made structures are formed similarly to holes and are sometimes referred to as a "hydraulic". In hydraulic design terms, it is a formation of a hydraulic jump which is created downstream of supercritical flow. In the design of man-made whitewater or other structures within a river or channel, it is usually created by a drop structure or a structure which creates a

significant constriction in the channel. Waves are noted by a smooth upward sloping face as the flow enters the hydraulic jump. This “green water” at the upstream portion of the formation is followed by a crest and downward sloping face. A wave can have a significant amount of whitewater or “haystack” and appear similar to a hole. These are called breaking waves. Sometimes a particularly large wave will also be followed by a long series of waves or “wave train”. Waves in channels can also be created without the formation of a hydraulic jump.

4.3 Minimum Criteria

Within the UDFCD region, infrastructure typically meets or exceeds the criteria outlined in this section. There are, however, numerous examples elsewhere in the country where these criteria are ignored, posing danger to users. Here are some of the minimum design criteria for boatable and, in some instances recreational channels:

1. All drop structures, including recreational "wave" or "hole" features as described later in this chapter, are specialized drop structures and should be designed in accordance with appropriate recommendations, considerations, guidance and procedures established in the *Hydraulic Structures* chapter of this manual.

2. Drop structures or other recreational features in rivers or channels have been designed and constructed since the 1970s. They are “works of engineering” as they safeguard life, health, and property and promote the public welfare. They necessitate design work requiring intensive preparation and experience in the use of mathematics and the engineering sciences. Therefore, their construction must adhere to design drawings sealed by a registered professional engineer.

3. Drop structures made of “natural materials” such as boulders or riprap are still structures and are works of engineering. They must be designed in accordance with appropriate criteria within this manual.

4. Structures should withstand stream forces for all flows up to and including the 100-year flood. This is critical because structures that experience movement or failure can create hazardous or changing hydraulic conditions well after a flooding event. Typically, structural movement would occur during high flow events that preclude maintenance or repair of the structure and coincides with in-river recreation such as rafting and kayaking. Therefore, structures within boatable channels should be designed and constructed to survive flooding without change in hydraulic performance. It is sometimes advantageous, however, to plan and design adjacent landscaping and other features on the banks or uplands (that do not impact safety or that can be replaced or repaired during normal flows) for lesser flooding events.

5. When analyzing impacts on flood conveyance, caution should be taken to avoid accounting for flood conveyance areas within the channel cross-section that will not be effective during flooding events. These could include deep pools, eddies, or areas of the channel that will fill with sediment or cobble. If the design relies upon the depth of pools or effectiveness of various portions (particularly areas with slow moving water) of the channel cross-section for conveyance of flood flows, then multi-dimension hydraulic analysis or physical modeling may be needed. Design of new drop structures or modifications of existing drop structures for in-channel recreation should not negatively impact the regulatory floodplain, cause increased bank erosion, or create localized channel instability from deposition or scour.

4.4 Design Considerations for Structures and Features

The following considerations should be reviewed for boatable and, in some instances, recreational channels.

1. **Egress.** Provide multiple opportunities for egress from the channel – particularly in critical locations such as before and after rapids or drop structures.

2. **Create Opportunities for Self Rescue**. Avoid hydraulic and physical condtions that make it difficult for in-channel users to access the banks. For structures that significantly impair self rescue, consider sloped racks or sides and ladders or stairs.

3. **Sharp Edges.** Avoid sharp edges and protruding objects.

4. **Strainers.** Avoid the creation of "strainers" and the potential for debris to collect and act as such. Accumulation of debris may occur at bridge piers, intakes, railing, or other infrastructure and on woody vegetation, features used for fish habitat, or bank stabilization.

5. **Intakes and Screens.** Prevent accidental entry into gates or inlet works with bar racks or screens at intakes (headgates) and design for approach velocities so as not to create pinning hazards.

6. **Utilities and Apparatus.** Provide physical separation or barriers if practical and (at a minimum) warning buoys and signs when hydraulic grates or screens, sluice gates, etc. are accessible and present a hazard to in-channel users.

7. **Fish and habitat considerations.** When it is appropriate to provide fish passage within the reach, integral features that support both recreational use and fish passage or habitat are desirable.

8. **Safety Signage.** Include warning signs upstream of hazards (intakes, etc.) and at the start of a drop structure or a series of drop structures. Signs to advise positive actions, such as encouraging the use of proper equipment, are also prudent.

4.4.1 Pinning and Overhead Obstructions

To reduce the chance of an in-channel user being pinned or trapped on a grate, screen, rack, or other feature that could become a strainer, reducing velocities going through the screen or object (approach velocity) and increasing the velocities of the flow passing by the screen or object (sweeping velocity) can be effective methods of reducing these potentially dangerous conditions. Well documented limits on approach velocities for safety are not available. For relevance, maximum design values for approach velocities for fish can vary from 0.2 to 0.8 ft/sec while maximum design values for approach velocities to reduce accumulation of trash of 0.5 feet per second have been used by the USBR. Consider a maximum design value for approach velocities into a screen or grate, of 0.5 or 1.0 ft/sec to reduce pinning of in-channel users. Approach velocities used for a particular application can depend upon sweeping velocities, the frequency of recreational users, the velocity and direction of the upstream currents, and other factors. Means to evenly distribute the flow across the screen should be considered. Note that recommended approach velocities to grates, screens, or bar racks in boatable channels are typically less than recommended maximum design velocities through racks and grates used in the design of typical drainage infrastructure.

Overhead clearance at bridges, low water crossings, utility crossing, or other structures that span boatable channels or portions of boatable channels should be sufficient to reduce hazards to in-channel users. There are no widely accepted minimum design clearances for these types of boatable channels. Consider

a minimum clearance (freeboard) in the range of six feet from the water surface of the recreational flow range to the underside of an overhead structure. Lesser amounts of freeboard may be appropriate during flood conditions.

4.5 Drop Structures

The following drop structure criteria are provided in addition to the criteria provided in the *Hydraulic Structures* chapter of this manual.

For the purposes of this chapter, the term "drop structure" refers to a constructed feature (or structure) in a channel that creates a downward step in the water surface and a resulting hydraulic jump downstream of the structure. These can typically have a hydraulic drop of as little as six inches or up to eight feet or more. These structures can be used for a number of purposes including diversions; various types of recreation including kayaking, paddle boarding, and swimming; river stability; and enhancement of habitat. Terminology for typical or specialized drop structures includes: grade control structures, control structures, holes, whitewater parks, boat chutes, diversions, low-head dams, weirs, riffles, glides, and sills. Regarding recreational whitewater, a feature or structure that creates a "wave" or "hole" is also considered a specialized drop structure.

Structures should be designed with carefully planned components that are consistent with recreational requirements for user safety. Drop structures in boatable channels should incorporate a boat chute, bypass, or full river passage to allow passage for boats. Intakes have been designed and operated successfully to create whitewater features and allow fish passage while keeping recreationalists out of the intake works. Engineers have used a wide variety of approaches depending upon site-specific requirements.

Photograph 10-32. The intake at Confluence Park, Denver is located on the side of the river opposite to where the whitewater bypass is located. In addition to this physical separation, buoys, two debris booms and a bar screen were included to help keep recreationalists away from the intake works. Photo courtesy of McLaughlin Whitewater Design Group.

Photograph 10-33. The intake works on the American River near Auburn, California relies on a submerged self-cleaning fine screen. The screen is located in the invert of a boatable channel. This design eliminates intake apparatus that can be hazardous to recreationists, screens for fish and solids, and has proven to require relatively little maintenance. Photo courtesy of Placer County Water Agency.

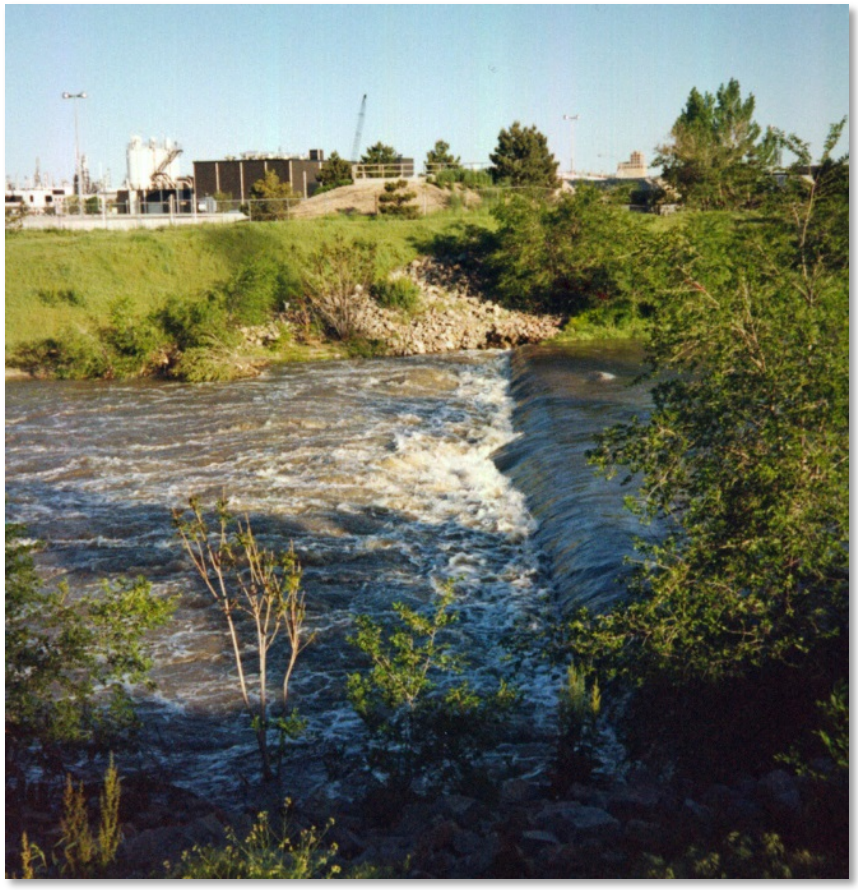
Warning signs and portage routes around such structures are appropriate in various situations. This chapter outlines some specific approaches and guidelines that have been used in past design efforts to reduce hazards of boatable drops. Boatable drop should be designed by professional engineers with experience with previously constructed projects that incorporate boatable elements, hydraulic modeling, scour analysis and floodplain regulations.

These are not the only approaches available to the engineer and do not address all issues. Design of drop structures intended to provide specific recreational attributes required for freestyle kayaking, slalom kayaking and canoeing may not follow all of the suggestions outlined in the Simplified Design Approach of the *Hydraulic Structures* chapter.

4.5.1 Overly-Retentive Hydraulic Jump

In whitewater river recreation, the characteristic for a hydraulic jump , referred to as a “hole” or “wave”, to keep a boat within a hydraulic jump is referred to as retentiveness. Retentiveness can be a desirable quality of a recreational wave or hole, but if the hydraulic jump is too retentive, it can hold swimmers or submerged craft. In this chapter, this dangerous hydraulic phenomenon is referred to as overly-retentive,

and the formation of overly-retentive hydraulics should be avoided. This hydraulic condition has a number of names including “submerged hydraulic jump,” “keeper,” “reverse roller,” and “drowning machine.”



Photograph 10-34. Currents downstream of dams or even drop structures can create an overly-retentive hydraulic jump that can trap in-channel users. Sometimes called “keepers” or “drowning machines,” these hydraulic conditions can be deceivingly dangerous. The misleadingly dangerous structure shown here created this condition with only 1.5 feet of hydraulic drop before UDFCD retrofitted it to be safely boatable.

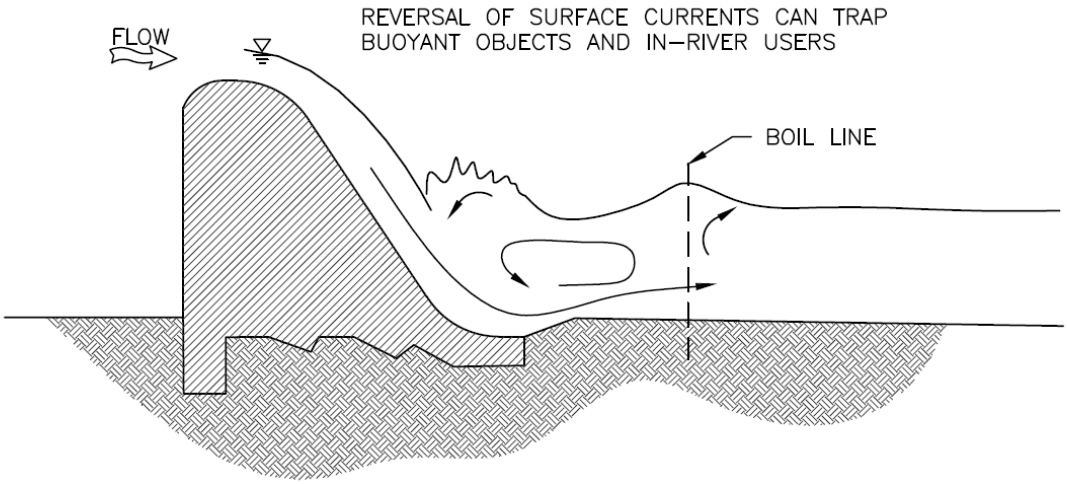
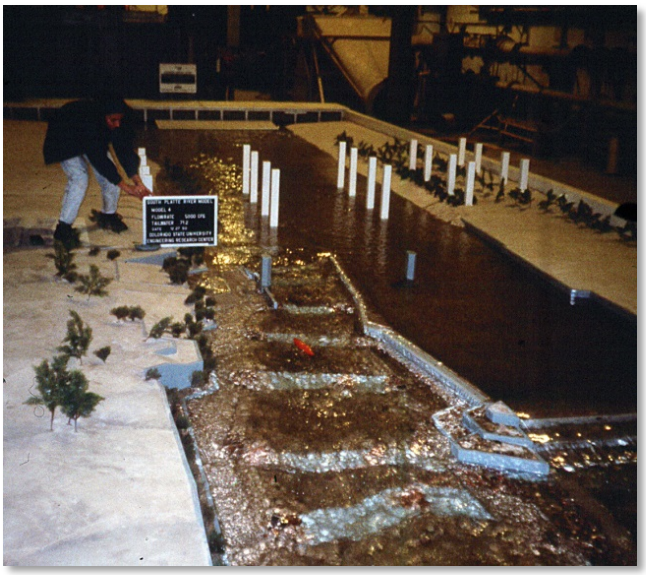


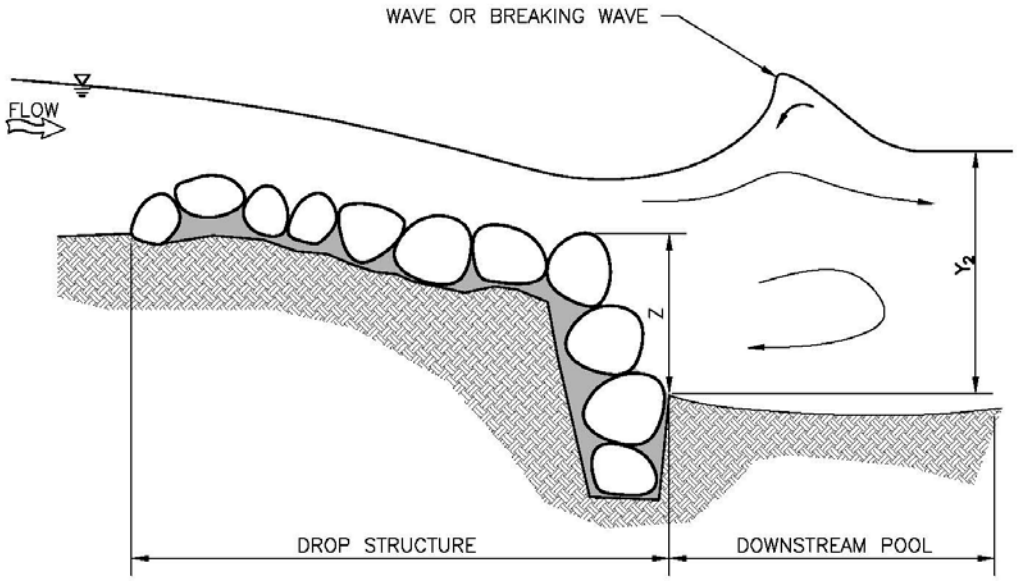
Figure 10-12. Overly-retentive currents at a hydraulic jump

One design approach to avoid an overly-retentive hydraulic jump is to direct the super-critical flow at a relatively flat angle. A downstream face on a drop structure having large grouted boulders and high roughness that is sloped at 10(H):1(V) has been used successfully on several projects in the UDFCD region. This slope should extend such that the jump occurs on the face of the drop structure.

Other approaches have also been used to avoid the formation of overly-retentive hydraulics. The stepped dam at Confluence Park in Denver has demonstrated that a stepped configuration can also be an effective approach to avoiding an overly-retentive hydraulic jump. The formation of a hydraulic jump at an abrupt drop has also been used to effectively avoid the formation of overly-retentive hydraulic jumps over a wide range of river flows. (Samad, et.al, 1986)

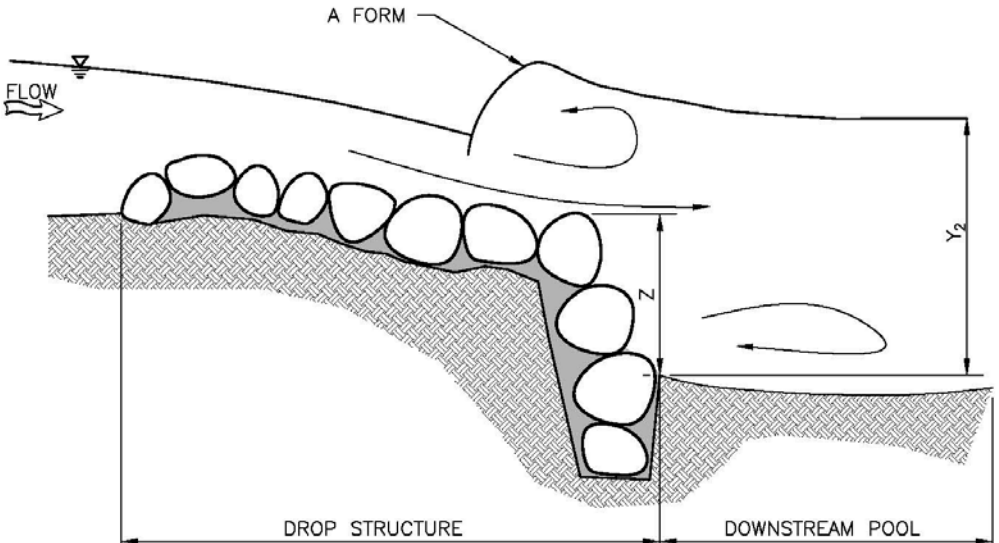


Photograph 10-35. A physical model aided in the 1996 design of Confluence Park. This was one of the first whitewater venues to employ the hydraulic jump at an abrupt drop design. As a result, the venue performed well over a very wide range of flows for a diverse user group. Photo courtesy of McLaughlin Whitewater Design Group.



'WAVE FORM'

NOTE: THE WAVE FORM CAN CREATE FUN FEATURES THAT ARE NON–RETENTIVE AND LOW HAZARD



'A' JUMP

THE A JUMP IS CREATED IF THE TAILWATER IS HIGH AND IS USUALLY UNAVOIADABLE THROUGHOUT THE ENTIRE RANGE OF RIVER FLOWS. THIS CONDITION CAN BE SOMEWHAT RETENTIVE AND POWERFUL, BUT NOT NECESSARILY HAZARDOUS.

Figure 10-13. Forms of a hydraulic jump at an abrupt drop

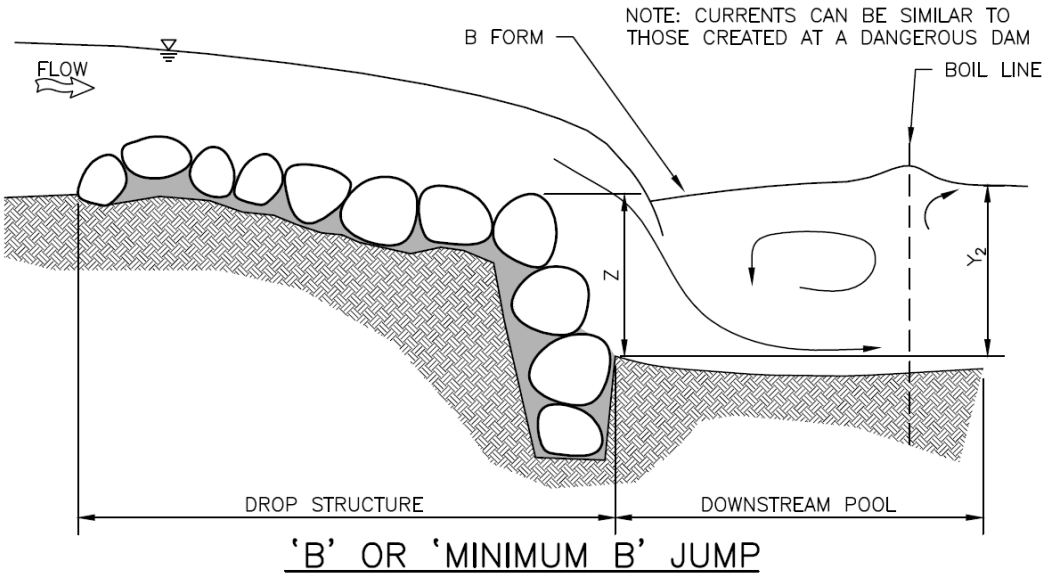


Figure 10-13. Forms of a hydraulic jump at an abrupt drop (continued)

Hydraulic Jump at an Abrupt Drop

Structures that employ a hydraulic jump at an abrupt drop have been effective in eliminating overly-retentive hydraulics. However, like many dams and drop structures, the elevation of the tailwater (Y_2) is critical to the resulting hydraulic formation. Figure 10-13 shows hydraulic jump forms and nomenclature as outlined by Moore and Morgan (1959). The reader is referred to this paper and papers by Hsu (1950), Rajaratnam (1977), Ohitsu, (1990), and Samad (1986).

Even in recreational channels that are not boatable (e.g., often have little or no flow), drop structures should be designed so as to avoid the creation of dangerous hydraulic conditions. Smaller drop structures with a 4(H):1(V) downstream sloped face have been used successfully throughout the UDFCD region.

4.5.2 Design Approach

The following considerations are oriented toward providing simple recreational passage around or through a drop structure located within a boatable channel. Considerations and issues provided in this chapter and drop structure criteria presented in the *Hydraulic Structures* chapter are still applicable. Design of specialized recreational features, boatable features with integral fish passage, reaches where deposition of sediments or cobbles are an issue, or other applications requires the expertise of an experienced professional which is beyond the scope of this chapter.

1. Select the maximum hydraulic drop (different than drop height) — generally one to four feet. If the hydraulic drop is more than 4 feet, a physical hydraulic model may be necessary. Physical hydraulic models may also be useful to optimize recreational hydraulics or when a complex structure is needed in a highly used recreational area. Allow for longer recovery zones downstream of drops with larger hydraulic drops. (See item 3.g below.).

2. Determine the type of structure and passage to be used. Be aware that boatable structures can increase the cost of the project. Structure selection should always be based on safety first, but may also be based upon costs, aesthetics, floodplain issues, sediment transport, and river morphology. These types include:

    a. **Full River Passage**. A structure or series of structures that span the entire channel width and are boatable throughout a range of flows, typical of most drop structures in Colorado that have been created primarily for recreational uses.

    b. **Bypass**. A boatable path that flows to one side of a drop structure or low-head dam and is typically constructed when a larger or existing drop structure is encountered. Design of a bypass can be more complex and costly and may likely fall outside of what would be considered to be appropriate for "simplified" design as described in the *Hydraulic Structures* chapter.

    c. **Boat Chute**. A localized passage through a drop structure such as at Alameda Avenue in Denver and at numerous locations along the South Platte River through the UDFCD region. These are often added to existing drop structures with the remainder of the drop structure not normally suitable for recreational passage.

When boat chutes or bypasses are employed, the drop structure or low-head dam is usually designed or modified with steps or other measures to reduce hazards associated with incidental passage. The stepped dam at Confluence Park is a successful example of this type of hazard reduction.

3. Determine basic drop structure characteristics to be compatible with public safety and recreational boating. Suggestions are as follows:

    a. Employ detailed multi-dimensional modeling or specialized design to avoid creation of an overly-retentive hydraulic condition:

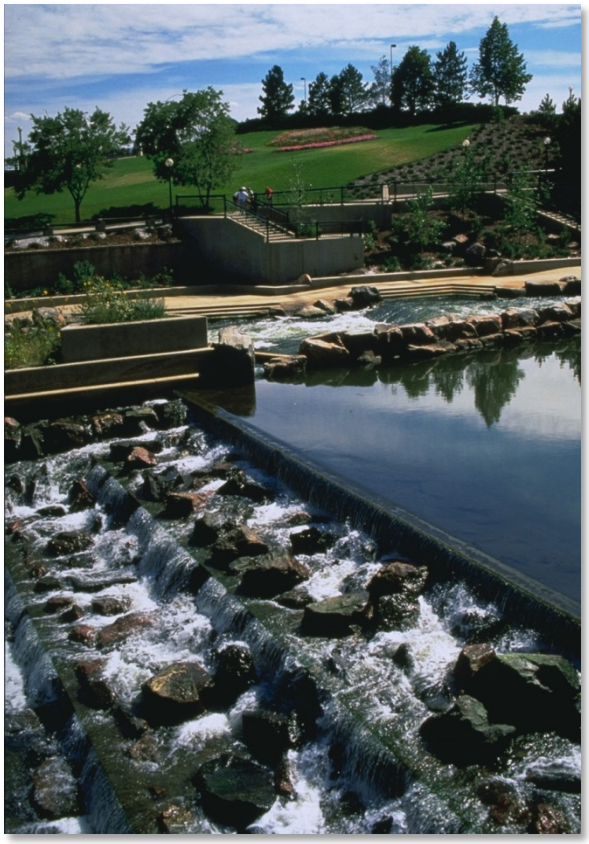
        i. Design for a Froude number of less than 1.5 at the toe of the drop.

        ii. Use a downstream face slope no steeper than 10(H):1(V). This is particularly relevant during higher flow conditions.

    b. Extend the face of the drop 1 to 2 feet below the predicted range of tailwater elevations.

    c. Where tailwater elevations may decrease over time, consider use of a downstream grade control feature, sometimes referred to as a counter weir.

    d. Where the passage location will not be clear to the user based on site, inclusion of features to identify locations of passage — often pilot rocks, signs, or buoys may be appropriate. Pilot rocks should be spaced far enough apart and in a fashion to avoid collection of debris and to not create a blockage or hazard.



Photograph 10-36. The stepped dam at Confluence Park was physically modeled at multiple flows up to the 100-year event. It was shown to not produce overly-retentive hydraulics throughout this wide range of flows. Photo courtesy of McLaughlin Whitewater Design Group.

    e. Provide for energy dissipation downstream of the structure while maintaining structural stability of the drop structure, adjacent banks and adjacent structures such as bridges. Note that local scour depths downstream of various structures have been observed to be over ten feet.

    f. Provide a smooth invert — particularly toward the center of a drop to reduce abrasions and the potential for foot entrapment. Smooth inverts can be created by using rounded boulders, sculpted concrete, concrete, or high levels of grout.

    g. Provide a recovery pool of sufficient length downstream of each drop or a series of drops to allow for recovery of boaters that have capsized or otherwise lost control. The recovery pool should include eddies which can be formed by the drop, intermediate jetties, or other features.

    h. Provide portage facilities including signs, paths, jetties, pier noses

    i. and armoring to support ingress and egress over a wide range of flows.

j. Consider the addition of anchor points to attach ropes strategically located near drop structures. These can be used by emergency personnel so they have something to connect onto during rescues or for removal of debris.

4. Obtain peer review of the preliminary and final designs.

5. Be onsite during placement of rock and features to reduce the occurrence of sharp edges and poor local hydraulic conditions. Be attentive to specific or nuanced placement detailed in drawings.

6. Plan for post-construction adjustment (tuning), adding or removing of boulders or portions of the structure after initial construction. Typically this would be conducted after a range of flows has been observed.

4.5.3 Retrofitting Existing Structures

When an existing dam or drop structure lacks features outlined in this chapter, retrofitting with portages, boatable passages, or other physical modifications may be needed. Retrofitting these structures may include installing a stepped or sloped surface along the downstream face of the dam or drop structure and providing appropriate barriers, signing and accessible portages with take-out and put-in landings. It may also include the addition of a boat chute or bypass to allow for passage of appropriate river craft. A structure that has too much drop may be replaced with two or more structures to reduce the drop at a single location. For example, replacing a 4-foot drop with two 2-foot drops could reduce a hazardous hydraulic condition.

Photograph 10-37. Pilot rocks can help recreationalists find a boat chute or preferred path through a drop structure. This is particularly helpful in wide rivers with a prominent horizon line. Photo courtesy of McLaughlin Whitewater Design Group.

Retrofitting dams or drop structures requires specific care to ensure that the retrofit meets the objective of improving public safety. Due to specific site and structure conditions, physical hydraulic models are sometimes appropriate in the design phase for retrofitting of dams and drop structures.

4.5.4 Integral Roughened Channel Fish Passage

Fish passage through drop structures can be critical in certain reaches of rivers and engineers should be alert to where they are needed. Fish passage usually refers to the ability of fish to swim upstream through the drop structure, but it can also include downstream passage of fish. The need and specific requirements can be established by the Colorado Parks and Wildlife, the US Fish and Wildlife Service, and other local governmental agencies. While identification of any regulatory requirements or project objectives should be established early, they can also arise through the USACE 404 permitting process. Where both fish passage and passage of in-channel users is desired, inclusion of integral fish passage features into boatable drop structures is preferred. Integration of these objectives into one passage usually results in a "roughened channel" type of fish passage, also referred to as rock ramps, natural fishways, riffle-pool fishways, and many others. Roughened channel fish passages can be readily included into boatable drop structures. In addition to fish passage at drop structures, recreational features and other infrastructure can

be designed to improve aquatic habitat.

Integrated features and objectives to improve habitat and provide for fish passage can include:

- Deep pools and thalwegs that are self-scouring,
- Resting areas,
- Creation of currents that encourage passage,
- Avoidance of depositions of fine or organic sediments,
- Avoidance of shallow zones to avoid bird predation,
- Creation of conditions conducive to benthic macroinvertebrates such as small sheltered spaces,
- Avoidance of fish stranding areas where rapid decreases in flows commonly occur, and
- Attraction flows that lead to the zones intended for upstream fish passage.

Care should be taken when incorporating the objectives above so that safety in not inadvertently impacted.

Criteria and objectives when fish passage is integrated into drop structures include:

- Selection of fish passage type and design to meet swimming capabilities and behaviors of target species,
- Maximum darting and sustained velocities,
- Maximum vertical drop heights, and
- Minimum depths.

Specific criteria depend upon the target species identified for passage and other factors. There are numerous agencies, publications, texts, and technical papers that can be used to establish criteria and provide design guidelines. Some of these include the US Bureau of Reclamation, the National Oceanic Atmosphere Administration (NOAA) in addition to the regulatory agencies listed earlier in this section. References for more detailed design/discussions include *Fisheries Handbook* (Bell 1991). In cases where fish passage or habitat is an important element or a permit requirement, it is best to include specialists in fish passage on the design team. However it should be recognized that the steepness, width, and depth criteria for whitewater boating can be compatible with those for fish passage.

Slopes of roughened channels or drop structures to meet fish passage objectives and criteria depend upon the target species, other related factors, and the size and configuration of the boulders that comprise the channel or slope of the drop structure. A typical range of slopes that have been used are 0.5 to 8 percent (Wildman, Parasiewicz, Katopodis, Dumont).

4.5.5 Supplemental Guidance for Drop Structures

In addition to the appropriate recommendations, considerations, guidance, and procedures established in the *Hydraulic Structures* chapter, and those outlined in this chapter, the following should be considered in the design and construction of boatable drop structures.

Photograph 10-38. Multi-use design of the whitewater bypass at Confluence Park conveys flood flows, offers continual access, and avoids overly-retentive hydraulic jumps over a wide range of flows. Photo courtesy of Thanis McLaughlin.

1. Determine and evaluate hydraulic conditions throughout the range of flows and tailwater elevations.
2. Allow for future downstream channel degradation and inaccuracies in estimation of tailwater elevations throughout the range of flows or consider the need for a downstream grade control structure (counter weir or small drop structure).
3. Include recovery zones or pools downstream of the drop structure where appropriate.
4. Avoid large recirculating eddies and enhance favorable swimming conditions to the banks to promote self-rescue.
5. Provide downstream bank protection as higher velocities can be carried farther downstream (compared to a conventional drop structure).
6. Include smooth inverts in the areas where velocities are high, depths are shallow, and there is a concentration of boating traffic.
7. Incorporate features to address sediment and bed material transport and other dynamic river processes.
8. Observe performance over a range of flows after initial construction. Adjustments after initial construction (or *tuning*) are advantageous and often needed. This can include adding or removing boulders and grouting. This does not include rebuilding portions of the structure that have failed or replacing important boulders that have moved during high flows.

4.6 Bridge Piers or other Steep-Sided Structures

Clear span bridges are preferable but may be cost prohibitive. Where practicable, keep piers out of the floodway and main channel corridor. Often two piers, one at each bank, are preferable to one pier in the center of the channel. However, piers with debris accumulation located near the toe of a steep-sided bank can be a hazard and may trap rafters between the bank and pier.

Efforts should be made to reduce the chance of pinning, broaching, or wrapping on bridge piers or other vertical or near vertical midstream obstructions, especially where approach velocities are high. Piers can be made less hazardous by extending them or their noses upstream of the bridge deck into less constricted portions of the channel where velocities may be lower. Design of piers or features that reduce the accumulation of debris without creating other hazards should be investigated.

Photograph 10-39. The "pier nose extensions" on this bridge reduce the accumulation of debris and thereby improve safety for in-river users. Photo courtesy of McLaughlin Whitewater Design Group.

4.7 Access and Portages

Egress from the water in a boatable channel should be evaluated by the design professional and impediments in critical areas avoided where practical.

Provide pathways (portages) around all drop structures, even if designed for boat passage, and around potentially dangerous obstructions or hydraulic conditions. Consider the use and maintenance of a buoy system upstream of these areas. Portages around boatable drop structures provide alternative route for those who do not wish to run whitewater due to hazardous flow conditions, presence of debris, or other reasons.

Photograph 10-40. Buoys upstream of Confluence Park Dam guide recreationalists away from the downstream dam and intake. Photo courtesy of McLaughlin Whitewater Design Group.

Portages should include an appropriately located "take-out" with slow velocities throughout a range of flows, such as an eddy. A jetty can be used to create an eddy or provide slow currents for access and portages as well as provide bank stabilization benefits. Locate take-outs and associated signage sufficiently upstream of a structure or obstruction. Design take-outs to resist local scour. Locate the downstream "put-in" far enough from the structure to avoid potential hazards associated with a range of flow conditions. For non-boatable structures such as dams, state or federal regulations may govern the boating exclusion zone upstream and downstream. These exclusion zones set the minimum distance from the dam or non-boatable structure to the beginning and endpoints of the portage path.

Photograph 10-41. This sculpted concrete jetty forms a small eddy downstream to enhance access to the river. The sculpted concrete surfacing also provides for direct access into the water's edge. Photo courtesy of McLaughlin Whitewater Design Group.

Improved access benefits all users. Accessibility standards for the pathways and facilities adjacent to the water are triggered by project funding from or use of lands of Federal, State or local governments. It should be noted that there are no accessibility standards for hand carried boat launches at the point at which the water is accessed; however, there are accessibility standards applicable to the pathways and facilities leading up to the water's edge.

Photograph 10-42. This access ramp was designed with universal access in mind. Photo courtesy John Anderson.

Guidance for universal design that works well for most people, including individuals with physical disabilities, should be reviewed. See the user accessibility guidance provided in the River Management Society and National Park Service publication titled *Prepare to Launch!* Most recent larger recreational venues with whitewater features incorporate improvements that provide better access for all. Access improvements and equipment to facilitate rescue personnel should be located in close proximity to drop structures and recovery zones where practical.

Recommendations for accessible portage paths and ingress and egress points include:

- Avoid longitudinal grades that exceed 1:12 for short rises and 1:20 for longer rises where practical. This is typically most challenging at points of entry and exit to and from the water.
- Provide durable, permanent, nonslip paving material capable of withstanding locally high water velocities without damage or undercutting.
- Provide a cross slope of no more than 2%.
- Avoid use of guard railings where practical as they tend to be damaged by flood waters and accumulate debris. Accordingly, avoid abrupt drop offs or excessively steep grades adjacent to paths. Where local conditions require guards within the floodway, consider solid, durable walls instead of open-work railings.
- Site the portage path above the one-year flood level where practical.

Access for the disabled is governed by the Architectural Barriers Act of 1968 (ABA, triggered by Federal funding of programs and facilities) the Americans with Disabilities Act of 1990 (ADA, applicable to facilities for public accommodation) and Section 504 of the Rehabilitation Act of 1973 (programs or activities that receive Federal funds). The applicability of these standards and guidelines for access to the disabled to a project should be researched by the design professional. The guidelines and recommendations above are not substitutes for this research. See the inset on the following page for resources pertaining to accessibility.

Accessibility Resources and Guidelines

ABA Accessibility Standards (www.access-board.gov)

ADA Accessibility Standards for Accessible Design (www.ada.gov)

American Canoe Association (ACA)

American Trails, Resources and Library

2010 ADA Standards Excerpts for Recreational Boating Facilities, California Department of Boating and Waterways (2013)

Best Management Practices, Western Wood Preservers Institute

Designing Accessible Launches in Accordance with Americans with Disabilities Act Accessibility Guidelines, National Park Service

Environmental and Aesthetic Impacts of Small Docks and Piers, NOAA Coastal Ocean Program

Floating Trail Bridges and Docks, US Forest Service

Guidance on the 2010 Standards for Accessible Design, Department of Justice

Guidelines for Developing Non-motorized Boat Launches in Florida, Florida Fish & Wildlife Conservation Commission

Guidelines for Public Safety At Hydropower Projects, Federal Energy Regulatory Commission

Hydropower Relicensing, Recreational Liability, and Access, American Whitewater

Iowa Water Trails Toolkit, Iowa Department of Natural Resources

Layout, Design and Construction Handbook for Small Craft Boat Launching Facilities, California Department of Boating and Waterways

Non-Motorized Boating in California (see Table 3.1: Overview of Key Facility Needs by Non-Motorized Boat Types in California)

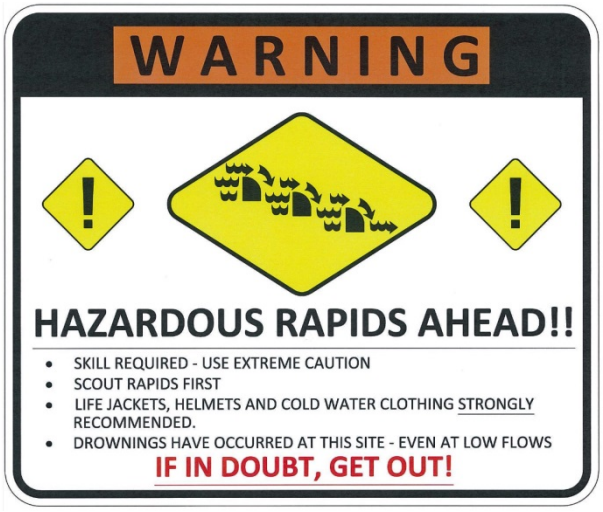
Prepare to Launch! Guidelines for Assessing, Designing and Building Access Sites for Carry-in Watercraft, River Management Society and National Park Service

Streambank Revegetation and Protection: A Guide for Alaska, Alaska Department of Fish & Game

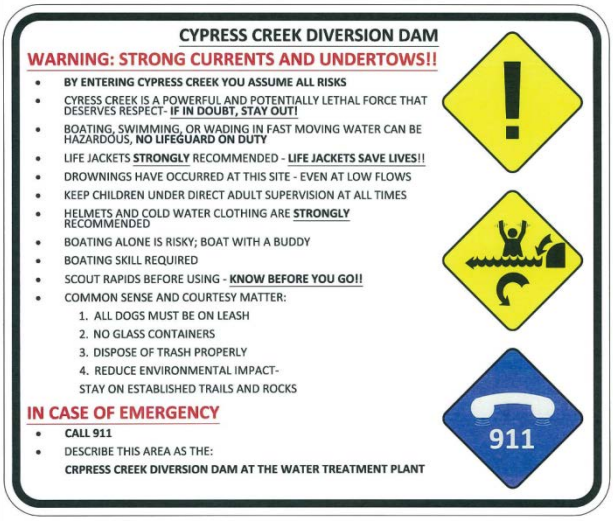
Wetland Trail Design and Construction, US Forest Service

4.8 Safety Signage

In addition to responsible design, signage should be provided at locations where public use is intended near hydraulic structures and where hazards are not obvious to the responsible user. Warning signs for dams or drop structures that are to be avoided (i.e., having no passage) are critical. There are a number of signage examples and guidelines across the United States.



Photograph 10-43. Signage prior to a boatable diversion in Florence Alabama. Courtesy of McLaughlin Whitewater Design Group.



Photograph 10-44. Additional signage placed adjacent to the facility in Florence Alabama. Photo courtesy of McLaughlin Whitewater Design Group.

There are currently no widely accepted standards for warning signage at river parks or boatable drop structures. One of the primary safety concerns is the prevalence of users without approved lifejackets, or Personal Floatation Devices (PFDs). Signage that emphasizes the need for PFDs is of utmost importance.

Signage wording should be reviewed by persons knowledgeable with both effective signage and river-related activities. Some considerations for wording include:

- Warning: Strong Currents and Undertows — Life Jackets Required
- Use Helmets and Cold Water Clothing
- Emergencies Call 911 (and/or provide phone number of fire department)
- Rapid Ahead - Scout Before Using (place upstream of portage)
- Skill Required
- Paddle Responsibly
- Bank Drops Off Quickly
- Don’t Go in the Water Alone
- Keep Children Under Direct Adult Supervision at All Times
- Drownings Have Occurred at This Site — Even at Low Flows

- Use at Your Own Risk

Signage to warn in-channel users of poor water quality, especially during wet-weather flow in urban areas, may also be appropriate.

Efforts to develop more universally accepted recommendations and suggested wording are being considered by several entities but do not exist at the time of publishing this manual. Some examples of signage are included in Chapter 7 of the Colorado Water Conservation Board's (CWCB) Floodplain and Stormwater Criteria Manual.

4.9 Maintenance Considerations

Maintenance of boatable channels is important to avoid accumulation of debris that could create a strainer and to identify any rock movement or structural issues that could create hazardous conditions. Improvements should be planned, designed, and constructed to avoid excessive maintenance requirements. Potential areas of sediment deposition resulting in aggradation or areas that accumulate debris, particularly in pools or zones with low velocities, should be identified. Maintenance needs and frequency of cleaning should be roughly approximated in the planning and design process. Paths, grading, and other ancillary infrastructure or considerations should be included to facilitate identified maintenance needs.

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Chapter 11
Culverts and Bridges

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1.0 Introduction and Overview

This chapter addresses the hydraulic function of culverts and bridges, i.e., conveyance of surface water through embankments such as roadways and railroads. Structural considerations, such as the design requirements to support loads, are not addressed in this chapter. The chapter is primarily focused on design of culverts with the exception of Section 7.0 which provides a brief overview of considerations with regard to bridges. When designing a culvert or bridge that will include a path, also see the *Stream Access and Recreational Channels* Chapter.

Photograph 11-1. Culverts frequently provide compatible conditions for upstream wetland growth.

A careful approach to design is essential, for new and retrofit situations, because crossings often significantly influence upstream and downstream flood risks, floodplain management, and public safety. Multiple factors have a bearing on the hydraulic capacity and overall performance of a structure. These include the size, shape, slope, material, inlet configuration, outlet protection, and other variables. Sizes and shapes of culverts vary from small circular pipes to extremely large arch sections used in place of a bridge.

In addition to the primary function of conveying flow, culverts can create conditions upstream that are suitable for wetland growth (Photograph 11-1). Aesthetic considerations should also be incorporated into a design, such as visually integrating a crossing into the surrounding landscape. This can be achieved through thoughtful grading, landscaping and wall design including finishing.

Much of the information and many of the references necessary to design culverts according to the procedure given in this chapter can be found in *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5 (FHWA 2005a). Examples of charts and nomographs from that publication are given in this chapter for some of the most common culvert scenarios; however, this chapter does not republish many of the nomographs, equations and technical background provided by FHWA's *Hydraulic Design of Highway Culverts* since it is readily available on the internet and provides a level of detail that goes beyond what most typical users of the Urban Storm Drainage Criteria Manual (USDCM) will require. Refer to the FHWA publication for special cases, larger culvert sizes, or specific technical topics not covered in this chapter.

2.0 Required Design Information

The hydraulic design of a culvert or bridge includes determining the types of information described in the following sections:

General Planning Considerations

- Drainage Master Plan
    - How will the proposed structure fit into the relevant major drainageway master plan, and are there multi-purpose objectives that could be satisfied? For example, box culverts can also serve as below-grade crossings, with one cell elevated to convey flows only during larger storm events (see the *Open Channels* chapter for criteria). Additionally, a culvert can be used to discharge at a

controlled flow rate while the area upstream from the culvert is, for example, used for detention storage to reduce a storm runoff peak (in such a case, the embankment that the culvert penetrates should effectively be designed as a dam).

- Careful consideration should be taken to ensure that upstream and downstream property owners are not adversely affected by new hydraulic conditions. When restricting flow to attenuate major events, evaluate the area of potential flooding upstream of the new culvert. If a culvert is replaced by one with more capacity, the downstream effects of the increased flow must be evaluated. Assure consistency with existing master plans and/or outfall studies.

- Safety Concerns

  - Are there specific public safety issues related to the culvert location, such as proximity to parks or other public areas that have a bearing on the culvert design? A key question is whether or not to include a safety/debris grate at the culvert inlet (grates should be avoided at culvert outlets).

  - Culverts are often located at the bottom of a steep slope. Large box culverts, in particular, can create conditions where there is a significant falling hazard, which poses risk to the public. In such cases, fencing (or guardrails for roadway applications) is recommended for public safety.

Specific Design Considerations

- Location

  - Culvert location is an integral part of roadway design. The designer should identify all live stream crossings, springs, low areas, gullies, and impoundment areas created by the new roadway embankment for possible culvert locations.

  - The culvert should be located as to not change the existing stream alignment and be aligned to give the stream a direct entrance and exit. Abrupt changes in direction at either end may reduce capacity making a larger structure necessary. Bends within a culvert should also be avoided where possible. If necessary, a direct inlet and outlet may be obtained by channel realignment, skewing the culvert, or a combination of these.

  - Where water must be turned into a culvert, headwalls, wingwalls, and aprons with configurations similar to those in Figure 11-13 should be used as protection against scour and to provide an efficient inlet.

- Design Flood Frequency and Discharge

  - The design flood frequency for culverts is closely related to the pavement encroachment and road overtopping criteria presented in Tables 1-2, 1-3 and 1-4 in the *Policy* chapter. Most municipalities within the Urban Drainage and Flood Control District (UDFCD) region have minimum design frequencies related to these tables that require culvert capacity for at least the 10-year event (and in some cases the 25-year event); however, for road and rail crossings of channels that drain a watershed of 130 acres or more, especially for arterial streets, freeways and critical crossings, a 100-year basis of design (plus freeboard above the allowable headwater) is common. Please note that state and federal standards apply to relevant highway projects. The design recurrence interval should be based on the criteria set forth in this manual in conjunction with local requirements and criteria for culvert sizing and road overtopping. The more stringent of the applicable criteria should be applied.

  - The required hydraulic capacity (i.e., design discharge) is based on the design flood frequency

and the resulting design flow rate calculated for the watershed tributary to the proposed culvert (see the *Runoff* chapter for information on hydrologic calculations). The structure should be designed to operate within acceptable limits of uncertainty of the design discharge.

- Culverts are frequently designed to overtop in a 100-year event while bridges are typically designed to pass this flow while allowing for freeboard.

- Allowable Headwater Depth for Culverts

  - Culverts frequently constrict the natural stream flow, which causes a rise in the upstream water surface. The elevation of the upstream water surface is termed *headwater elevation*. The depth of headwater is measured from the invert of the culvert inlet to the headwater elevation for a known event. In selecting the design headwater elevation, the designer should consider the following:

    1. The headwater depth /culvert diameter ratio (*HW/D*) should not exceed 1.5 for the 100-year event peak flow unless there is justification and sufficient measures are taken to protect the culvert inlet (for example, a concrete headwall). Piping failure can be of concern for deep headwater depths, especially if there are animal burrows in the embankment.

    2. Assess the impacts caused by exceeding the design headwater depth, including:

       a. Hazard to human life and safety.

       b. Potential damage to the culvert, embankment stability and roadway.

       c. Traffic interruption in the event of roadway overtopping.

       d. Anticipated upstream and downstream flood risks, for a range of return frequencies.

    3. The elevation of the watershed divides should be higher than the design headwater elevations in order to prevent the headwater from spilling into adjacent watersheds. In flat terrain, watershed boundaries are often poorly defined, and culverts should be located and designed to minimize disruption of the existing flow paths and avoid spillover into adjacent watersheds due to culvert backwater effects.

- Tailwater Depth for Culverts

  - Tailwater is the flow depth in the downstream channel, measured from the invert of the culvert outlet to the water surface (assuming normal (uniform) flow in the channel downstream of the culvert). Knowledge of tailwater depth is critical for culvert design because a submerged outlet may cause the culvert to flow full rather than partially full.

  - Tailwater depth is typically calculated using a computer program, such as HEC-RAS or HY-8, as the water surface profile in the downstream channel, or using an alternative method for computing the normal depth. A field inspection of the downstream channel should be made to determine whether there are obstructions that will influence the tailwater depth. Tailwater depth may be controlled by several factors, including the stage in a contributing stream, headwater/backwater from structures downstream of the culvert, reservoir water surface elevations, or other downstream features.

- Allowable Outlet Velocity for Culverts

- The outlet velocity of a culvert, measured at the downstream end of the culvert, is usually higher than the maximum velocity that a natural channel can withstand without experiencing significant erosion of the bed and/or banks. Most culverts require adequate outlet protection (typically riprap or a stilling basin), and this is a frequently overlooked issue during design. Use UD-Culvert, available at www.udfcd.org to determine the length of recommended outlet protection.

- Permissible velocities at the outlet will depend upon streambed type, and the type of energy dissipation (outlet protection) that is provided. As a general rule, the velocity at the downstream edge of a project right-of -way or downstream constraint should not be greater than the pre-construction velocity.

- If the outlet velocity of a culvert is too high, the velocity may be reduced by increasing the barrel roughness, since slope and roughness are the principal factors affecting the outlet velocity. Variations in shape and size of a culvert seldom have a significant effect on the outlet velocity. If changing the barrel roughness does not provide a satisfactory reduction in outlet velocity, it may be necessary to incorporate some type of outlet protection or energy dissipation device.

- Environmental Permitting

  - Environmental permitting constraints often are applicable for new culverts or retrofits as well as for construction of bridges. For example, the Section 404 permit, administered by the United States Army Corps of Engineers (USACE), regulates construction activities in jurisdictional wetlands and "Waters of the United States." The local USACE representative should be consulted when designing a crossing to assess the permitting requirements. Culverts also often have regulatory floodplain implications and a Conditional Letter of Map Revision (CLOMR) and/or Letter of Map Revision (LOMR) is often required when a new culvert is installed.

- Fish Passage and Culverts

  - At some culvert locations, the ability of the structure to accommodate migrating fish is an important design consideration. For such sites, federal and state fish and wildlife agencies (such as the United States Fish and Wildlife Services and the Colorado Division of Wildlife) should be consulted early in the planning process. Some situations may require the construction of a bridge to span the natural stream. However, culvert modifications such as oversizing the diameter or rise of the culvert, placing the culvert below the stream bed and filling the lower portion with native streambed material can often be used to meet the design criteria established by the regulatory agencies and the fish and wildlife agencies.

- Culvert Details

  - Culvert size and shape.

  - Culvert material.

  - Alignment, grade, and length of culvert.

  - Need for protective measures against abrasion and corrosion and type of coating, if required.

  - Culvert inlet design.

  - Culvert end treatment and erosion protection.

- Amount and type of cover material required.

Other Design Considerations

Other design considerations include the following:

- What are the impacts of various culvert sizes, dimensions, and materials on upstream and downstream flood risks, including the implications of embankment overtopping?
- What type of sediment load and bed load can be anticipated for the culvert? For streams with a heavy bed load, abrasion and debris blockage can be of concern. For culverts with milder slopes or abrupt changes to a flatter grade within the culvert, filling in of culverts with sediment can be problematic and lead to increased maintenance frequency. If the culvert is in an area where there is potential for significant debris (mountainous terrain, pine beetle kill areas, recently burned areas, etc.), appropriate conservative assumptions for blockage and overflow paths should be applied.

  Deposits in culverts may also occur due to the following conditions:

  - At moderate flow rates, the culvert cross section may be larger than that of the stream, so the flow depth and sediment transport capacity is reduced.
  - Point bars form on the inside of stream bends. Culvert inlets placed at bends in the stream will be subject to deposition in the same manner. This effect is most pronounced in multiple-barrel culverts with the barrel on the inside of the curve often becoming almost totally plugged with sediment deposits.
- Structural and geotechnical considerations which are beyond the scope of this chapter.

3.0 Culvert Hydraulics

3.1 Key Hydraulic Principles

For the purposes of this review, it is assumed that the reader has a basic working knowledge of hydraulics and is familiar with the Manning's Equation (Equation 11-1), Continuity Equation (Equation 11-2), and Energy Equation (Equation 11-3):

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} \qquad \text{Equation 11-1}$$

Where:

Q = flow rate or discharge (cfs)
n = Manning roughness coefficient (see Table 11-1)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = longitudinal slope (ft/ft)

$$Q = v_1 A_1 = v_2 A_2 \qquad \text{Equation 11-2}$$

Where:

Q = flow rate or discharge (cfs)
v = velocity (ft/s)
A = cross-sectional area of flow (ft^2)

Subscripts refer to two different locations within a culvert or channel between which flow is constant.

$$\frac{v^2}{2g} + \frac{p}{\gamma} + z + \text{losses} = \text{constant} \qquad \text{Equation 11-3}$$

Where:

v = velocity (ft/s)
g = gravitational acceleration (32.2 ft/s^2)
p = pressure (lb/ft^2)
γ = specific weight of water (62.4 lb/ft^3)
(Note: p/γ = pressure head or depth of flow [ft])
z = height above datum (ft)

Table 11-1. Manning's roughness coefficients

	Reinforced Concrete Pipe (RCP)	Aluminized Steel Pipe (ASP)	Polymer Coated Steel pipe	Corrugated Aluminum Pipe	Polyvinyl Chloride Pipe (PVC)	High Density Polyethylene Pipe (HDPE)
Manning's Roughness Coefficient	0.013	0.013	0.013	0.013	0.011	0.012

3.1.1 Energy and Hydraulic Grade Lines

The concepts of energy grade line (EGL) and hydraulic grade line (HGL), and related terms, are illustrated for open channel flow (Figure 11-1) and closed conduit flow (Figure 11-2).

Open Channel Flow
The EGL, also known as the line of total head, is the sum of velocity head ($v^2/2g$), the depth of flow or pressure head (p/γ), and elevation above an arbitrary datum represented by the distance (z). The energy grade line slopes downward in the direction of flow by an amount equal to the energy gradient (H_L/L), where H_L equals the total energy loss over the distance L.
The HGL, also known as the line of piezometric head, is the sum of the depth of flow or pressure head (p/γ), and the elevation (z). The HGL does not include the velocity head.

For open channel flow, the term p/γ is equivalent to the depth of flow and the hydraulic grade line is the same as the water surface (Point 5 on Figure 11-1).

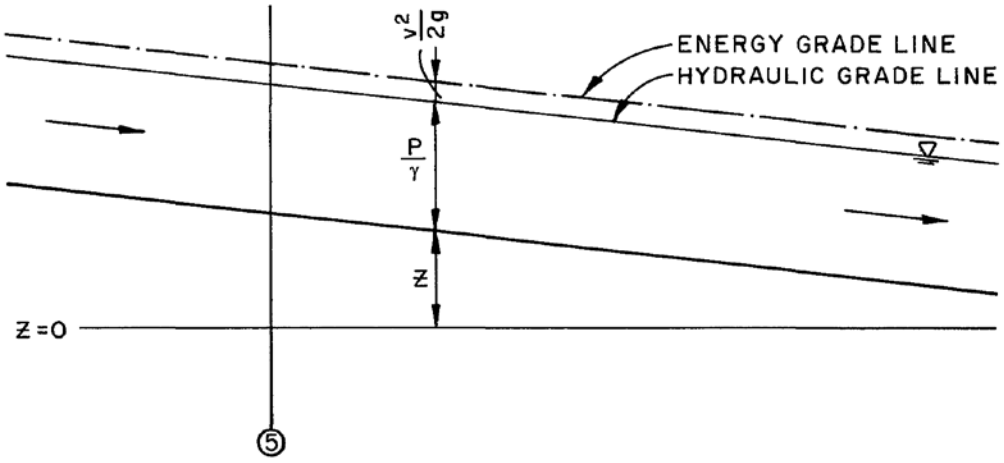


Figure 11-1. Illustration of terms for open channel flow

Closed Conduit Flow

While it is preferable to design culverts for open channel flow conditions (i.e. non-pressurized flow), when the culvert is designed with a headwater depth exceeding the top of the culvert (not uncommon) pressurized flow may develop under some tailwater conditions and/or during events that exceed the design capacity of the culvert. For pressure flow in closed conduits, p/γ is the pressure head and the hydraulic grade line is above the top of the conduit provided that the pressure relative to atmospheric pressure is positive (see Figure 11-2).

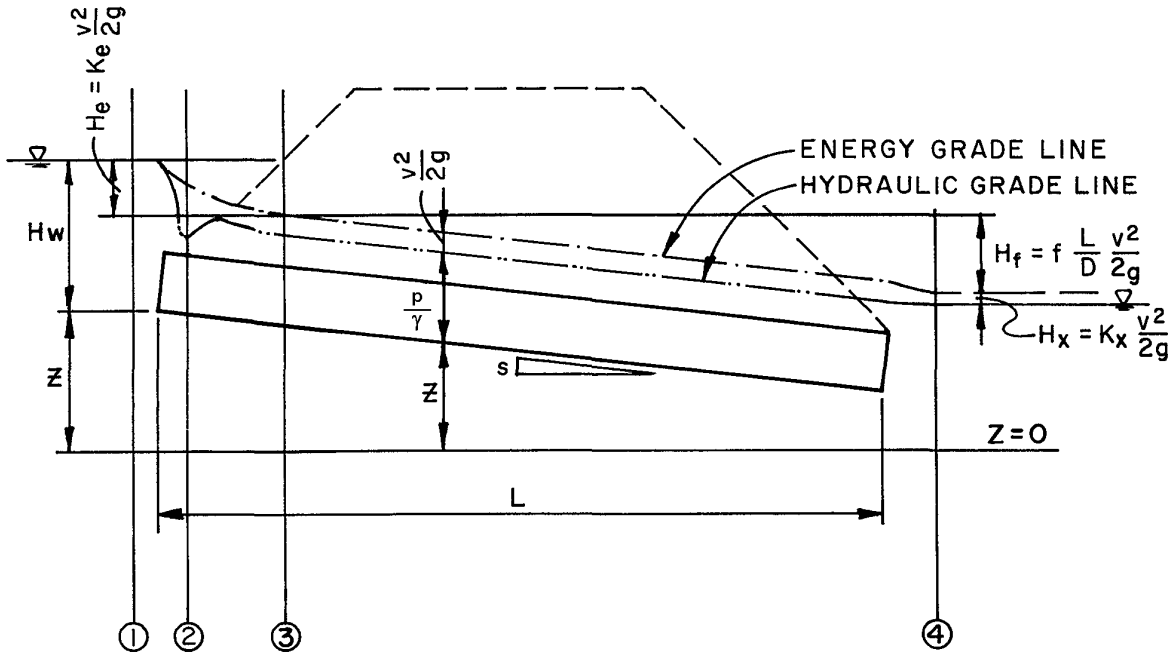


Figure 11-2. Illustration of terms for closed conduit flow

When ponding occurs at the entrance of a culvert (see Point 1 on Figure 11-2) the velocity is considered minimal and the energy grade line and hydraulic grade line are nearly the same. As water enters the culvert at the inlet, the flow is contracted by the inlet geometry causing a loss of energy (see Point 2). As a turbulent velocity distribution is reestablished downstream of the entrance (see Point 3), a loss of energy occurs due to friction and/or resistance from the culvert. In short culverts, the entrance losses are likely to be high relative to the friction loss. At the culvert exit (Point 4), additional losses occur through turbulence as the flow expands and is retarded by the tailwater in the downstream channel.

3.1.2 Inlet and Outlet Control

There are two basic types of flow conditions in culverts: (1) *inlet control* and (2) *outlet control*[1]. For each type of control, a different combination of factors is used to determine the hydraulic capacity of the culvert. The determination of actual flow conditions can be difficult; therefore, the designer must check for both types of control and design for the most adverse condition.

Inlet Control

A culvert operates under inlet control when the flow capacity of the culvert is controlled at the inlet by these factors:

- Depth of headwater.

[1] "Outlet control" refers to all head loss mechanisms other than the culvert inlet. These outlet control mechanisms include head loss attributed to pipe friction, bends, culvert outlet, and tailwater. "Outlet control" is the common naming convention for these losses, including in FHWA 2005a.

- Inlet edge configuration.
- Cross-sectional area.
- Barrel shape (e.g., circular, elliptical, rectangular, etc.).

With inlet control, the culvert barrel usually flows only partially full. Inlet control for culverts can occur under unsubmerged or submerged conditions.

Unsubmerged Inlet: The headwater depth is not sufficient to submerge the top of the culvert and the culvert invert slope is supercritical (Figure 11-3).

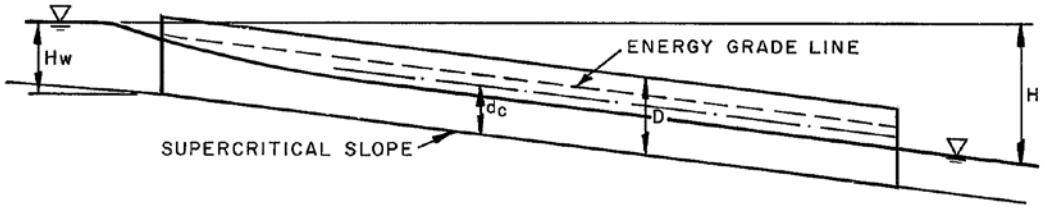


Figure 11-3. Inlet control – unsubmerged inlet

Submerged Inlet : The headwater submerges the top of the culvert and the pipe does not flow full (Figure 11-4). This is the most common condition of inlet control.

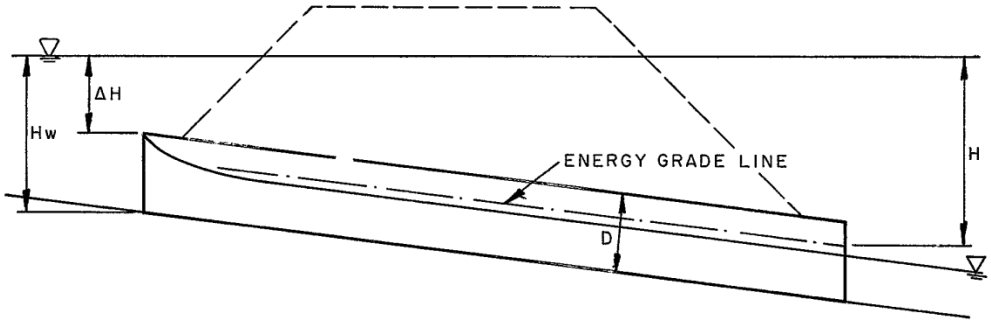


Figure 11-4. Inlet control – submerged inlet

A culvert flowing under inlet control is sometimes referred to as a "hydraulically short" culvert.

Outlet Control

The hydraulic control of a culvert can switch from the inlet to the outlet under several conditions, such as high headwater, relatively flat culvert slope, or sufficiently long culvert length. [2]

With outlet control, culvert hydraulic performance is determined by the following factors:

- Depth of headwater,
- Inlet edge configuration,
- Cross-sectional area,
- Bends (if applicable),
- Culvert shape,
- Barrel slope,
- Barrel length,
- Barrel roughness, and
- Depth of tailwater.

Outlet control for culverts can occur under partially full or full conduit conditions.

Partially Full Conduit: The headwater depth is insufficient to submerge the top of the culvert, and the culvert slope is subcritical, resulting in the culvert flowing partially full (Figure 11-5). This is the least common condition of outlet control.

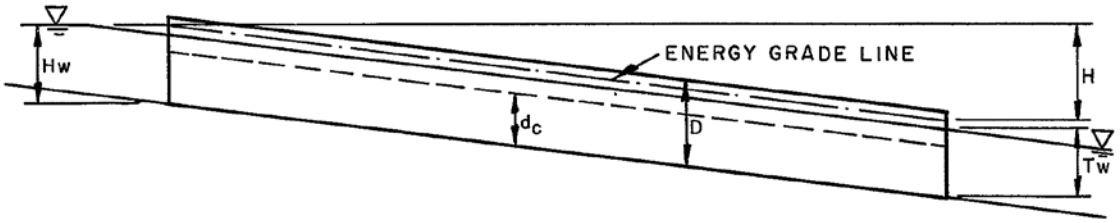


Figure 11-5. Outlet control – partially full conduit

Full Conduit: The culvert flows full along its length (Figure 11-6). This is the most common condition of outlet control.

[2] Over a range of event frequencies (and even within an event during dynamic conditions), most culverts experience both inlet and outlet control conditions at times.

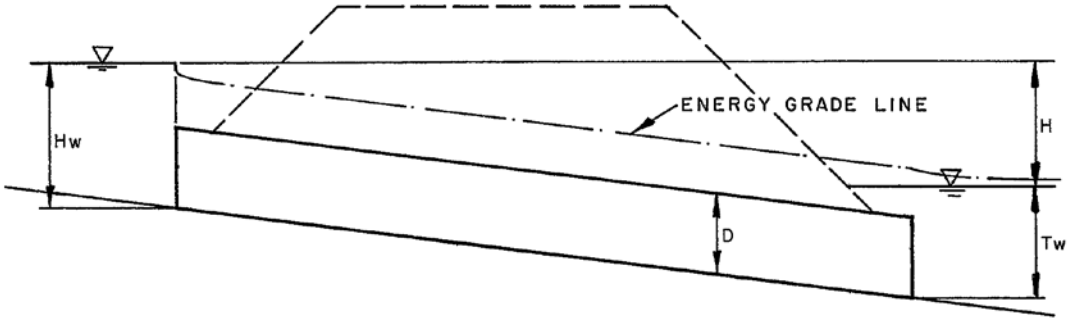


Figure 11-6. Outlet control – full conduit

A culvert flowing under outlet control is sometimes referred to as a "hydraulically long" culvert. With outlet control, factors that may affect performance for a given culvert size and headwater depth are barrel length, barrel roughness, and tailwater depth.

3.2 Energy Losses

The energy losses that must be evaluated to determine the carrying capacity of a culvert are:

- Inlet (or entrance) losses (Section 3.2.1)
- Friction losses (through the culvert) (Section 3.2.2)
- Bend losses (if applicable) (Section 4 of the *Streets, Inlets, and Storm Drains* chapter)
- Outlet (or exit) losses (Section 3.2.3)

It is noteworthy that the entrance losses in a culvert can be as important as the friction losses, particularly in short culverts.

3.2.1 Inlet Losses

For inlet losses, the governing equations are:

$$Q = CA\sqrt{2gH} \qquad \text{Equation 11-4}$$

and

$$H_e = K_e \frac{V^2}{2g} \qquad \text{Equation 11-5}$$

Where:

Q = flow rate or discharge (cfs)
C = contraction coefficient (dimensionless)
A = cross-sectional area (ft^2)
g = acceleration due to gravity (32.2 ft/s^2)

H = total head (ft)
H_e = head loss at entrance (ft)
K_e = entrance loss coefficient (dimensionless, see Section 5.0)
V = average velocity (ft/s)

Capacity based on headwater relevant to culvert rise.

The Federal Highway Administration (FHWA) has determined that the orifice equation is not valid representation of actual capacity until the headwater (H) is at least 3 times the height (rise) of the culvert. For H less than 0.5(rise), open channel minimum energy equations should be applied, and for 0.5(rise) < H < 3(rise), empirical best-fit equations should be applied. This methodology is programmed into HY-8 and into the UD-Culvert workbook.

3.2.2 Friction Losses

Pipes Flowing Partially Full
Friction head loss for pipes flowing partially full can be determined from the Manning's equation reformulated to calculate head loss:

$$H_f = \left(\frac{29 n^2 L}{R^{4/3}}\right)\left(\frac{V^2}{2g}\right) \qquad \text{Equation 11-6}$$

Where:

H_f = frictional head loss in culvert barrel (ft)
n = Manning roughness coefficient (dimensionless)
L = culvert length (ft)
R = hydraulic radius (ft, area/wetted perimeter)
A = cross-sectional area of culvert barrel (ft^2)
V = average velocity (ft)
g = acceleration due to gravity (32.2 ft/s^2)

Pipes Flowing Full
Friction head loss for turbulent flow in pipes flowing full can be determined from the Darcy-Weisbach equation.

$$H_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) \qquad \text{Equation 11-7}$$

Where:

H_f = frictional head loss (ft)
f = friction factor (dimensionless)
L = culvert length (ft)
D = pipe diameter (ft)
V = average velocity (ft)
g = acceleration due to gravity (32.2 ft/s^2)

3.2.3 Outlet Losses

For outlet (or exit) losses, the governing equations are related to the difference in velocity head between: a) the pipe flow, and b) the downstream channel at the end of the pipe. The downstream channel velocity is usually neglected, resulting in the outlet losses being equal to the velocity head of full flow in the culvert barrel, given by the following:

$$H_o = \frac{V^2}{2g} \qquad \text{Equation 11-8}$$

Where:

H_o = outlet head loss (ft)
V = average velocity in culvert barrel (ft)
g = acceleration due to gravity (32.2 ft/s^2)

3.2.4 Total Losses

Combining the relationships for entrance loss, friction loss, and outlet (or exit) loss, the following equation for total head loss is obtained (i.e., difference in the headwater and tailwater elevations):

$$H = \left[1 + K_e + \frac{29n^2L}{R^{1.33}}\right]\frac{V^2}{2g} \qquad \text{Equation 11-9}$$

Where:

H = difference in the headwater and tailwater elevations (ft)
K_e = entrance loss coefficient (dimensionless)
n = Manning roughness coefficient (dimensionless)
L = culvert length (ft)
R = hydraulic radius (area/wetted perimeter)
V = average velocity (ft)
g = acceleration due to gravity (32.2 ft/s^2)

4.0 Culvert Sizing and Design

The hydraulic design of culverts can be completed using several different methods, including the following described in this chapter:

- Capacity Charts (Section 4.1)
- Nomographs (Section 4.2)
- Computer Applications (Section 3.04.3)

The capacity charts and nomographs are methods that were frequently used before the widespread use of computers; however, they are older methods that are now less commonly used in lieu of computer applications. The capacity charts and nomographs still have utility for independently sizing culverts or for checking results generated from software packages. Hence, all three of these methods for culvert sizing are addressed in this manual.

4.1 Capacity Charts

Capacity charts can provide a good understanding of how culvert size requirements vary depending on multiple variables. Descriptions are provided below for the application of capacity charts for inlet control (Section 7.17.14.1.1), outlet control (Section 7.17.14.1.2), as well as a procedure for their use (Section 7.17.14.1.3).

It is important to recognize that there are numerous restrictions on the use of capacity charts in terms of culvert entrance and exit conditions. Capacity charts for all of the types of entrance conditions that a designer may encounter are not provided in this manual. For capacity charts for a range of entrance conditions refer to FHWA Hydraulic Engineering Circular No. 10 (FHWA 1972), available for download at: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/hec/hec10.pdf. Perhaps most important to recognize is that capacity charts should only be used for free outfall conditions. This is important because for some conditions, such as flood flows on relatively flat slopes, high tailwater conditions will inevitably be encountered and capacity charts would not be suitable.

Examples of capacity charts used for culvert sizing are shown on Figure 11-7. The upper chart is for circular culvert diameters from 18 to 36 inches and the lower chart is for circular culvert diameters from 36 to 66 inches. The discussion below refers to these charts.

Each chart contains a series of curves which show the discharge capacity per culvert barrel (in cfs) for each of several sizes of similar culvert types, given various headwater depths (measured in feet above the culvert invert at the inlet). The curved lines represent the ratio of the culvert length (L) in feet, to 100 times the slope (s) in units of ft/ft. Each culvert size on the chart is described by two lines: one solid and one dashed. The solid line represents the division between outlet and inlet control. The dashed line represents the maximum $L/(100s)$ ratio for which the curve may be used without modification.

4.1.1 Culverts Under Inlet Control

When using the capacity charts, for values of $L/(100s)$ less than that shown on the solid line, the culvert is operating under inlet control. The headwater depth is determined from the $L/(100s)$ value given on the solid line. The inlet control curves (solid) are plotted from model test data. The outlet control curves (dashed) were computed for culverts of various lengths with relatively flat slopes. Free outfall at the outlet was assumed; therefore, tailwater depth is assumed not to influence the culvert performance.

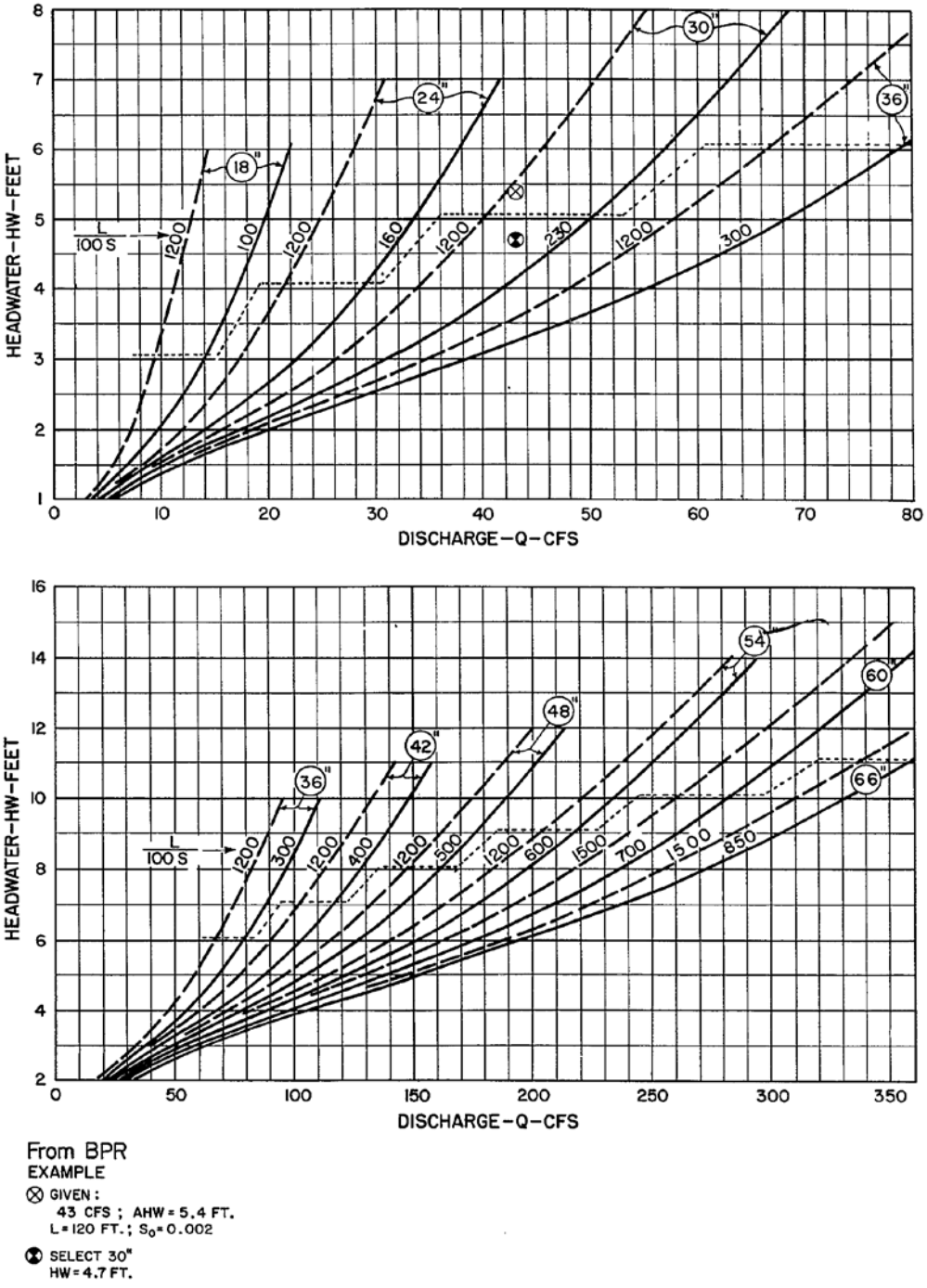


Figure 11-7. Culvert capacity chart—example

(Assumes free outfall conditions and includes elevation plus velocity head in headwater.)

4.1.2 Culverts Under Outlet Control

When using the capacity charts for culverts flowing under outlet control, the head loss at the entrance is not determined by the capacity charts, but is computed using entrance loss coefficients. In addition, the hydraulic roughness of the culvert material is taken into account in computing resistance loss for full or part-full flow, with Manning's *n* values ranging from 0.012 to 0.032, depending on the pipe material (see Table 11-1).

Except for large pipe sizes, headwater depths on the charts extend to 3.0 times the culvert height. Pipe arches and oval pipe show headwater up to 2.5 times their height since they are used in low fills. The dotted line, stepped across the charts, shows headwater depths approximately twice the barrel height and indicates the upper limit of unrestricted use of the charts. Above this line the headwater elevation should be checked with the nomographs (see Section 4.2) or with computer programs (see Section 4.3). Also, as stated in Section 2.2, UDFCD's policy is that the headwater depth/culvert diameter ratio (HW/D) should not exceed 1.5 unless there is justification and sufficient measures are taken to protect the embankment from piping.

The headwater depth given by the charts is actually the difference in elevation between the culvert invert at the entrance and the total head (i.e., the elevation head plus velocity head for flow in the approach channel). In most cases, the water surface upstream from the inlet is so close to the same level as the total head that the chart determination may be used as headwater depth for practical design purposes (assuming minimal velocity head). For practical purposes, approach velocities up to about 3 feet per second can be neglected. However, for approach velocities greater than 3 feet per second, the velocity head should be subtracted from the curve determination of headwater to obtain the actual headwater depth.

4.1.3 Capacity Chart Procedure

The procedure for sizing a culvert using the capacity charts is summarized below. Data can be compiled in the Design Computation Form shown on Figure 11-8.

1. Identify design data and list on the Design Computation Form:

   - *Q* = flow or discharge rate (cfs) for the design discharge (Q1) and a check discharge (Q2) for a different storm event (e.g., 50-year or 100-year event).
   - Tailwater elevations for both Q1 and Q2 (calculated using HEC-RAS, HY-8 or other method) (ft).
   - *L* = length of culvert (ft).
   - *s* = slope of culvert (ft/ft).
   - Allowable Hw = headwater depth (ft).
   - Culvert type and entrance type for the first trial culvert design.

2. Compute *L*/(100*s*).

3. Find the design discharge (*Q)* in the appropriate capacity chart. Locate the appropriate chart (based on culvert size, shape, and entrance condition) in FHWA Hydraulic Engineering Circular No. 10 (HEC 10), *Capacity Charts for the Hydraulic Design of Highway Culverts* (FHWA, 1972), available for download at www.fhwa.dot.gov.

4. Using the design discharge and capacity chart from Step 3, find the L/(100s) value for the smallest pipe that will pass the design discharge. If this value is above the dotted line (the maximum L/(100s) ratio for which the curves may be used without modification), use the nomographs (from FHWA 2005a) to check headwater conditions.

5. If L/(100s) is less than the value of L/(100s) given for the solid line, then the value of Hw is the value obtained from the solid line curve. If L/(100s) is larger than the value for the dashed outlet control curve, then special measures must be taken, and the reader is referred to *Hydraulic Design of Highway Culverts* (FHWA 2005a).

6. Check the headwater depth (Hw) value obtained from the charts with the allowable Hw. If the indicated Hw is greater than the allowable Hw, then check the next largest pipe size to see if the Hw elevation is acceptable (i.e., is less than the allowable *Hw*).

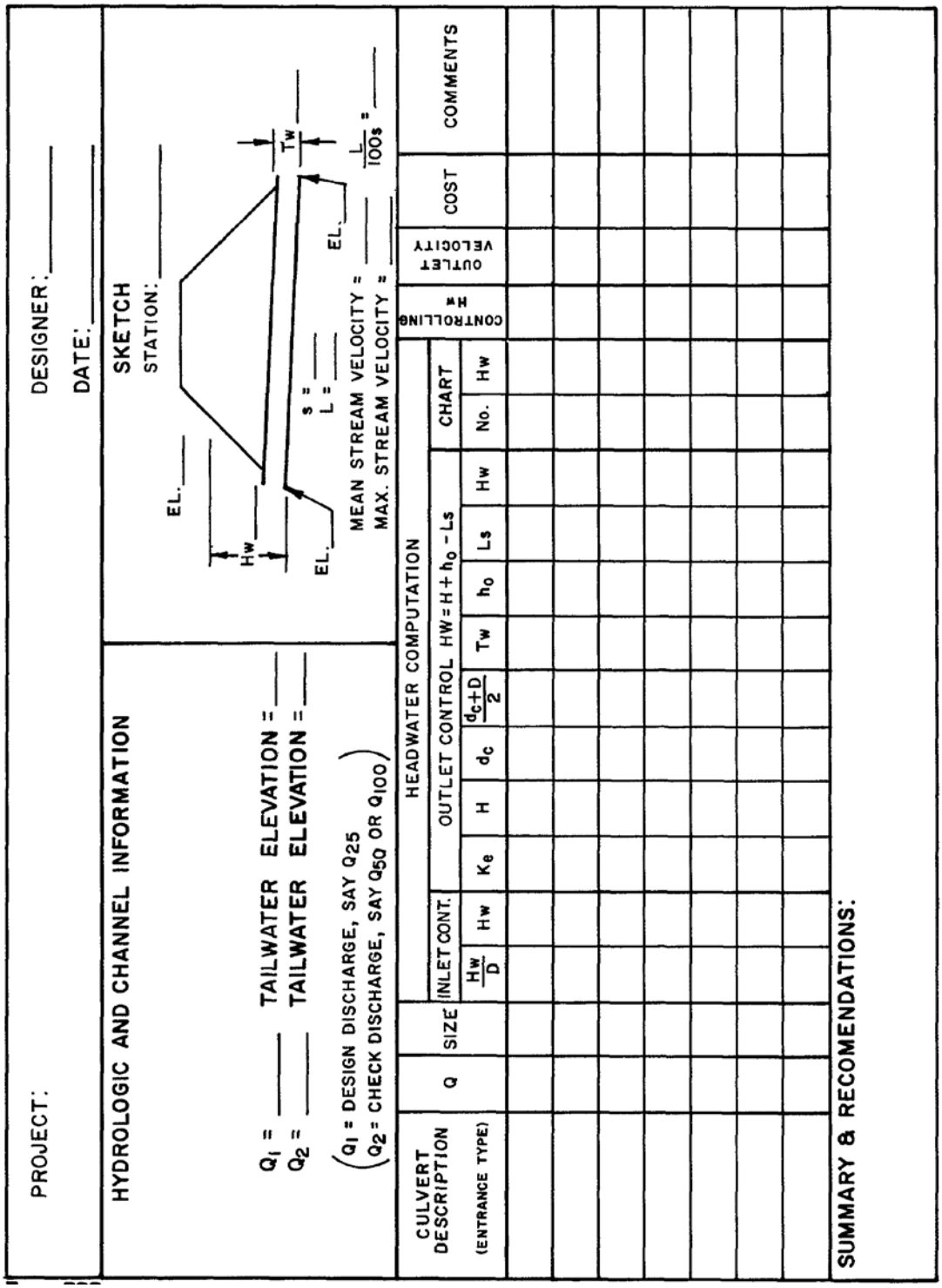


Figure 11-8. Design computation for culverts—blank form

4.2 Nomographs

Examples of nomographs for designing culverts are presented on Figure 11-9 (Inlet Control Nomograph) and Figure 11-10 (Outlet Control Nomograph). A disadvantage of the nomographs is that they require trial and error, whereas the capacity charts described in Section 4.1 are direct.

As noted previously, the capacity charts can be used only when the flow passes through critical depth at the outlet. If the critical depth at the outlet is less than the tailwater depth, then the nomographs or other method must be used.

Nomograph Procedure
The nomograph procedure for culvert design requires the use of both the inlet control and outlet control nomographs (for examples, refer to Figure 11-9 for an inlet control nomograph and Figure 11-10 for an outlet control nomograph). Data can be compiled in the design computation form shown on Figure 11-8. Steps in the nomograph procedure are listed below:

1. List design data on the design computation form:
   - Q (cfs).
   - L (ft).
   - Invert elevations for culvert inlet and outlet (ft).
   - Allowable H_w (ft).
   - Mean and maximum flood velocities and depths in stream (ft/s).
   - Culvert type, shape and entrance type for first selection.
2. Determine a trial size culvert. Assume a maximum average velocity based on channel considerations and use this to compute the culvert's cross-sectional area (A) using the Continuity Equation ($A = Q/V$). Calculate the culvert diameter D that corresponds to A. Round D up to the nearest standard culvert size.
3. Find the headwater depth H_w for a trial size culvert for inlet control and outlet control. Select the appropriate inlet and outlet nomographs, based on the culvert diameter, entrance type, design discharge and allowable headwater, from the *Hydraulic Design of Highway Culverts* (FHWA 2005a). For inlet control (see Figure 11-9 for example inlet control nomograph), connect a straight line through D and Q to scale (1) of the H_w/D scales and project horizontally to the proper scale. (As noted on the nomograph, the different scales correspond to different culvert entrance types). Compute H_w and, if too large or too small, try another culvert size before computing H_w for outlet control.
4. Compute the H_w for outlet control (see Figure 11-10 for example outlet control nomograph). Connect the culvert diameter scale and the culvert length scale with a straight line (select the proper culvert length scale based on the type of culvert entrance). Draw a straight line from the design discharge on the discharge scale through the intersection point of the first drawn line and the turning point line and extend this to the head scale (head loss, H). Compute H_w from the equation:

$$H_w = H + h_o - Ls \qquad \text{Equation 11-10}$$

Where:

H_w= headwater depth (ft)
H = head loss (ft)
h_o = tailwater depth or height of the hydraulic grade line measured from the outlet invert (ft)
L = length of culvert (ft)
s = slope of culvert (ft/ft)

For T_w greater than or equal to the top of the culvert:

$$h_o = T_w \qquad \text{Equation 11-11}$$

For T_w less than the top of the culvert:

$$h_o = \frac{(d_c + D)}{2} \text{ or } T_w \text{ (whichever is greater)} \qquad \text{Equation 11-12}$$

Where:

h_0 = approximate height of hydraulic grade line above outlet invert (ft)
d_c = critical depth (ft)
D = culvert diameter (ft)
T_w= tailwater depth (ft)

Compare the headwater elevations calculated with the inlet and outlet control nomographs; the higher H_w dictates whether the culvert is under inlet or outlet control. If outlet control governs and the H_w is unacceptable, select a larger trial size culvert and find another H_w with the outlet control nomographs. After a larger pipe size is selected by the outlet control nomograph, it does not need to be re-checked for headwater with the inlet control nomograph, since the smaller size of culvert had previously been evaluated for allowable headwater based on inlet control.

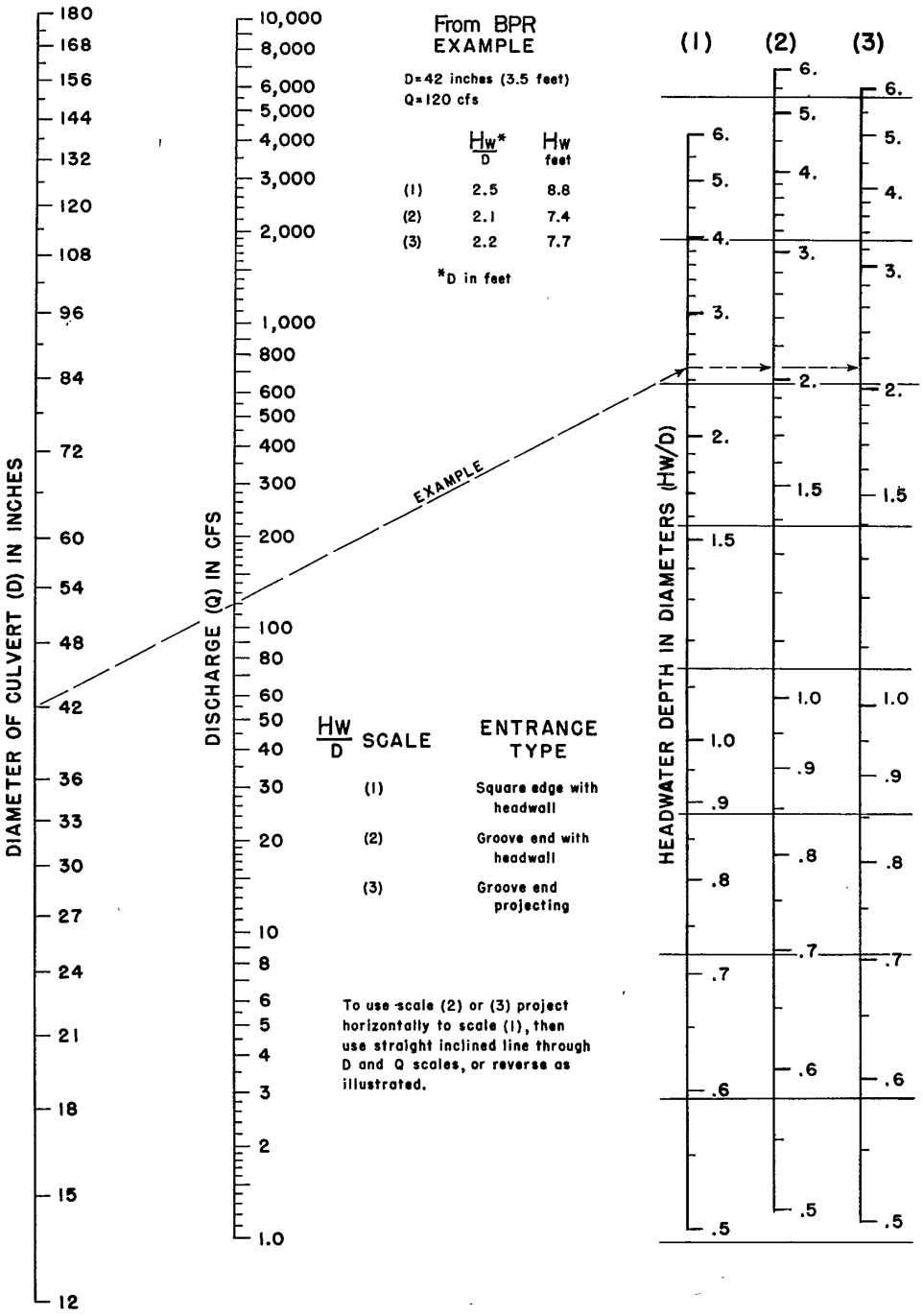


Figure 11-9. Inlet control nomograph—example

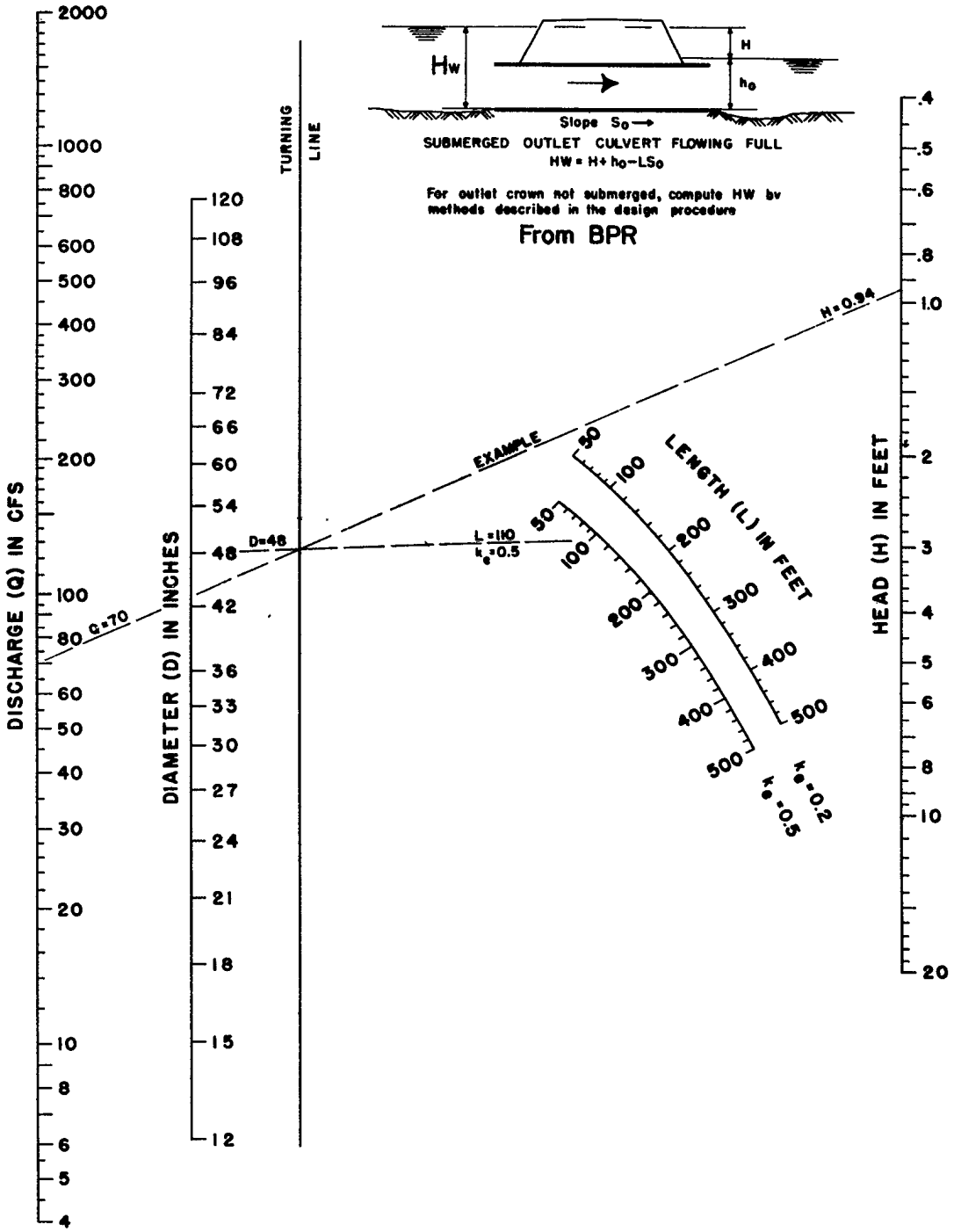


Figure 11-10. Outlet control nomograph—example

4.3 Computer Applications

Although the nomographs continue to be useful tools, especially for engineers who were trained in these methods, engineers increasingly use computer applications for culvert design. Examples of public domain computer applications that are acceptable by UDFCD for the hydraulic design of culverts are listed in the text box at right.

In addition to the public domain computer applications listed in the text box, numerous proprietary computer applications are also available for the hydraulic design of culverts. Proprietary model applications are discouraged because of the costs to municipalities and/or UDFCD to obtain and operate the proprietary software. UDFCD and municipalities may consider on a case-by-case basis whether the use of specific proprietary software may be used.

Computer Applications for the Hydraulic Design of Culverts

The following public domain computer applications are available for free download at the addresses shown and are acceptable for use in conjunction with this chapter:

- UDFCD Excel™ workbook: *UD-Culvert* www.udfcd.org
- Federal Highway Administration (FHWA) HY-8 Culvert Analysis program (FHWA 2009).

  http://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/
- U.S. Army Corps of Engineers Hydrologic Engineering Center - River Analysis System (HEC-RAS):

  http://www.hec.usace.army.mil/software/hec-ras/

4.4 Design Considerations

The design of a culvert installation is more difficult than the process of sizing culverts, since other considerations arise with site-specific factors. The procedure for design in this manual only represents guidelines, since actual design considerations encountered are too varied and too numerous to be generalized. However, the process presented should be followed to ensure that a special problem is not overlooked. Evaluate several combinations of entrance types, invert elevations, and pipe diameters to determine the most economic design that will meet the conditions imposed by topography and engineering.

Specific design considerations are identified and discussed in Sections 0.04.4.1 through 4.6.

4.4.1 Design Computation Forms

The use of design computation forms is a convenient method to use to obtain consistent designs and promote cost-effectiveness. An example form was shown previously on Figure 11-8.

4.4.2 Invert Elevations

After determining the allowable headwater elevation, the tailwater elevation, and the approximate culvert length, culvert invert elevations must be assumed. Significant scour is not likely when the culvert has the same slope as the channel. To reduce the chance of failure due to scour, invert elevations corresponding to the natural grade should be used as a first trial. Investigate the flow conditions downstream from the culvert to determine if scour is likely and evaluate the area upstream of the planned culvert for the potential of debris and adverse consequences from increased sedimentation. Providing a drop at the outlet of the culvert and including a depressed basin consistent with drop structure details provided in the

Hydraulic Structures chapter provide a location for sedimentation without potential for clogging.

4.4.3 Minimum Culvert Diameter

Since small diameter pipes are often plugged by sediment and debris, UDFCD recommends a minimum pipe diameter of 15 inches for storm drains and culverts.

4.4.4 Limited Headwater

If there is insufficient headwater elevation to obtain the required discharge, it is necessary to either oversize the culvert barrel, lower the inlet invert, use an alternate cross section (arch or elliptical), or use a combination of the preceding to increase the discharge rate.

If the inlet invert is lowered, special consideration must be given to headcutting and scour from the acceleration of flow into the culvert. The use of a drop structure, riprap or other type of protection along with headwalls, apron and toe walls should be evaluated to obtain a proper design.

4.4.5 Culvert Outlet

The outlet velocity must be checked to determine if significant scour will occur downstream during the major storm. If scour is indicated, which is frequently the case, refer to the *Outlet Protection* section of this chapter (Section 6.0). Inadequate culvert outlet protection is a common problem. When adequate culvert outlet protection is not provided, the culvert outlet can be undermined and downstream channel degradation can be significant.

4.4.6 Minimum Slope

To minimize sediment deposition in the culvert, the culvert slope must be sufficient to maintain a minimum velocity of 3 feet per second during the average annual flow event. If the minimum velocity is not obtained based on the design slope and average annual flow event, the pipe diameter may be decreased, the slope steepened, a smoother pipe used, or a combination of these employed to increase velocity.

5.0 Culvert Inlets

A culvert cannot convey any more water than can enter the inlet. This is frequently overlooked by engineers who give full consideration to slope, cross section, hydraulic roughness, and other parameters. Culvert designs using uniform flow equations rarely carry their design capacity due to limitations imposed by the inlet.

The longer a culvert is the more important is the design of the entrance. A large culvert unable to flow at the design capacity represents wasted investment. Typically, air vents are necessary immediately downstream of the entrance of a long culvertto allow entrained air to escape and to act as breathers should less-than-atmospheric pressures develop in the pipe.

Where constraints exist such as limited headwater depth, erosion problems, or where sedimentation is likely, a more efficient inlet may be required to obtain the necessary discharge for the culvert. Conversely, if detention or other temporary water storage upstream from the culvert is desirable, an inlet with more limited capacity may be the most desirable choice (in such a case, the embankment should effectively be designed as a dam). The design of a culvert, including both the inlet and the outlet, requires a balance between cost, hydraulic efficiency, purpose, and topography at the proposed culvert site.

The inlet types described in this chapter may be selected to fulfill either of the above requirements. The entrance coefficient, K_e, a variable in Equation 11-5, is a measure of the hydraulic efficiency at the inlet, with lower values indicating greater efficiency. Entrance coefficients recommended for use are given in Table 11-2. Different types of inlets and their suited uses are defined in Section 5.1.

Table 11-2. Entrance loss coefficients

Type of Entrance	Entrance Coefficient, K_e
Pipe entrance with headwall	
Grooved edge	0.20
Rounded edge (0.15*D* radius)	0.15
Rounded edge (0.25*D* radius)	0.10
Square edge (cut concrete and CMP)	0.40
Pipe entrance with headwall & 45° wingwall	
Grooved edge	0.20
Square edge	0.35
Headwall with parallel wingwalls spaced 1.25*D* apart	
Grooved edge	0.30
Square edge	0.40
Special inlets	
Projecting Entrance	
Grooved edge	0.20
Square edge	0.50
Sharp edge, thin wall	0.90

5.1 Types of Inlets

5.1.1 Inlets with Headwalls

Headwalls may be used for a variety of reasons, including increasing the efficiency of the inlet, providing embankment stability, and providing embankment protection against erosion. The relative efficiency of the inlet varies with the pipe material used as well as with the orientation of headwalls and wingwalls relative to the direction of flow entering the culvert. Figure 11-11 illustrates an inlet configuration with a headwall and wingwalls.

Photograph 11-2. Culverts at a skew can be sediment traps. Where they cannot be avoided consider how the design can best facilitate maintenance including sediment removal.

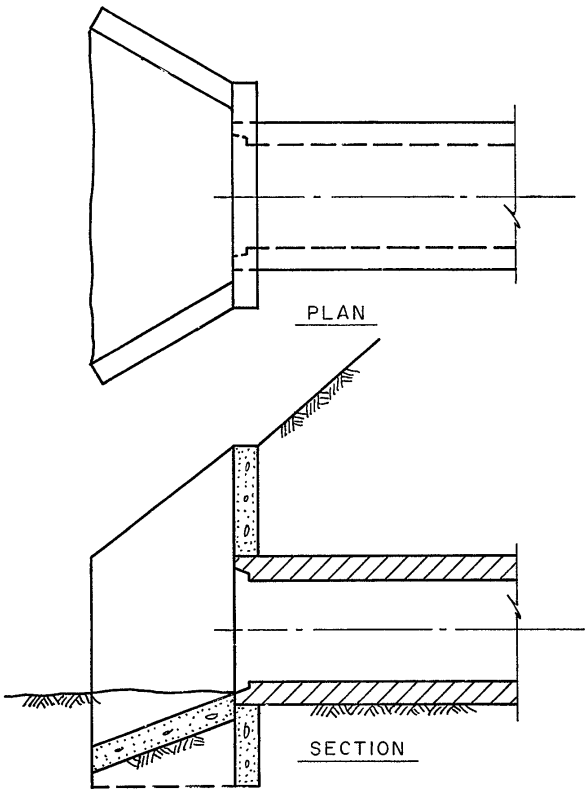


Figure 11-11. Inlet with headwall and wingwalls

Corrugated Metal Pipe
Corrugated metal pipe in a headwall is essentially a square-edged entrance with an entrance coefficient of approximately 0.4. The entrance losses may be reduced by rounding the entrance. The entrance coefficient may be reduced as follows:

- Reduce to 0.15 for a rounded edge with a radius equal to 0.15 times the culvert diameter
- Reduce to 0.10 for rounded edge with a radius equal to 0.25 times the diameter of the culvert

Concrete Pipe
For tongue-and-groove or bell-end concrete pipe, little increase in hydraulic efficiency is realized by adding a headwall. The primary reason for using headwalls is for embankment protection and for ease of maintenance. The entrance coefficients for concrete pipe are:

- 0.2 (approximate) for grooved and bell-end pipe
- 0.4 for cut concrete pipe

Wingwalls
Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable and/or where the culvert is skewed to the normal channel flow. Wingwalls are often needed to transition from the channel bottom to the embankment slope without creating grades that are too steep. Little increase in hydraulic efficiency is realized with the use of wingwalls, regardless of the pipe material used and, therefore, the use should be justified for reasons other than an increase in hydraulic efficiency. Figure 11-12 illustrates several cases where wingwalls are used. For parallel wingwalls, the minimum distance between wingwalls should be at least 1.25 times the diameter of the culvert pipe.

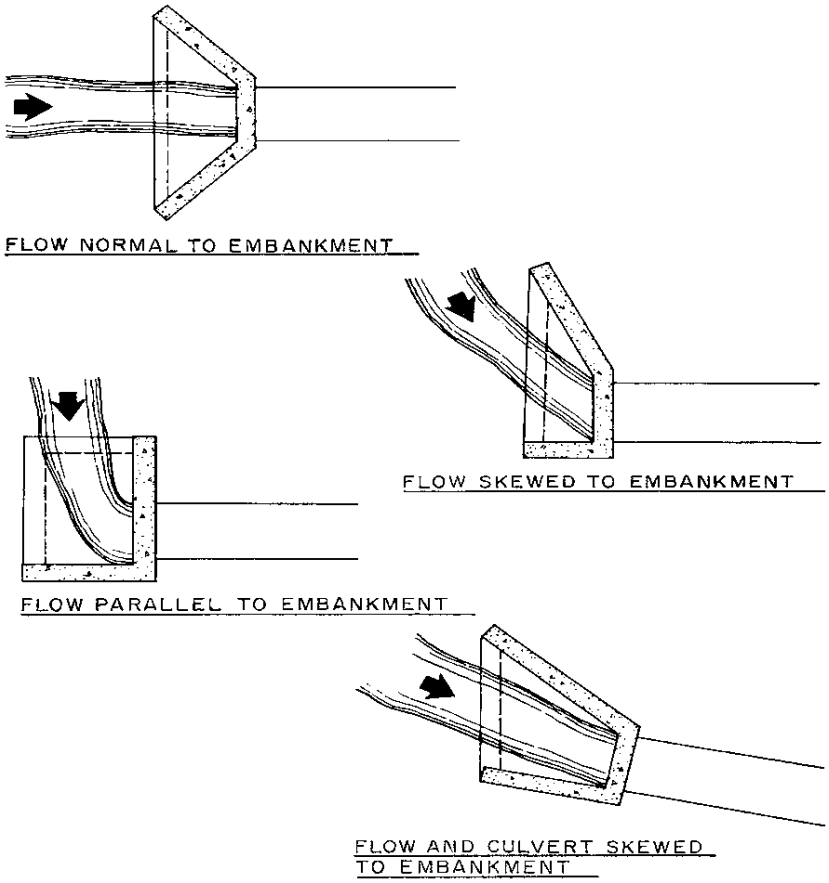


Figure 11-12. Typical headwall-wingwall configurations

Aprons
If high headwater depths are to be encountered, or if the approach velocity of the channel will cause scour, a short channel apron should be provided at the toe of the headwall. This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.
Culverts with wingwalls should be designed with a concrete apron extending between the walls. Aprons must be reinforced to control cracking. As illustrated on Figure 11-12, the actual configuration of the wingwalls varies according to the direction of flow and will also vary according to the topographical requirement placed upon them.

For conditions where scour may be a problem due to high approach velocities and special soil conditions, such as alluvial soils, a toe wall/cutoff is often desirable for apron construction.

5.1.2 Special Inlets

A large variety of inlets exist in addition to those described previously. Among these are special end-sections (i.e., flared end sections), which are frequently used at both ends of the culvert. This section discusses special inlets for concrete and corrugated metal pipes, two of the most common pipe materials; although similar improved inlets are manufactured for other pipe types. Because of the difference in requirements due to pipe materials, special end-sections for corrugated metal pipe and concrete pipe are discussed separately. Separate discussions are also provided for mitered inlets and inlets for long conduits.

Corrugated Metal Pipe
Special end-sections for corrugated metal pipe add little to the overall cost of the culvert and have the following advantages:

- Less potential damage and maintenance compared to a projecting entrance.
- Increased hydraulic efficiency. When using design charts, as discussed in Section 4.0, charts for a square-edged opening for corrugated metal pipe with a headwall may be used.

Concrete Pipe
As is the case with corrugated metal pipe, concrete end-sections protect the end of the pipe during maintenance activities, and may aid in increasing the embankment stability or in retarding erosion at the inlet. When properly designed they can also provide an improved appearance compared to a projecting entrance.
The hydraulic efficiency of this type of concrete inlet is dependent on the geometry of the end-section to be used. Where the full contraction to the culvert diameter takes place at the first pipe section, the entrance coefficient, K_e, is equal to 0.5, and where the full contraction to the culvert diameter takes place in the throat of the end-section, the entrance coefficient, K_e, is equal to 0.25.

Other Considerations for Long Culverts

Whenever it is suspected the conduit could operate at Froude Number higher than 0.7 for flows up through the design flow, or when the headwater at the conduits entrance is above the top of the conduit, the engineer must consider installation of adequate air vents along the conduit. These are necessary to minimize major pressure fluctuations that can occur should the flow become unstable. When instabilities occur, air is trapped and less-than-atmospheric pressures have been shown to occur intermittently. Under this condition, air vents can mitigate and reduce structural loads and fluctuating hydraulic capacity in the conduit. Access manholes and storm inlets are useful for permitting air to flow in and out of a conduit as filling and emptying of the conduit occurs. They might also be helpful in providing water ejection ports should the conduit ever inadvertently flow full and cause a pileup of water upstream.

A large rectangular conduit with a special entrance and an energy dissipater at the exit may need an access hole for vehicle use in case major repair work becomes necessary. A vehicle access point might be a large, grated opening just downstream from the entrance. This grated opening can also serve as an effective air vent for the conduit. Equipment may be lowered into the conduit by a crane or A-frame. A long conduit should be easy to inspect, and, therefore, access manholes are desirable at various locations. If a rectangular conduit is situated under a curb, the access manholes may be combined with inlets. Manholes should be aligned with the vertical wall of the box to allow rungs in the riser and box to be aligned.

Mitered Inlets

Mitered inlets are simply culvert pipes cut with the slope of the embankment. They are most commonly used with corrugated metal pipe. The hydraulic efficiency of mitered inlets is dependent on the construction procedure used. If the embankment is not paved, the entrance, in practice, usually does not conform to the side slopes, giving essentially a projecting entrance with $K_e = 0.9$. If the embankment is paved, a sloping headwall is obtained with $K_e = 0.60$ and, by beveling the edges, $K_e = 0.50$.
Uplift is an important factor for a mitered inlet. It is not good practice to use unpaved embankment slopes where a mitered entrance may be submerged to a depth of more than 1.5 times the culvert rise.

Inlets to Long Conduits

While inlets are important in the design of short culverts, such as road crossing, they are even more significant in the economical design of long culverts and pipes. Unused capacity in a long conduit is a wasted investment. Long conduits are costly and require detailed engineering, planning, and design work. The inlets to such conduits are extremely important to the functioning of the conduit and must receive special attention.

Most long conduits require special inlet considerations to meet the particular hydraulic characteristics of the conduit. Generally, on larger conduits, hydraulic model testing will result in better and less costly inlet construction. For additional considerations for long conduits, see the inset.

Inlets to Rectangular Conduits

The entrances take on a special degree of importance for rectangular conduits because the flow must be limited to an extent to ensure against overcharging the conduit. Special maximum-flow limiting entrances are often used with rectangular conduits. These special entrances should reject flow over the design discharge so that, if a runoff larger than the design flow occurs, the excess water will flow via other routes, often overland. A combined weir-orifice design is useful for this purpose. Model tests are needed for dependable design (Murphy 1971).
A second function of the entrance should be to accelerate the flow to the design velocity of the conduit, usually to meet the velocity requirements for normal depth of flow in the upstream reach of the conduit.

For additional considerations for rectangular conduits, see the inset on the following page.

Other Considerations for Rectangular Culverts

The use of rectangular conduits of large flow capacity can sometimes have cost advantages over large-diameter pipe. They can also be poured in place, allowing incorporation of utilities into the floor and roof of the structure.

Major disadvantages of rectangular conduits as storm sewers are:

1. The conduit's capacity drops significantly when the water surface reaches its roof since the wetted perimeter dramatically increases. The drop is 20% for a square cross section and more for a rectangular cross section where the width is greater than the height.

2. The economics of typical structural design usually does not permit any significant interior pressures, meaning that if the conduit reached a full condition and the capacity dropped, there could be a failure due to interior pressures caused by a choking of the capacity (Murphy 1971).

Internal Pressure: An obstruction, or even a confluence with another conduit, may cause the flow in a near-full rectangular conduit to strike the roof and choke the capacity. The capacity reduction may then cause the entire upstream reach of the conduit to flow full, with a resulting surge and pressure head increase of sufficient magnitude to cause a structural failure. When structural design has not been based on internal pressure, internal pressures are typically limited to no more than 2 to 4 feet of head. Surges or conduit capacity choking cannot be tolerated if the structure is not designed for the internal pressure resulting from these conditions. Thorough design is required to overcome this inherent potential problem.

Air Entrainment: Entrained air causes a swell in the volume of water and an increase in depth than can cause flow in the conduit to reach the height of the roof with resulting loss of capacity; therefore, hydraulic design must account for entrained air. In rectangular conduits and circular pipes, flowing water will entrain air at velocities of about 20 ft/sec and higher. Additionally, other factors such as entrance condition, channel roughness, distance traveled, channel cross section, and volume of discharge all have some bearing on air entrainment. Volume swell can be as high as 20% (Hipschman 1970).

Slope and Alignment: Structural requirements and efficiency for sustaining external loads, rather than hydraulic efficiency, usually control the shape of the rectangular conduit. A rectangular conduit should have a straight alignment and should not decrease in size or slope in a downstream direction. It is desirable to have a slope that increases in a downstream direction as an added safety factor against it flowing full. This is particularly important for supercritical velocities that often exist in long conduits.

Curves and Bends: The analysis of curves in rectangular conduits is critical to ensure its hydraulic capacity. When the water surface (normal, standing or reflecting waves) reaches the roof of the conduit, hydraulic losses increase significantly and the capacity drops. Superelevation of the water surface must also be investigated, and allowances must be made for a changing hydraulic radius, particularly in high-velocity flow. Dynamic loads created by the curves must be analyzed to assure structural integrity for the maximum flows. See the *Hydraulic Structures* chapter of the USDCM.

5.1.3 Projecting Inlets

Projecting inlets (protruding pipes at the inlet) should not be used. Headwalls, wingwalls, and flared end sections should be used to maximize efficiency and minimize turbulence, head loss, and erosion. This is especially important for flexible pipe materials (metal or plastic). This condition can cause severe suction and displacement of the pipe.

5.1.4 Improved Inlets

Inlet edge configuration is one of the prime factors influencing the performance of a culvert operating under inlet control. Inlet edges can cause a severe contraction of the flow, as in the case of a thin edge, projecting inlet. In a flow contraction, the effective cross-sectional area of the barrel may be reduced to about one-half of the actual barrel cross-sectional area. As the inlet configuration is improved, the flow contraction is reduced, thus improving the performance of the culvert.

A tapered inlet is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section. Tapered inlets improve culvert performance by providing a more efficient control section (the throat). However, tapered inlets are not recommended for use on culverts flowing under outlet control because the simple beveled edge is of equal benefit. The two most common improved inlets are the side-tapered inlet and the slope-tapered inlet (Figure 11-13). FHWA (2005a) *Hydraulic Design of Highway Culverts* provides guidance on the design of improved inlets.

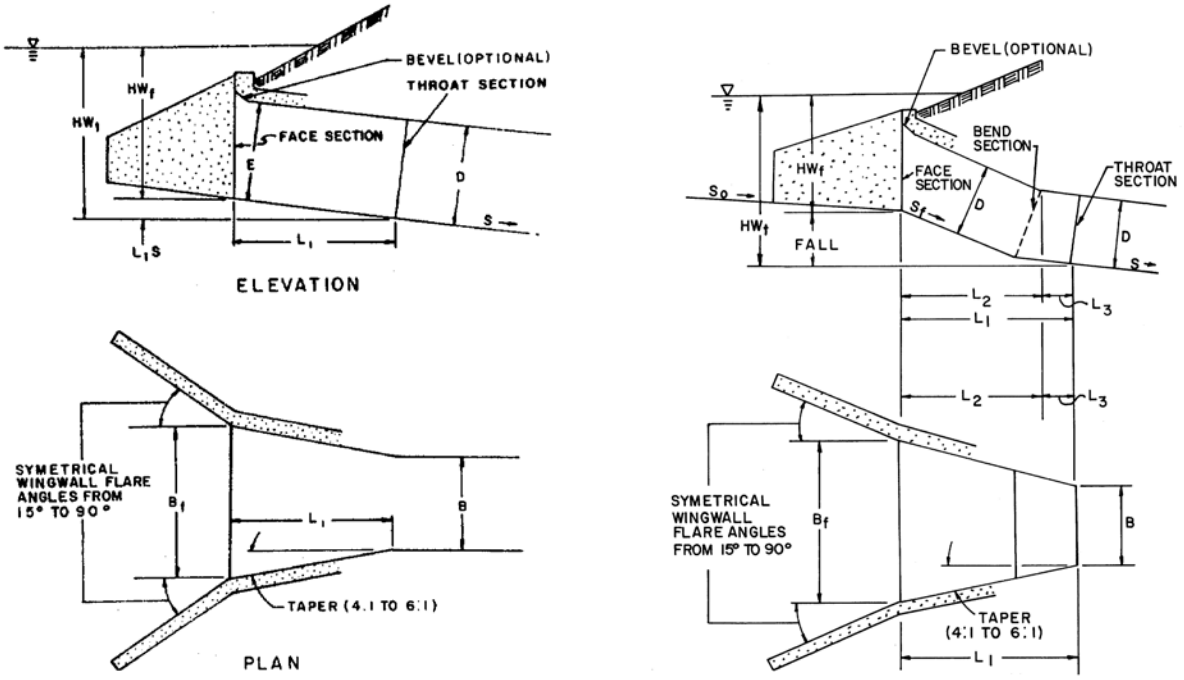


Figure 11-13. Side-tapered and slope-tapered improved inlets

5.2 Inlet Protection

Inlets on culverts, especially on culverts to be installed in live streams, should be evaluated relative to debris control and buoyancy.

5.2.1 Debris Control

Accumulation of debris at a culvert inlet can result in the culvert not performing as designed. This may result in damage due to inundation of the road and upstream property. The designer has three general options for addressing the problem of debris plugging a culvert:

Retain the debris upstream of the culvert.

Attempt to pass the debris through the culvert.

Install a bridge to create more cross-sectional area for passage of debris past the embankment.

If the debris is to be retained by an upstream structure or at the culvert inlet, frequent maintenance may be required. The design of a debris control structure should include a thorough study of the debris problem and should consider the factors listed in the text box below.

Debris Study Considerations

Factors to be considered in a debris study include:

- Type of debris
- Quantity of debris
- Alternate overland flow paths (under plugged conditions)
- Expected changes in type and quantity of debris due to future land use
- Stream flow velocity in the vicinity of culvert entrance
- Maintenance access requirements
- Availability of storage
- Maintenance plan for debris removal
- Assessment of damage due to debris clogging, if protection is not provided

Hydraulic Engineering Circular No. 9, *Debris Control Structures Evaluation and Countermeasures* (FHWA 2005b), should be used when designing debris control structures.

5.2.2 Buoyancy

The forces acting on a culvert inlet during flows are variable and indeterminate. When a culvert is functioning under inlet control, an air pocket forms just inside the inlet, creating a buoyant effect when the inlet is submerged. The buoyancy forces increase with an increase in headwater depth under inlet control conditions. These forces, along with vortexes and eddy currents, can cause scour, undermine

culvert inlets, and erode embankment slopes, thereby making the inlet vulnerable to failure, especially if deep headwater conditions are present.

In general, installing a culvert in a natural stream channel constricts the normal flow. The constriction is accentuated when the capacity of the culvert is impaired by debris or damage.

The large unequal pressures resulting from inlet constriction are, in effect, buoyant forces that can cause entrance failures, particularly on corrugated metal pipe with mitered, skewed, or projecting ends. The failure potential will increase with steepness of the culvert slope, depth of the potential headwater, flatness of the fill slope over the upstream end of the culvert, and the depth of the fill over the pipe.

Anchorage at the culvert entrance helps to protect against these failures by increasing the deadload on the end of the culvert, protecting against bending damage, and by protecting the fill slope from the scouring action of the flow. Providing a standard concrete headwall or endwall helps to counteract the hydrostatic uplift and to prevent failure due to buoyancy.

Because of a combination of high head on the outside of the inlet and the large region of low pressure on the inside of the inlet, a large bending moment is exerted on the end of the culvert, which may result in failure. This problem has been noted in the case of culverts under high fills, on steep slopes, and with projecting inlets. In cases where upstream detention storage is necessary and headwater depth in excess of 20 feet is required, to restrict discharge it is recommended to reduce the culvert size rather than use an inefficient projecting inlet.

5.3 Safety Grates

Always consider the use of safety grates at inlets to culverts and underground pipes while also evaluating hydraulic forces and clogging potential. Several fatalities can be attributed to the lack of a safety grate on small (< 42-inch) pipes and long culverts (See Table 11-3). At the same time, field experience has shown that undersized or poorly designed grates can become clogged during heavy runoff and the culvert may be rendered ineffective.

Based on UDFCD investigations of culvert related fatalities, safety grating should be required when any of the following conditions are or will be true:

- It is not possible to “see daylight” from one end of the culvert to the other,
- The culvert is less than 42 inches in diameter, or
- Conditions within the culvert (bends, obstructions, vertical drops) or at the outlet are likely to trap or injure a person.

Exceptions to the above criteria consist of street curb-opening inlets and driveway culverts that are subject to a ponding depth of no more than 12 inches at the flow-line and culvert entrances that are made inaccessible to the public by fencing.

The safety grate design process is a matter of identifying all safety hazard aspects and then taking reasonable steps to minimize them while providing adequate inflow capacity to the culvert. Generally, the most common aspect to consider in evaluating the safety hazard of a culvert (or underground pipe) opening is the possibility of a person, especially children, being carried into the culvert or becoming pinned at the culvert entrance by flowing water approaching the inlet. In reviewing hazards, it is necessary to consider depth and velocity of flow, surrounding site features, the appearance of the site

during high water (i.e, what will be visible to someone that may be unfamiliar with the site and what will be hidden), the length and size of the culvert, and other similar factors. Furthermore, in the event that someone is carried to the culvert with the storm runoff, the exposure hazard may in some cases be even greater if the person is pinned to the grating by the hydrostatic pressure of the water rather than being carried through the culvert. Large, sloped grates anchored well in front of the culvert entrance reduce the risk of pinning.

Where public safety and/or debris potential indicate that a safety grate is required, Use Figure OS-1 in Volume 3 of the USDCM to size the grate while separately ensuring that velocity does not exceed 2 feet per second at every stage of flow entering the culvert. The grate should be inclined at a slope no steeper than 3(H):1(V) (flatter is better) and have a clear opening at the bottom of no more than 9 inches to permit passage of debris and bed load at lower flows. Large debris can still become trapped behind the safety grate so it is also important to consider how maintenance personal will access this area when necessary. Access could be via a manhole access behind the headwall, a hatch within the grate, or a hinged grate. Based on site specifics, consider the option to lock access behind the safety grate. The bars on the face of the grate should be parallel to flow and spaced to provide no more than 5-inch clear openings. Transverse support bars located at the back of the grate need to be as few as possible, but sufficient to keep the grate from collapsing under full hydrostatic loads.

Grating should not be installed at the outlet of a culvert or storm drain because a human swept into the culvert will be trapped inside the grate where they will face certain death. Additionally, debris will impinge against the grate and cause significant flow capacity reductions and potential flood upstream areas. Pressurization in the pipe can also result in an unreasonable risk to the health and safety of the public.

Photograph 11-3. Grating at conduit outlets are prone to clogging and will hamper rescue efforts, cause pressurization of the pipe, and potentially flood upstream areas.

Safety Grate Design

- Use Figure OS-1 in Volume 3 of the USDCM to size the grate. This requires an open area at least four times the outlet pipe for outlets having a minimum dimension of 24 inches and greater.
- Ensure velocity does not exceed 2 feet per second.
- Incline the slope of the grate to 3(H):1(V) or flatter.
- Design a clear opening at the bottom of no more than 9 inches.
- Place bars on the face of the grate parallel to flow.
- Limit the openings between bars to no more than 5-inchs clear.
- Design access to the back side of the grate for maintenance and debris removal.

Table 11-3. Pipe and culvert related fatalities

Date	Location	Pipe Diameter	Culvert Length	Fatalities	Age	Survivors	Description
5/5/1996	Kentucky	30-inch	>100 feet	1	9	1, injured	Tried to cross ponded water.
8/4/1998	Illinois	12-inch	0.5 miles	1	6		Playing in ponded water.
9/9/1999	Delaware	unreported	1500 feet	2	11, 12	1 (age 8)	Tried to cross ponded water.
8/17/2000	Colorado	48-inch	900 feet	1	37		Firefighter attempted rescue in ponded water. Ten to 12 feet of headwater at inlet.
9/23/2000	Ohio	14-inch	N/A	2	13		Boys playing in basin. It filled quickly to 15 feet of head on a 14-inch unprotected culvert.
9/20/2009	Illinois	unreported	unreported	1	56		Attempting to clear debris from the inlet of a detention discharge pipe.
2/19/2011	California	Large box culvert	2600 feet	2	16,17		Attempted to raft a small tributary and unintentionally entered a walled section followed by a long box culvert.
5/31/2013	Oklahoma	Large box culvert	1200 feet	5	3 to 21	6	Sought shelter during a tornado warning.
6/20/2014	Nebraska	96-inch	1100 feet	1	29		Drove car into ditch and was swept into the culvert after escaping his partially submerged car.
6/30/2014	Iowa	54-inch	> 1 mile	1	17	1	Attempted to retrieve a flying disc.
5/19/2015	Louisiana	unreported	unreported	1	15		Drowned after being swept into an unprotected irrigation drainage pipe on his property.
5/23/2015	Oklahoma	30-inch	600	1	44	1	Firefighter attempted to cross ponded water, swept into storm drain.
5/24/2015	Texas	24-inch	800 feet	1	14		Unobserved entry.

5.3.1 Collapsible Grating

UDFCD does not generally recommend the use of collapsible grating. On larger culverts where grating is found to be necessary, the use of collapsible grating may be desirable. Such grating must be carefully designed from the structural standpoint so that collapse is achieved with a hydrostatic load of approximately one-half of the maximum allowable headwater. Collapse of the grate should be such that it clears the waterway opening adequately to permit the inlet to function properly.

5.3.2 Upstream Trash Collectors

In lieu of a collapsible grate and where a safety hazard exists, a grate situated a reasonable distance upstream from the actual inlet is often satisfactory. This type of grating may be a series of vertical pipes or posts embedded in the approach channel bottom. If blocking of this grating occurs, the backwater effect causes water to flow over the top of the grating and into the culvert with only minimal upstream backwater effect. The grating must not be so high as to cause the water to rise higher than the maximum allowable elevation.

6.0 Outlet Protection

Scour at culvert outlets is typical and mitigation must be included in the design. This section provides background information and speaks to the complexity of this transitional area. See the *Hydraulic Structures* chapter for detailed discussion and details of outlet protection practices.

Photograph 11-4. Energy dissipation and outlet protection are essential to promote channel stability.

Compared to the stream, flow in a culvert barrel is usually confined to a lesser width and greater depth. This results in increased velocity and potentially erosive capabilities as flow exits the barrel. Turbulence and erosive eddies form as the flow expands to conform to the natural channel. However, the velocity and depth of flow at the culvert outlet and the velocity distribution upon reentering the stream are not the only factors that need consideration.

The characteristics of the stream bed and bank material, velocity, and depth of flow in the stream at the culvert outlet, and the amount of sediment and other debris in the flow are all contributing factors to scour potential. Due to the variation in expected flows and the difficulty in evaluating some of these factors, scour prediction is not a exact science.

As discussed in the *Hydraulic Structures* chapter, riprap channel expansions and concrete aprons stabilize the transition and redistribute or spread the flow. Barrel outlet expansions operate in a similar manner. Headwalls and cutoff walls protect the integrity of the fill. At some locations, use of a rougher culvert material may alleviate the need for a special outlet protection device. When outlet velocities are high enough to create excessive downstream problems, consideration should be given to more complex energy dissipation devices. These include hydraulic jump basins, impact basins, drop structures, and stilling wells. Design information for the general types of energy dissipators is provided in the *Hydraulic Structures* chapter of the USDCM and in *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA 1983 and 2000).

7.0 Bridges

7.1 General

Photograph 11-5. Shared-use path over Grange Hall Creek.

Bridges are used to carry roadways, railroads, shared-use paths, and utilities over surface waters. Generally a bridge is defined as having a span of 20 feet or more, as opposed to a culvert. If a bridge is not sized properly with regard to the design flow, overtopping and flooding will occur, leading to public hazards, erosion damage, and possible structural failure. However, bridge design also includes assumption of a certain level of risk that is usually determined by the owner or local jurisdiction. This section provides a brief overview of hydraulic design of bridges, and includes references for additional design guidance. Structural design is not addressed here – for that information, readers are directed to the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges.

There are many references for bridge hydraulics, some of which are available online. A key source of information is the Federal Highway Administration (FHWA). A listing of references available through their website can be accessed using the following link:
http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm

Some of the key references for bridge hydraulics published by FHWA and others are provided below:

- Federal Highway Administration, Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1, 1978.
- Federal Highway Administration, Hydraulic Design of Safe Bridges, Hydraulic Design Series No. 7, 2012.
- Federal Highway Administration, River Engineering for Highway Encroachments – Highways in the River Environment, Hydraulic Design Series No. 6 (FHWA HDS-6), December 2010.
- American Association of State Highway and Transportation Officials (AASHTO), Highway Drainage Guidelines, 2007. Chapter 7: Hydraulic Analysis for the Location and Design of Bridges.
- Arizona Department of Water Resources. Design Manual for Engineering Analysis of Fluvial Systems. March 1985.

The Colorado Department of Transportation (CDOT) also provides a good reference on bridge design and hydraulics in Chapter 10 of the CDOT Drainage Design Manual. This is available on their website, www.coloradodot.info/.

Most roadway bridges are designed to pass the 100-year flood event. However, other types of bridges (such as for shared-use paths) may allow a greater risk and lesser design capacity. Designers should always verify the design event with the owner and local jurisdiction. If the bridge is located within a regulatory floodplain, special consideration must be given to the impacts of the bridge on 100-year floodplain water surface elevations. Contact the local government to determine requirements. At a minimum a floodplain development permit will be required. Impacts to federally designated floodplains may require a Letter of Map Change with FEMA.

7.2 Backwater and Hydraulic Analysis

Bridge openings should be designed to have minimal impact on the flow characteristics and floodplain. However, most bridges and abutments create a constriction of the floodplain. This constriction and losses through the structure create a backwater surface increase on the upstream side of a bridge. Ideally, the backwater elevation remains below that of the bridge deck for critical design discharges. Backwater can be determined with manual calculations or through use of a computer model. The computer program most used is the model HEC-RAS, developed by the U.S. Army Corps of Engineers (USACE) and available online at www.hec.usace.army.mil/. Other 1- and 2-dimensional hydraulic models include both public and proprietary software programs. FEMA maintains a list of software approved for the basis of map changes on their website, www.fema.org.

HEC-2 was a common computer model used by FEMA for establishing floodplain water surface profiles until 1995, when it was replaced with HEC-RAS. The HEC-RAS User's Manual and Hydraulic Reference Guides (also available through the USACE website) provide a thorough description of the input parameters required for the model. In addition, some considerations to remember in a bridge analysis include:

- Proper location of cross sections at the bridge (see Figure 11-14 and Figure 11-15)
- Increase in expansion and contraction coefficients upstream and downstream of the bridge.
- Definition of ineffective flow areas at the approach to and exit from the bridge (Figure 11-15). Additional cross sections located within the contraction and expansion reaches (as shown in Figure 11-14) should have ineffective flow areas defined based on the locations of the dashed lines within the cross section.

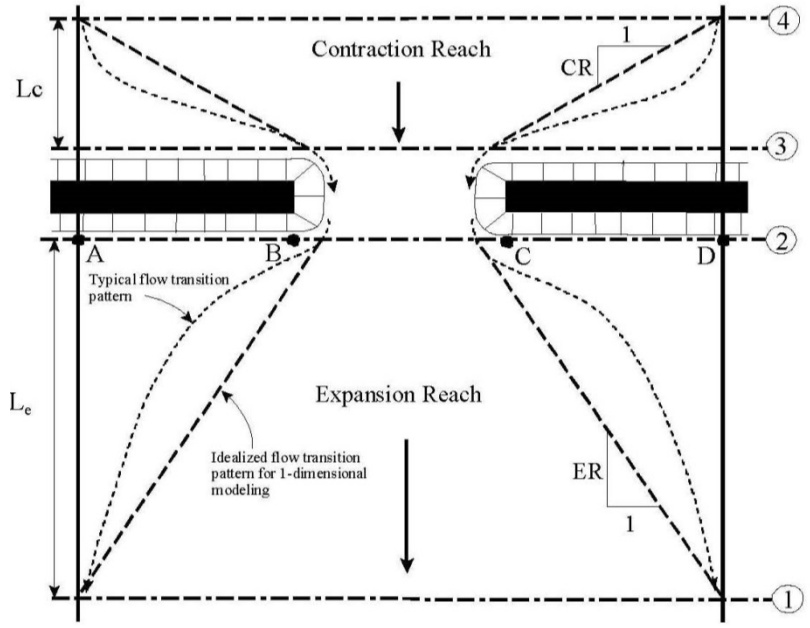


Figure 11-14. Hydraulic cross section locations

(Source: HEC-RAS Hydraulic Reference Manual)

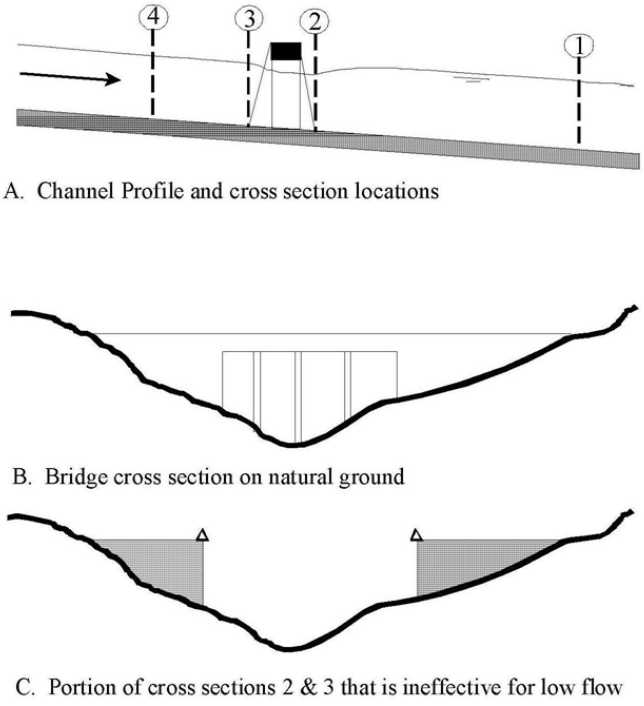


Figure 11-15. Cross section locations and ineffective flow area definition

(Source: HEC-RAS Hydraulic Reference Manual)

7.3 Freeboard

Contrary to culverts which are typically designed with a backwater elevation, freeboard for bridges is critical because the heavy debris flow that can occur during a major flood can permanently damage the structure, potentially leaving an important roadway out of service. Bridge freeboard is the vertical distance between a design water surface elevation and the low chord of the bridge superstructure. It is a key component in bridge hydraulic design. Freeboard accommodates the inherent uncertainty of the design flow rate and also accommodates the passage of ice, debris, and waves during a flood event. Criteria for bridge freeboard vary from 1-foot to 4-feet in Colorado depending on the jurisdiction and risk of debris specific to the channel. Additionally, some criteria define freeboard based on the geometry of the bridge (e.g., Colorado Department of Transportation (CDOT) provides figures for measuring freeboard for bridges with a vertical curve and continuous grade). When the local jurisdiction does not have criteria regarding to bridge freeboard, refer to CDOT, Colorado Water Conservation Board (CWCB), or AASHTO as appropriate.

7.4 Bridge Scour Analysis

The increased flow velocities at a bridge constriction often leads to scour, which is of particular concern because it can undermine a bridge's foundations and potentially cause collapse of the structure. Established methodologies for estimating scour at bridges are contained in the FHWA guidelines below (both available at www.fhwa.dot.gov/engineering/hydraulics/):

- Federal Highway Administration, Evaluating Scour at Bridges, Hydraulic Engineering Circular No. 18 (HEC-18), Fifth Edition, 2012.
- Federal Highway Administration, Stream Stability at Highway Structures, Hydraulic Engineering Circular No. 20 (HEC-20), Fourth Edition, 2012.

The methods described in HEC-18 and HEC-20 are incorporated into the HEC-RAS computer program in its Hydraulic Design/Scour module. The program will automatically calculate the needed input parameters to the scour routines from the hydraulic output. However, it is critical to understand what the parameters are, if the program is calculating them correctly, and whether or not the resulting values are reasonable. This can depend on the way data are imported for bridge geometry, bank stations, and other input variables. Localized bridge scour is comprised of:

- Contraction scour
- Local Scour (Piers)
- Local Scour (Abutments)

These 3 components are all added together to arrive at a final scour envelope (Figure 11-17).

FHWA recommends calculation of scour with the absence of riprap at roadway bridges. This includes both piers and abutments. Reliance upon riprap for overall bridge stability and foundation design is not advised. However, riprap is often used as a scour countermeasure. FHWA provides guidance on selecting and designing scour countermeasures, including riprap at bridge piers and abutments:

- Federal Highway Administration, Bridge Scour and Stream Instability Countermeasures, Experience, Selection, and Design Guidance. Hydraulic Engineering Circular No. 23, Third Edition, 2009. Volumes 1 and 2. http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=23&id=142

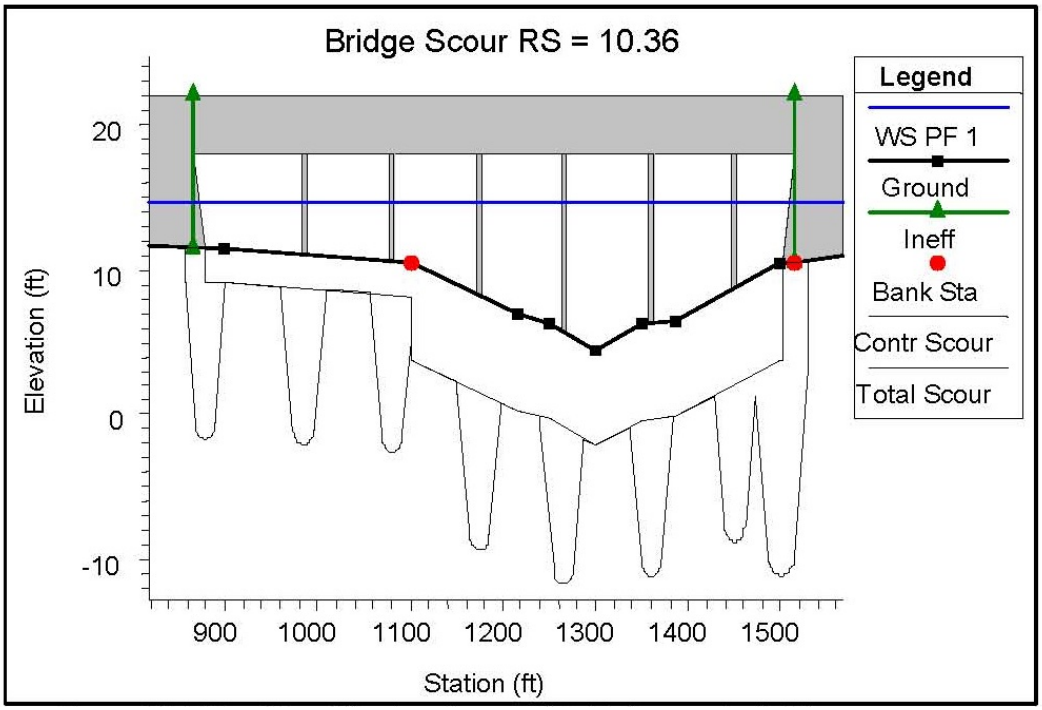


Figure 11-16. Example of scour envelope, as calculated with HEC-RAS

(Source: HEC-RAS Hydraulic Reference Manual)

It is important to note that the above methodology for calculating scour assumes that unconsolidated alluvial material makes up the channel bottom within the scour envelope. If bedrock is located within the scour envelope, or especially if bedrock is exposed at the surface of the channel bottom, other methodology should be used to determine the bedrock erodibility. The Erodibility Index Method was developed to evaluate scour in bedrock and is described in *Scour Technology: Mechanics and Engineering Practice*, 420 pp. (Annandale 2006)

A scour analysis must address long-term patterns of channel change. An understanding of fluvial geomorphology is important in determining this portion of the analysis. This includes evaluation of sediment transport, patterns of channel invert or overbank lowering (degradation), patterns of deposition (aggradation), and lateral migration. Aggradation can lead to a loss of capacity under a bridge, and degradation can cause undermining of a bridge foundation. In the case of long term degradation of a channel, grade control structures downstream of the bridge might be considered. However, it is important to note that local scouring around a bridge's structural elements can still occur even with grade control structures. Long term aggradation indicates the possible need for upstream bed and bank stabilization measures that would reduce sediment loading. These issues are described in the FHWA HDS-6 and in the Arizona Department of Water Resources design manual (both referenced at beginning of this chapter). In addition, many fluvial geomorphic textbooks are available.

FHWA is continually studying scour at bridges as part of its Scour Technology program. Updated information can be found at: http://www.fhwa.dot.gov/engineering/hydraulics/scourtech/index.cfm. Recently, advancements have been made in the methods for estimating scour at bridges under the National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board of the National Academies. A list of NCHRP projects can be found at http://www.trb.org/NCHRP/NCHRPProjects.aspx. Bridge scour studies are included in Research Field 24. Such advancements were incorporated into the 2012 version of HEC-18.

8.0 Design Examples

This section demonstrates culvert design using two different methods presented in this chapter. For the purpose of comparison, the following problem is used for both examples:

Size a culvert given the following:

$Q_{5\text{-yr}}$ = 20 cfs, $Q_{100\text{-yr}}$ = 35 cfs, L = 95 feet

The maximum allowable headwater elevation is 5288.5 ft. Channel invert elevations are 5283.5 at the inlet and 5281.5 at the outlet. The tailwater depth is computed as 2.5 feet for the 5-year storm, and 3.0 feet for the 100-year storm. Assume the channel is an excavated channel with gravel (uniform section, clean) and the culvert is circular.

8.1 Example using UD-Culvert

The following example problem for a culvert under an embankment illustrates the culvert design procedures using UD-Culvert workbook. Note that UD-Culvert is based on HY-6.

Solution:

Step 1. Calculate tailwater elevations:

$T_{w\ 5\text{-yr}}$ = 5,281.5 ft + 2.5 ft = 5,284.0 ft

$T_{w\ 100\text{-yr}}$ = 5,281.5 ft + 3.0 ft = 5284.5 ft

Step 2. Set invert elevations at natural channel invert elevations to avoid scour. Compute culvert slope and $L/100s$:

$$S = \left(\frac{5283.5 - 5281.5}{95}\right) = 0.021$$

$$\frac{L}{100s} = \left(\frac{95}{2.1}\right) = 45.2$$

Step 3. Start with an assumed culvert size for the 5-year storm by adopting a velocity of 6.5 ft/s and computing:

$$A = \frac{20}{6.5} = 3.1 \text{ ft}^2$$

This corresponds to a culvert diameter of 2 feet (24 inches):

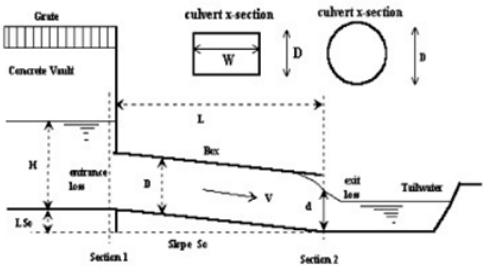
$$D = 2\sqrt{\frac{A}{\pi}} = 2 \text{ ft}$$

Step 4. For this example, assume a square edge with headwall (K_e = 0.5) and concrete pipe will with a Manning's *n* of 0.013.

Step 5. Note that for the 5-year flow rate of 20 cfs for the given input parameters, the workbook indicates that the culvert will be able to pass the design flow rate at an elevation slightly below 5,286.5. However, with the increased tailwater during the 100-year event, a larger culvert will be needed to pass the 100-year design flow below the allowable headwater limit of 5,288.5. A larger culvert size should be selected and analyzed.

Step 6. Increase the culvert to 27 inches to pass the 100-year flow of 35 cfs. Using the same procedure detailed above, output shows that the culvert continues to be outlet controlled. However, the controlling culvert flow rate at the maximum headwater depth of 5288.5 is adequate to pass the 100-year flow.

Project: **Culvert design example**
Basin ID:
Status:



Clear Worksheet
Clear Results
Calculate

Design Information (Input):

Circular Culvert:	Barrel Diameter in Inches	D =	24	inches
	Inlet Edge Type (choose from pull-down list)	Square End with Headwall	Square End with Headwall	
OR:				
Box Culvert:	Barrel Height (Rise) in Feet	Height (Rise) =		ft.
	Barrel Width (Span) in Feet	Width (Span) =		ft.
	Inlet Edge Type (choose from pull-down list)	Square Edge w/ 90-15 Deg. Headwall	Square Edge w/ 90-15 Deg. Headwall	
	Number of Barrels	No =	1	
	Inlet Elevation at Culvert Invert	Inlet Elev =	83.5	ft. elev.
	Outlet Elevation at Culvert Invert **OR** Slope of Culvert (ft v./ft h.)	Outlet Elev =	81.5	ft. elev.
	Culvert Length in Feet	L =	95	ft.
	Manning's Roughness	n =	0.013	
	Bend Loss Coefficient	K_b =	0	
	Exit Loss Coefficient	K_x =	1	

Design Information (calculated):

Entrance Loss Coefficient	K_e =	0.50
Friction Loss Coefficient	K_f =	1.17
Sum of All Loss Coefficients	K_s =	2.67
Orifice Inlet Condition Coefficient	C_d =	0.86
Minimum Energy Condition Coefficient	KE_{low} =	-0.0342

Calculations of Culvert Capacity (output): Recalculate

Water Surface Elevation (ft., linked) — Enter HW Elev	Tailwater Surface Elevation ft	Culvert Inlet-Control Flowrate cfs	Culvert Outlet-Control Flowrate cfs	Controlling Culvert Flowrate cfs (output)	Inlet Equation Used:	Flow Control Used
84.00	84.00	1.20	0.00	**0.00**	Min. Energy. Eqn.	N/A
84.50	84.00	4.50	9.31	**4.50**	Min. Energy. Eqn.	INLET
85.00	84.00	8.30	13.16	**8.30**	Regression Eqn.	INLET
85.50	84.00	13.00	16.12	**13.00**	Regression Eqn.	INLET
86.00	84.00	17.10	18.61	**17.10**	Regression Eqn.	INLET
86.50	84.00	20.50	20.81	**20.50**	Regression Eqn.	INLET
87.00	84.00	23.40	22.80	**22.80**	Regression Eqn.	OUTLET
87.50	84.00	25.90	24.62	**24.62**	Regression Eqn.	OUTLET
88.00	84.00	28.20	26.32	**26.32**	Regression Eqn.	OUTLET
88.50	84.00	30.30	27.92	**27.92**	Regression Eqn.	OUTLET
89.00	84.00	32.30	29.43	**29.43**	Regression Eqn.	OUTLET
89.50	84.00	34.10	30.85	**30.85**	Regression Eqn.	OUTLET
90.00	84.00	35.80	32.23	**32.23**	Orifice Eqn.	OUTLET

Figure 11-17. Example problem using UD-Culvert (5-year tailwater)

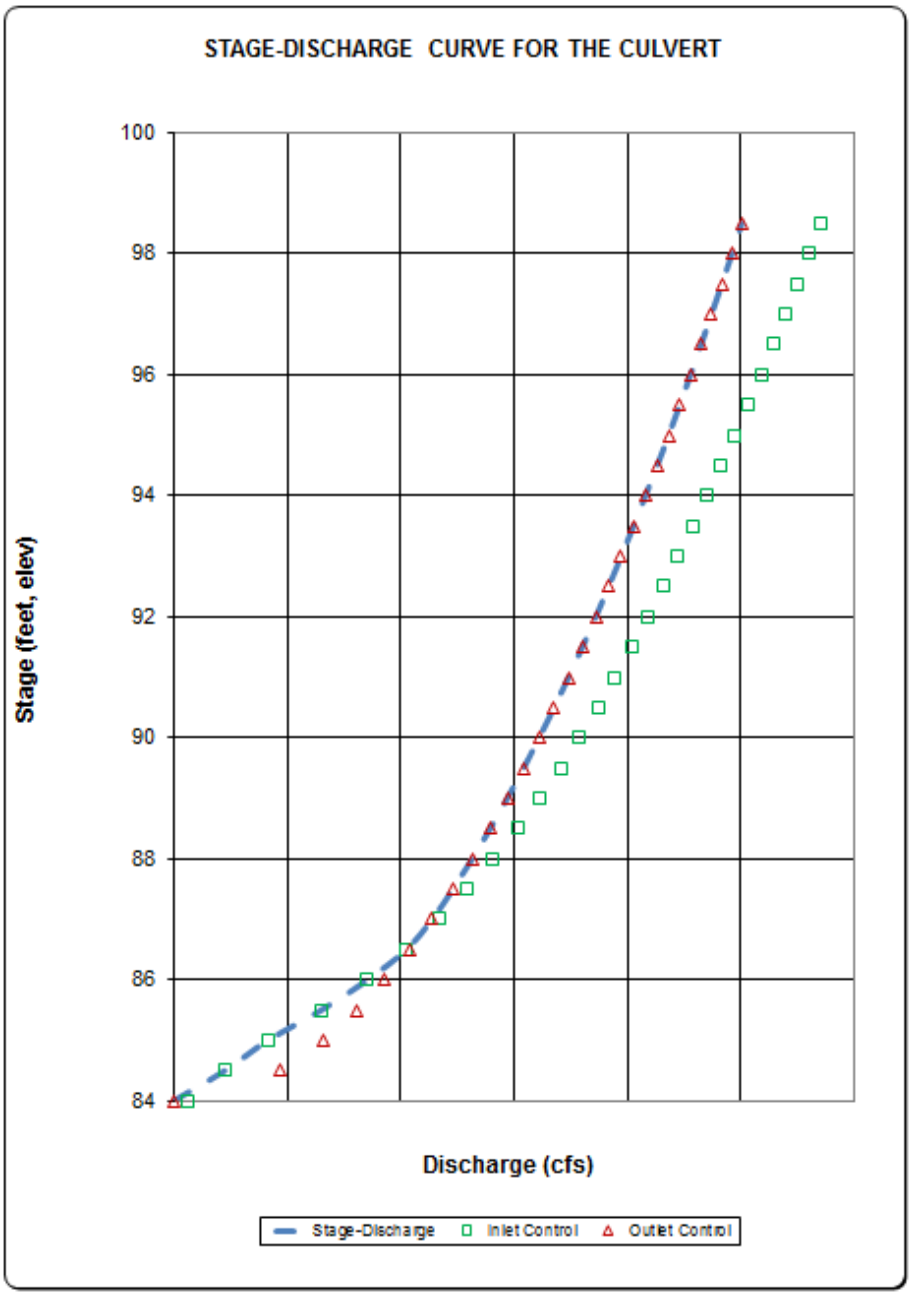


Figure 11-18. Rating curve generated using UD-Culvert (5-year event)

8.2 Example Using HY-8

The example culvert design presented in section 8.1 is repeated here using the computer program HY-8. Note that UD-Culvert is based on HY-6, thus results will differ slightly from the example in section 8.1.

This section guides the user through the typical steps to set up and run a model in HY-8. To begin, start a new project by adding a "Crossing" with the information in Table 11-4 and the values solved for in the previous example.

Table 11-4. HY-8 program inputs

Parameter	Value
Min Flow (cfs)	0
Design Flow (cfs)	$Q_{5\text{-yr}}$ or $Q_{100\text{-yr}}$
Max Flow (cfs)	35
Channel Type	Trapezoidal Channel
Bottom Width (ft)	10
Side Slope (H:V) (_:1)	2
Channel Slope	0.03 ft/ft
Manning's n (channel)	0.025
Channel Invert Elevation (ft)	5283.5
Roadway Profile Shape	Constant Roadway Elevation
First Roadway Station (ft)	0
Crest Length (ft)	100
Crest Elevation (ft)	5288.5
Roadway Surface	Paved
Top Width (ft)	150
Shape	Circular
Material	Concrete
Diameter	2.0 feet
Embedment Depth	0
Manning's n	0.012
Inlet Type	Conventional
Inlet Edge Condition	Square edge with headwall and Groove end with headwall
Inlet Depression?	No
Inlet Station	0
Inlet Elevation	5283.5
Outlet Station	95
Outlet Elevation	5281.5
Number of Barrels	1

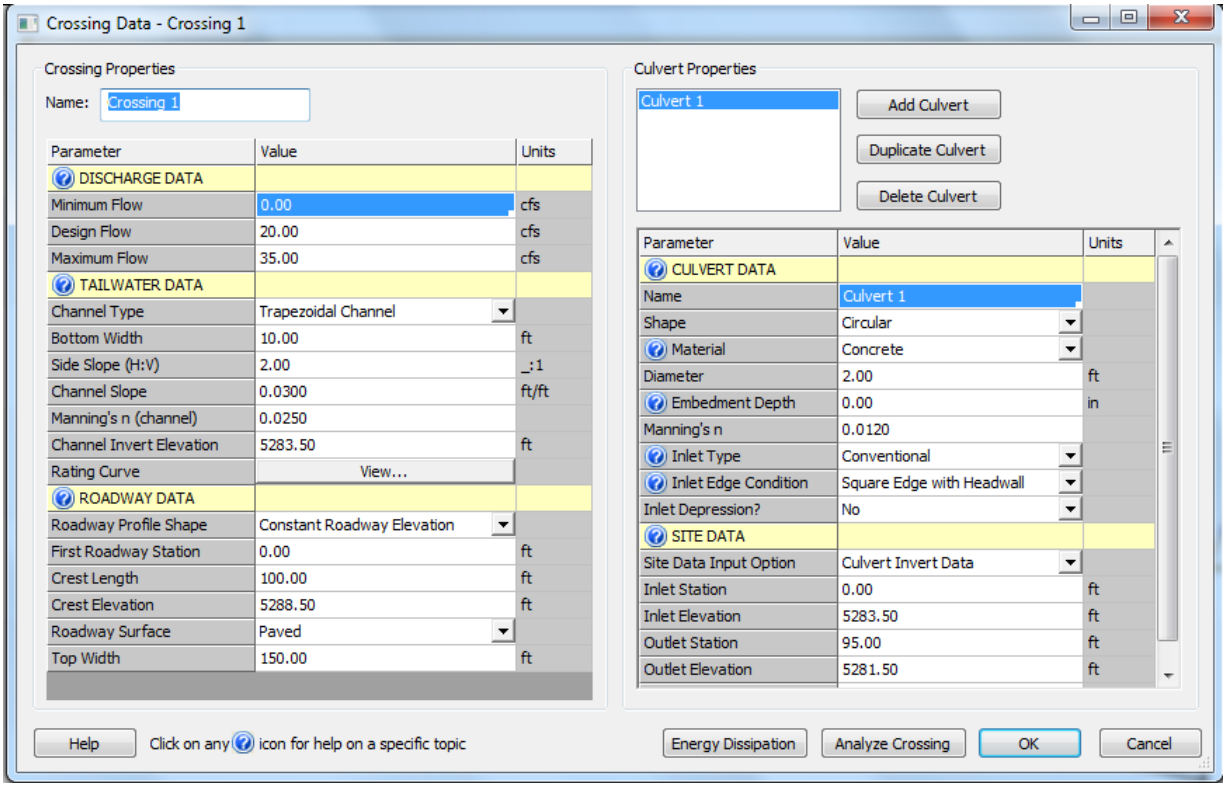


Figure 11-19. Adding a crossing in HY-8

The culvert may now be analyzed using "Analyze Crossing" near the bottom right corner of the box. This should generate an output screen that looks like Figure 11-20. If any critical input values are missing, the program will not execute properly.

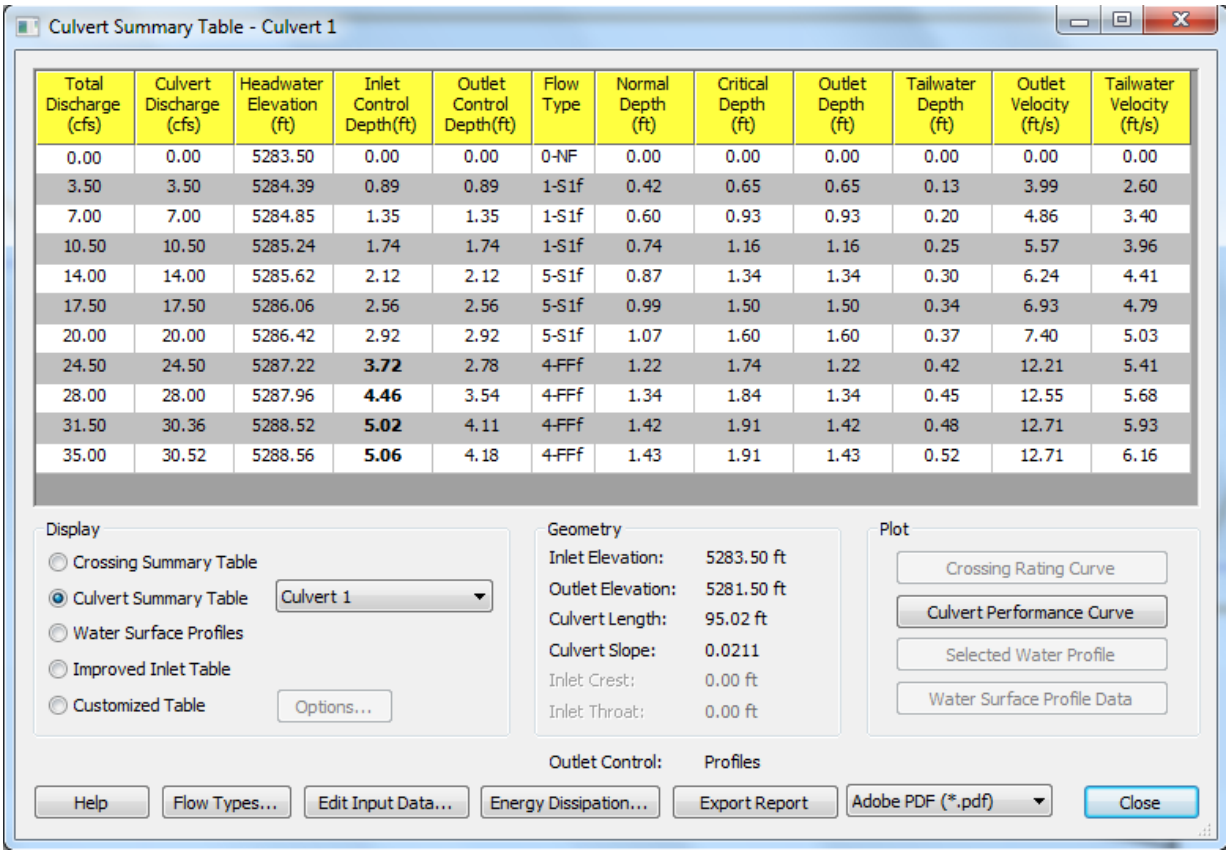


Figure 11-20. HY-8 output

HY-8 provides extensive output for modeled culverts and has options for exporting reports and generating rudimentary figures. Please refer to the HY-8 User's Manual for further interpretation of model output and options for presenting results.

9.0 Checklist

Criterion/Requirement	✓
Culvert diameter should be at least 18 inches.	
HW/D ratio should not exceed 1.5 unless justified and adequate measures are implemented to protect embankment.	
Safety grating is provided when any of the following conditions are or will be true: ▪ It is not possible to "see daylight" from one end of the culvert to the other, ▪ The culvert is less than 42 inches, or ▪ Conditions within the culvert (bends, obstructions, vertical drops) or at the outlet are likely to trap or injure a person.	
Review any proposed changes with local, state, and federal regulators.	
When a culvert is sized such that the overlying roadway overtops during large storms, check the depth of cross flow with the *Streets, Inlets, and Storm Drains* chapter.	
Provide adequate outlet protection in accordance with Section 6.0 of this chapter and the *Hydraulic Structures* chapter.	

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Chapter 12
Storage

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1.0 Overview

Detention storage facilities manage stormwater quantity by attenuating peak flows during flood events. Depending on the design, they can also enhance stormwater quality by incorporating design components to promote sedimentation, infiltration, and biological uptake. This chapter provides guidance for the analysis and design of storage facilities implemented independently or in combination with stormwater quality facilities. Specific design guidance for stormwater quality facilities (e.g., extended detention basins, wetland basins, sand filters, etc.) are in Volume 3 of the USDCM.

Photograph 12-1. Detention facilities can be designed to integrate the management of both stormwater quality and quantity.

Other topics discussed in this chapter include:

- Regional, sub-regional, and onsite detention facilities,
- Full spectrum detention,
- Basin sizing methodology,
- Outlet structures and safety grates,
- Emergency spillways,
- Landscape considerations,
- Designing for maintenance; and
- Parking lot detention.

Photograph 12-2. Detention facilities can become attractive amenities and have potential to increase property values in commercial and residential settings, especially with the assistance of experienced landscape architects.

UDFCD strongly encourages the development of multipurpose, attractive detention facilities that are safe, maintainable and viewed as community assets rather than liabilities.

2.0 Implementation of Regional, Sub-regional, and On-site Detention Facilities

Colorado law requires detention be provided to control the 100-year peak flow for all new development in the unincorporated portions of all counties, and most incorporated municipalities in Colorado require the same. There are three basic approaches for locating storage facilities in relation to their upstream watersheds. These are:

- Regional Detention
- Subregional Detention
- Onsite Detention

These three approaches are described in the following sections.

2.1 Regional Detention

Regional detention basins serve multiple property owners in watershed areas ranging from about 130 acres to one square mile. Figure 12-1 provides an example configuration for an on-line regional detention approach.

In some cases, regional detention is effective for watershed areas larger than one square mile and for multiple facilities arranged in series; however, due to the complexities associated with how they function within a watershed, these configurations must be modeled and approved in the context of a formal master planning process.

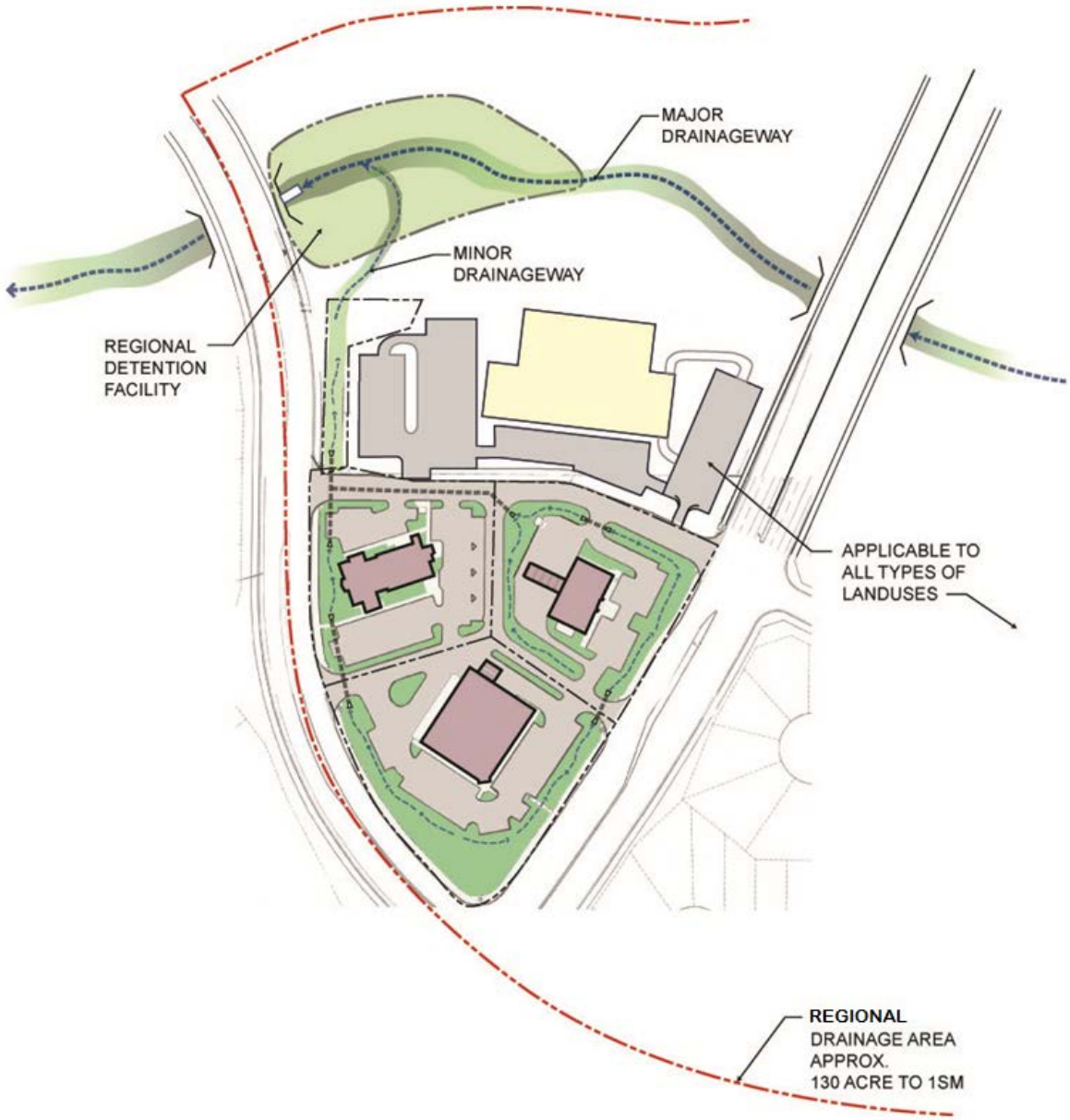

Figure 12-1. Example configuration for regional detention (Source: Arapahoe County)

Regional detention facilities may be constructed by a public entity such as a municipality, special district, or property owner but should always be based on a master plan or a detailed hydrologic model approved by the local jurisdiction that accounts for future development upstream and impacts downstream of the facility.

Compared to on-site facilities, regional detention facilities typically require proportionally less total land area and are more cost effective to construct and maintain. Well-designed regional facilities may also provide more favorable riparian habitat and offer greater opportunities for achieving multi-use objectives, such as combining with park and open space resources and connecting shared use paths.

There are limitations associated with the implementation of on-line regional detention facilities. To avoid excessive accumulation of sediment, it is not recommended that regional detention facilities be constructed on streams experiencing significant upstream bed or bank erosion unless stabilization improvements are constructed ahead of the basin.

When an on-line regional facility is designed to provide water quality, storm water best management practices (BMPs) are still required in the tributary watershed to address water quality and channel stability for the reach upstream of the regional facility. In accordance with MS4 permits and regulations, areas of "New Development and Significant Redevelopment" must be treated with BMPs prior to discharging to a State Water. See Chapter 1 of Volume 3 of the USDCM for additional information when incorporating water quality into a regional facility.

2.2 Subregional Detention

Subregional detention generally refers to facilities that serve multiple landowners or lots and have a total watershed of less than 130 acres. Figure 12-2 illustrates a typical sub-regional detention approach in a commercial area. Most detention facilities located within residential communities are subregional in that they serve multiple lots that are each individually owned. Subregional detention facilities are located off-line from the receiving stream.

Like regional facilities, subregional detention facilities may be constructed by a public entity such as a municipality or special district to serve several landowners in the upstream drainage area, but are more typically designed and constructed by a single developer to serve an area being developed.

Subregional detention offers many of the same benefits as regional facilities in comparison to onsite detention, and is also subject to the same limitations, described in Section 2.1.

Figure 12-2. Example configuration for subregional detention (Source: Arapahoe County)

2.3 Onsite Detention

Onsite detention refers to facilities serving one lot, generally commercial or industrial sites draining areas less than 20 to 30 acres. Figure 12-3 illustrates a typical on-site detention approach.

On-site facilities are usually designed to control runoff from a specific land development site and are not typically located or designed to effectively reduce downstream flood peaks along the receiving stream. The volume of runoff detained in the individual on-site facility is relatively small and, their effectiveness in aggregate has been shown to diminish along the downstream reaches of streams. The application of consistent design and implementation criteria and assurance of their continued maintenance and existence is of paramount importance if large numbers of on-site detention facilities are to be effective in controlling peak flow rates on a watershed scale (Glidden 1981; Urbonas and Glidden 1983).

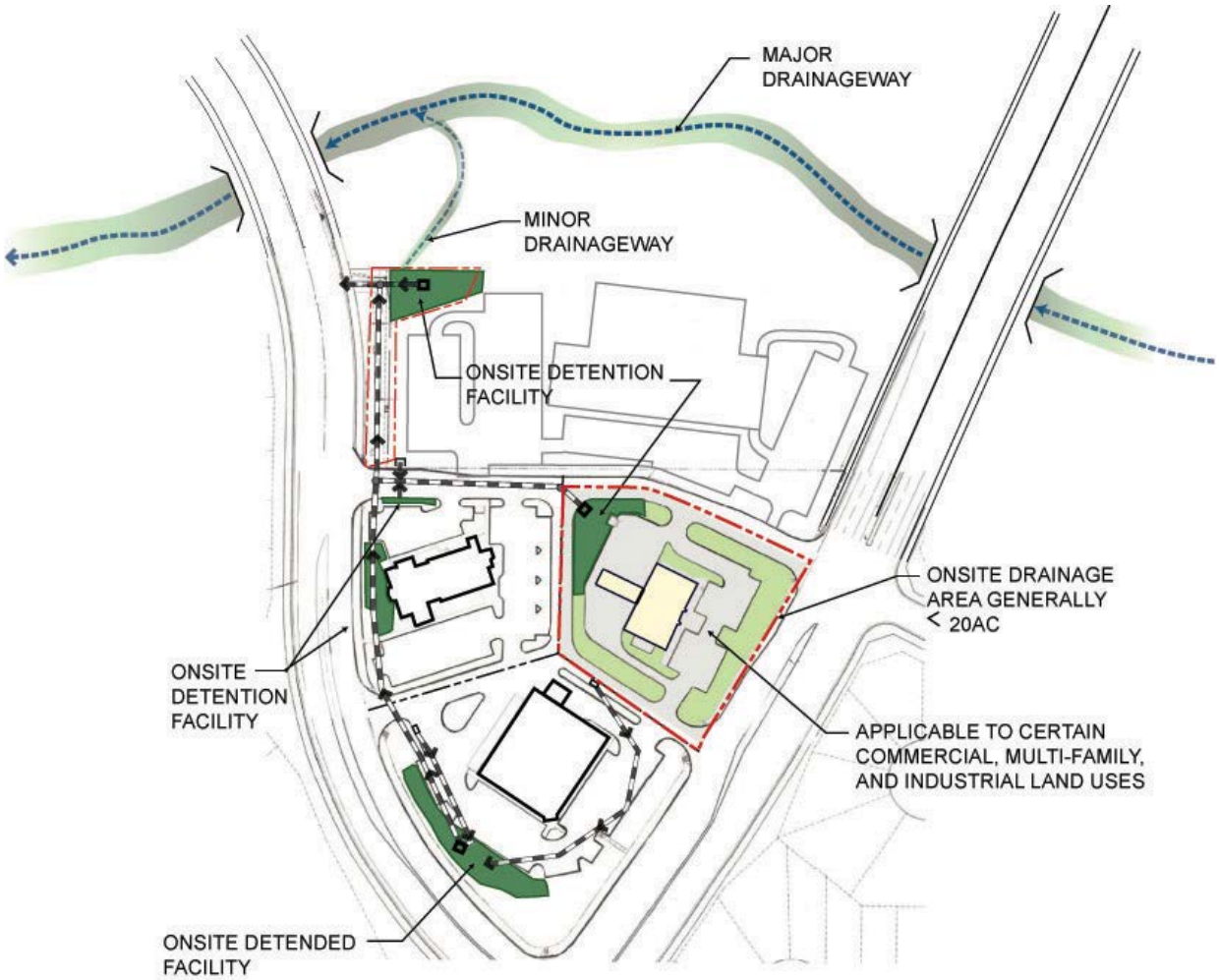

Figure 12-3. Example configuration for on-site detention (Source: Arapahoe County)

The principal advantage of on-site facilities is that developers can be required to build them as a condition of site approval. Major disadvantages include the need for a larger total land area for multiple smaller on-site facilities as compared to a larger regional facility serving the same tributary catchment area. If the individual on-site facilities are not properly maintained, they can become a nuisance to the community and a basis for many complaints to municipal officials. It is also difficult to ensure adequate maintenance and long-term performance. Approximately 100 on-site facilities built, or required by municipalities to be built, as a part of land developments over about a 10-year period were inspected and it was concluded that a lack of adequate maintenance and implementation contributed to a loss of continued function or even presence of these facilities (Prommesberger 1984).

2.4 Detention and UDFCD 100-Year Floodplain Management Policy

In light of the difficulties involved in ensuring the long term effectiveness of on-site detention and privately maintained subregional detention facilities, UDFCD adheres to the following policies when developing hydrology for the delineation and regulation of the 100-year flood hazard zones:

1. Hydrology must be based on fully developed watershed conditions (e.g., imperviousness) as estimated to occur, at a minimum, over the next 50 years.

2. No detention basin will be recognized in the development of hydrology unless:

    a. It serves a watershed that is at least 130 acres or otherwise provides substantial flood reduction, and

    b. It is owned (or controlled by legal document) and maintenance is either performed or required by a public agency, and

    c. The public agency has committed to ensure that the detention facility continues to operate in perpetuity as designed.

These policies are for the definition and administration of the 100-year floodplain and floodway zones and the design of facilities along major drainageways. The intent is not to discourage communities from using subregional or onsite detention discussed above. Subregional and onsite detention can be very beneficial for stormwater quality and quantity management, reducing the sizes of local storm drains and other conveyances, and providing a liability shield (defense) when needing to address the issue of keeping stormwater-related damages to downstream properties from increasing as upstream lands are developed.

3.0 Full Spectrum Detention as the Recommended Approach

The design guidance provided in this chapter is based on an approach termed "full spectrum detention." The intent of full spectrum detention is to reduce the flooding and stream degradation impacts associated with urban development by controlling peak flows in the stream for a range of events.

3.1 Background

Roofs, streets, parking lots, sidewalks, and other impervious surfaces increase peak flows, frequency of runoff and total volume of stormwater surface runoff when compared to pre-development conditions.

This increase is most pronounced for the smaller, more frequent storms and can result in stream degradation and water quality impacts as well as flooding during the large events.

Criteria for stormwater detention design have evolved from a focus on the minor and major events to an approach shown to better control peak flows for a wide range of events. In the interest of stream stability, specific focus should be placed on frequent events. Incorporating a slow release for the water quality capture volume (WQCV) helps to address very frequent urban runoff events; however, it is also important to extend the volume of water attenuated to capture the range of flows that transport the most bed load in the receiving stream. This range of flows depends on reach-specific characteristics but is typically between the annual event and the 5-year peak flow rate. Runoff events in this range can produce profound geomorphic changes in ephemeral, intermittent and perennial streams resulting in severe erosion, loss of riparian habitat, and water quality degradation.

Furthermore, outflow hydrographs from traditional detention facilities tend to be "flat-topped" and broad, maintaining flows near the maximum release rates for relatively long periods of time. This allows hydrographs released from multiple independent basins to overlap and add to each other to a greater degree than they would have during pre-development conditions. Thus, traditional detention practices can result in an increase in *watershed-wide* discharges even if individual detention facilities each would control peak discharges to pre-developed conditions.

Full spectrum detention is designed to address these two limitations of traditional detention. First, it is focused on controlling peak discharges over the full spectrum of runoff events from small, frequent storms up to the 100-year flood. Second, full spectrum detention facilities produce outflow hydrographs that, other than a small release rate of the excess urban runoff volume (EURV), replicates the shape of pre-development hydrographs. Full spectrum detention modeling shows reduction of urban runoff peaks to levels similar to pre-development conditions over an entire watershed, even with multiple independent detention facilities.

3.2 Excess Urban Runoff Volume

The lower portion of volume in a full spectrum detention facility is designed to capture and slowly release the excess urban runoff volume (EURV). The EURV is the difference between the developed condition runoff volume and the pre-development volume. Based on the hydrologic methods used within the UDFCD region, the EURV appears to be relatively consistent at any given level of imperviousness for the range of storms (generally beyond the 2-year event) that produce runoff. This is illustrated in Figure 12-4. The full spectrum detention concept is to reduce runoff for all the frequent storms (smaller than approximately the 2-year event) to as close to zero as possible and less than the threshold value for erosion in most streams. When this is done, the remaining runoff from a site approximates the runoff volume for pre-development conditions.

The EURV is typically two to three times the water quality capture volume (WQCV) and the release rates are generally comparable. Therefore, designing for EURV typically results in a design that also meets the recommended drain time for treatment of the WQCV.

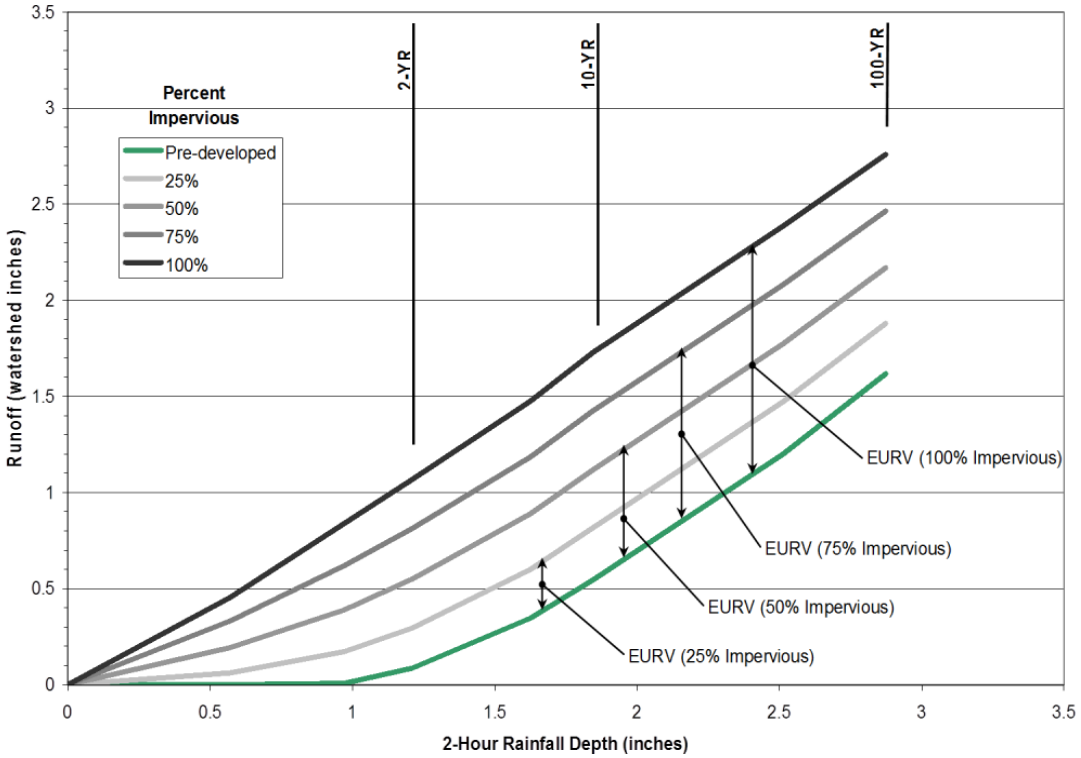

Figure 12-4. EURV is relatively constant for runoff producing storms

The upper portion of volume in a full spectrum detention facility is designed to reduce the developed condition 100-year peak discharge down to 90 percent of the pre-development 100-year peak flow rate from the tributary sub-watershed. Through modeling, it has been found that releasing 90 percent of the 100-year event peak discharge at each full spectrum detention basin within a watershed results in flows in the receiving stream that are near pre-development. Figure 12-5 illustrates the effectiveness of full spectrum detention in comparison to traditional practices for a test watershed made up of fifty 100-acre subwatersheds each modeled with a detention basin (Wulliman and Urbonas, 2005).

Benefits of Implementing Full Spectrum Detention on a Watershed Level

- A properly designed full spectrum detention facility can reduce urban peak discharges to levels similar to pre-development conditions for the full spectrum of runoff events from small, frequent storms up to the 100-year event. This reduces the stresses imposed by urban runoff on streams so degradation will occur at reduced rates compared to conventional detention practices.
- With the capture and slow release of the EURV mitigating to some degree the additional runoff impacts associated with development, the remaining volume that is released from a full spectrum facility approximates the runoff from the upstream area for pre-development conditions. This allows regional full spectrum detention to effectively control peak discharges within a watershed even when multiple independent facilities are used.
- The design of full spectrum detention is relatively simple, and certainly no more complex than traditional detention practices.
- Required 100-year storage volumes for full spectrum detention facilities are generally similar to traditional flood control and water quality detention practices.

Because of these benefits, UDFCD recommends the use of full spectrum detention over typical detention criteria associated with stormwater quantity.

3.3 Compatibility of Full Spectrum Detention with Minor and Major Event Detention

The EURV and 100-year detention volumes are similar in magnitude to 10-year/100-year detention facilities volumes. The main difference is that the EURV described in Section 2.2 is drained at a much slower rate than the 10-year detention volume would be based on past criteria provided in this manual.

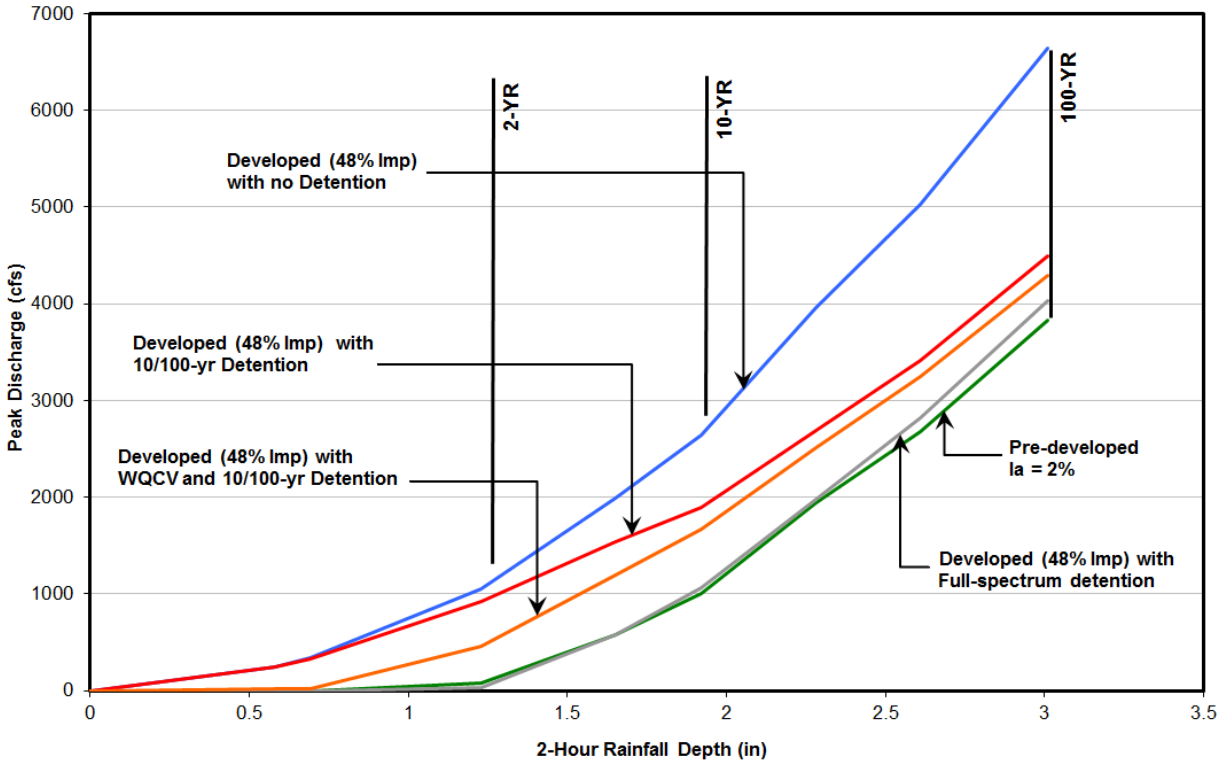

Figure 12-5. Comparison of full spectrum detention and conventional practices for a sample watershed consisting of fifty 100-acre subwatersheds

Where existing master plans recommend detention facilities designed to address minor and major events, UDFCD generally intends that these will be implemented as full spectrum facilities; however, the final determination of detention policy should be made by each jurisdiction.

There may be opportunities to convert existing 10-year/100-year detention facilities into full spectrum facilities by reducing the capacity of the 10-year control orifice to a EURV release rate, and ensuring that the debris grate for the EURV orifices and the 100-year outlet and emergency spillway for the facility are adequate.

3.4 Water Quality Capture Volume and Full Spectrum Detention

This section provides criteria for incorporating five types of WQCV treatment best management practices (BMPs) into full spectrum detention basins. Volume 3 of the USDCM further describes these BMPs. They are:

- Extended detention basins,
- Retention ponds,
- Constructed wetland ponds,
- Sand filters, and
- Rain gardens (bioretention)

The 100-year full spectrum detention volume described in this chapter is consistently expressed as the total detention volume including EURV; also, EURV consistently includes the water quality volume. Therefore, the WQCV and the EURV are both inclusive of the 100-year full spectrum detention volume and UDFCD does not recommend adding any part of the WQCV to either the EURV or the 100-year volumes calculated based on Section 3.0.

Figure 12-6 illustrates an extended detention basin combined with full spectrum detention. In the figure, Zone 1 represents the water quality portion of the facility. Zone 2 represents the difference between the EURV and Zone 1. Zone 3 represents the difference between the 100-year volume and the EURV. The design volume, drain time, and release rate of each zone of an extended detention basin combined with full spectrum detention is shown in Table 12-1.

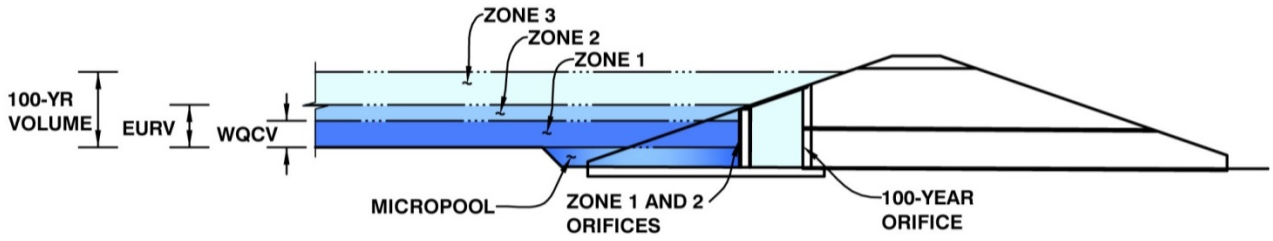

Figure 12-6. Extended detention basin combined with full spectrum detention

Table 12-1. Extended detention basin combined with full spectrum detention

Zone	Volume	Drain Time of Zone, hrs	Maximum Release Rate
1	40-hr WQCV	40	Based on drain time
2	EURV minus (40-hr WQCV))	12 to 32[1]	Based on drain time
3	100-yr minus EURV	Based on release rate	0.9(predevelopment Q_{100})

[1]Colorado law requires 97% of the 5-year event to drain within 72 hours.

Because each of the five WQCV treatment BMPs has slightly different sizing criteria and release rate criteria, as described in Volume 3 of the USDCM, the design of full spectrum detention facilities also varies based on type of WQCV BMP. The design of a retention pond combined with full spectrum detention is shown in Figure 12-7 and in Table 12-2.

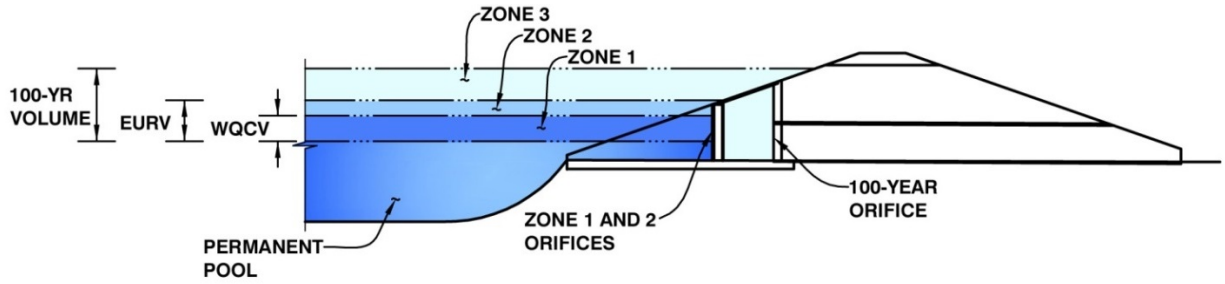

Figure 12-7. Retention pond combined with full spectrum detention

Table 12-2. Retention pond combined with full spectrum detention

Zone	Volume	Drain Time of Zone, hrs	Maximum Release Rate
1	12-hr WQCV	12	Based on drain time
2	EURV minus 12-hr WQCV	12 to 60[1]	Based on drain time
3	100-yr minus EURV	Based on release rate	0.9(predevelopment Q_{100})

[1]Colorado law requires 97% of the 5-year event to drain within 72 hours.

The design of a constructed wetland pond combined with full spectrum detention is shown in Figure 12-8 and in Table 12-3.

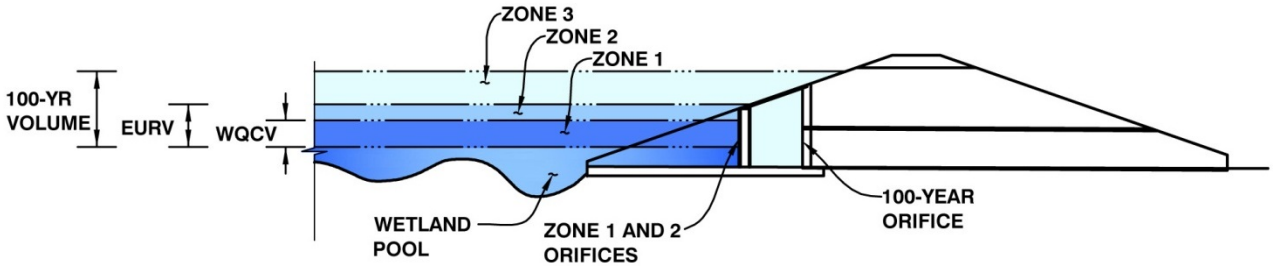

Figure 12-8. Constructed wetland pond combined with full Sspectrum detention

Table 12-3. Constructed wetland pond combined with full spectrum detention

Zone	Volume	Drain Time of Zone, hrs	Maximum Release Rate
1	24-hr WQCV	24	Based on drain time
2	EURV minus 24-hr WQCV	12 to 48[1]	Based on drain time
3	100-yr minus EURV	Based on release rate	0.9(predevelopment Q_{100})

[1]Colorado law requires 97% of the 5-year event to drain within 72 hours.

The design of a sand filter combined with full spectrum detention is shown in Figure 12-9 and in Table 12-4. Although the water quality event is released through the filter media, it is recommended that an orifice be provided to drain Zone 2 (the balance of the EURV) and a grated inlet or spillway be used to control the release of Zone 3 (the balance of the 100-year volume). This configuration reduces the amount of Zone 2 and 3 runoff flowing through the filter media.

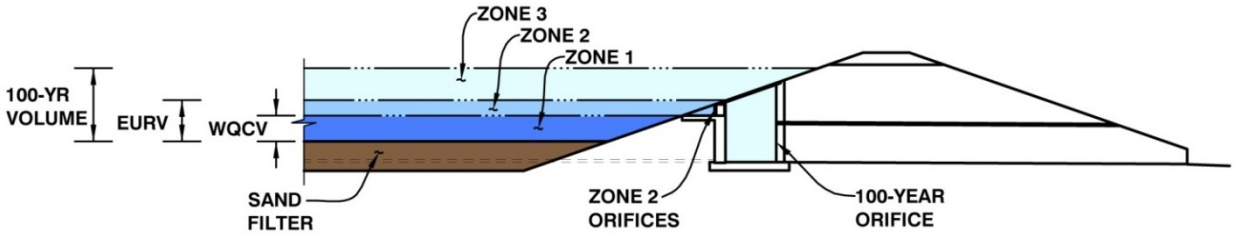

Figure 12-9. Sand filter combined with full spectrum detention

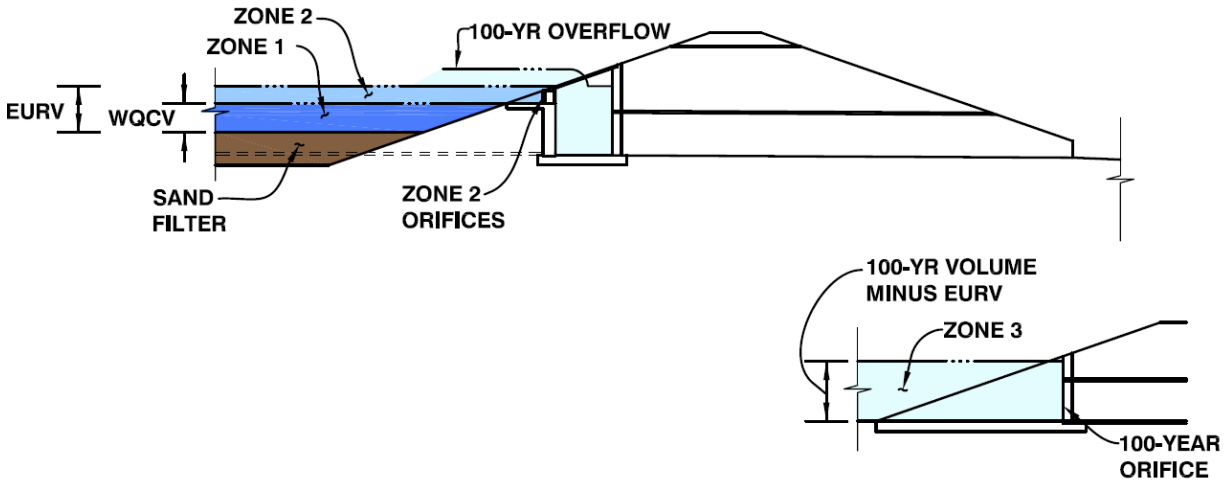

Figure 12-10. Sand filter and zone 2 combined with downstream zone 3 basin

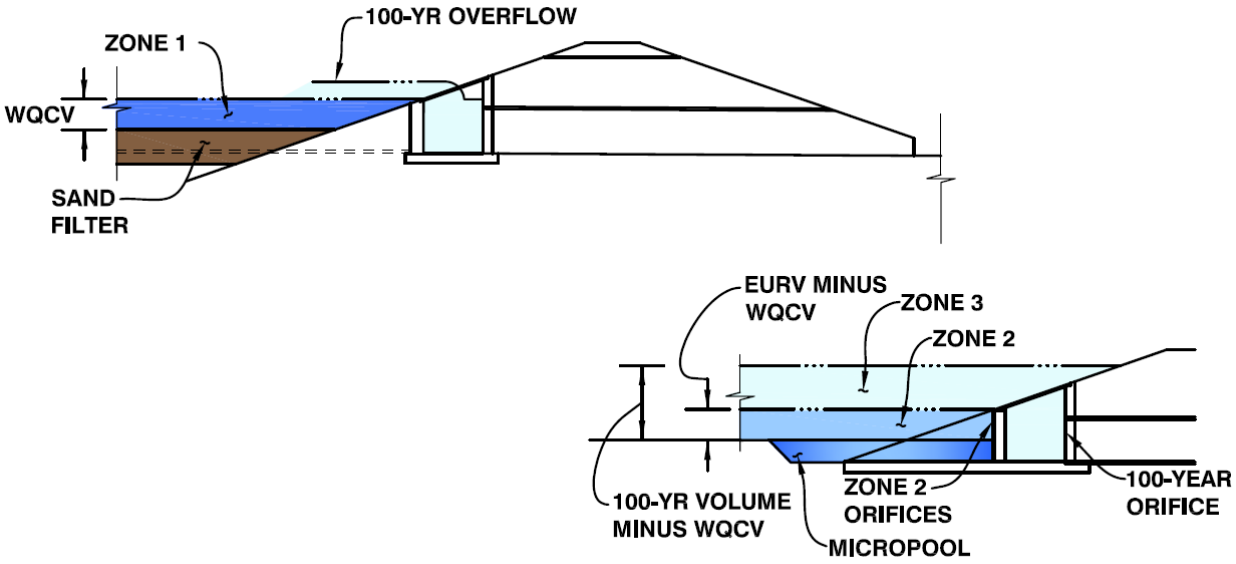

Figure 12-11. Stand-alone sand filter with downstream zone 2/zone 3 basin

The design of a bioretention facility combined with full spectrum detention is shown in Figure 12-12 and in Table 12-4. As in a sand filter, it is recommended that an orifice plate be provided to drain Zone 2 (the balance of the EURV) and a grated inlet or spillway be used to control the release of Zone 3 (the balance of the 100-year volume). Because these facilities are often implemented in compact areas and in multiple installations such as in parking medians and small landscaped areas, and because maintaining vegetation is critical to the facility, it is recommended to separate these facilities from Zone 3 or from both Zone 2 and 3. Configurations of separate facilities are shown in Figures 12-13 and 12-14. In these cases, the volume, drain time, and release rate of the zones are still determined based on Table 12-4.

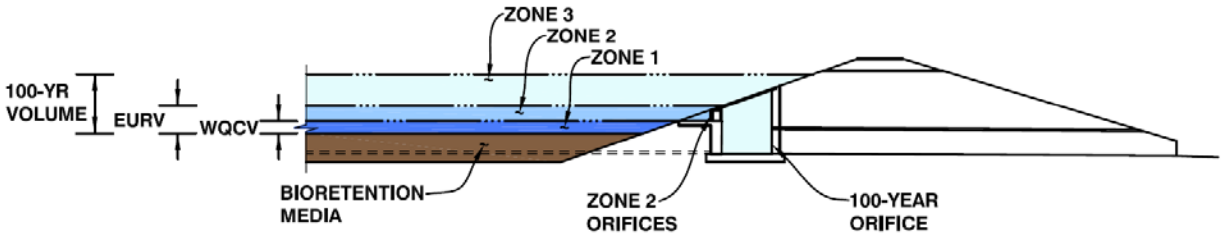

Figure 12-12. Bioretention combined with full spectrum detention (not ideal for vegetation)

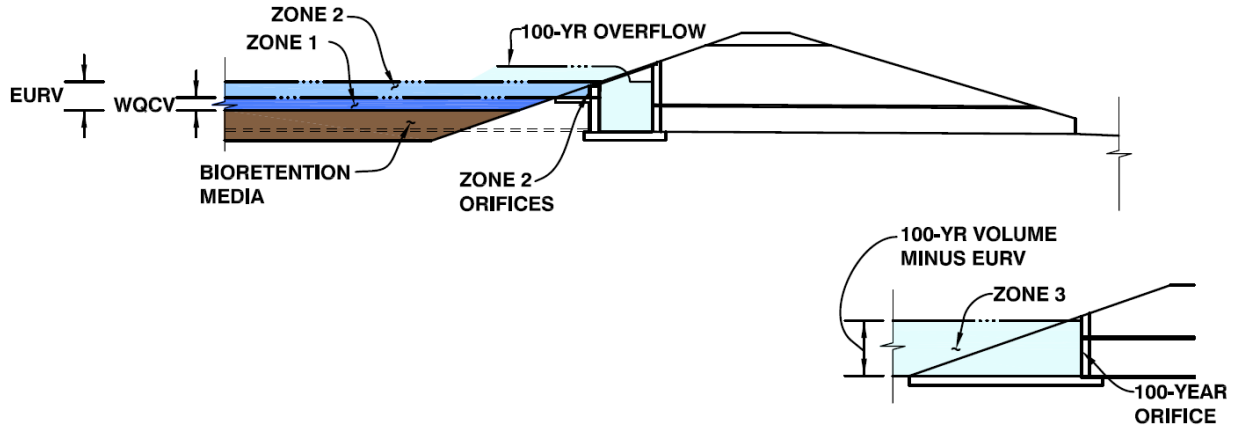

Figure 12-13. Bioretention and zone 2 combined with downstream zone 3 basin

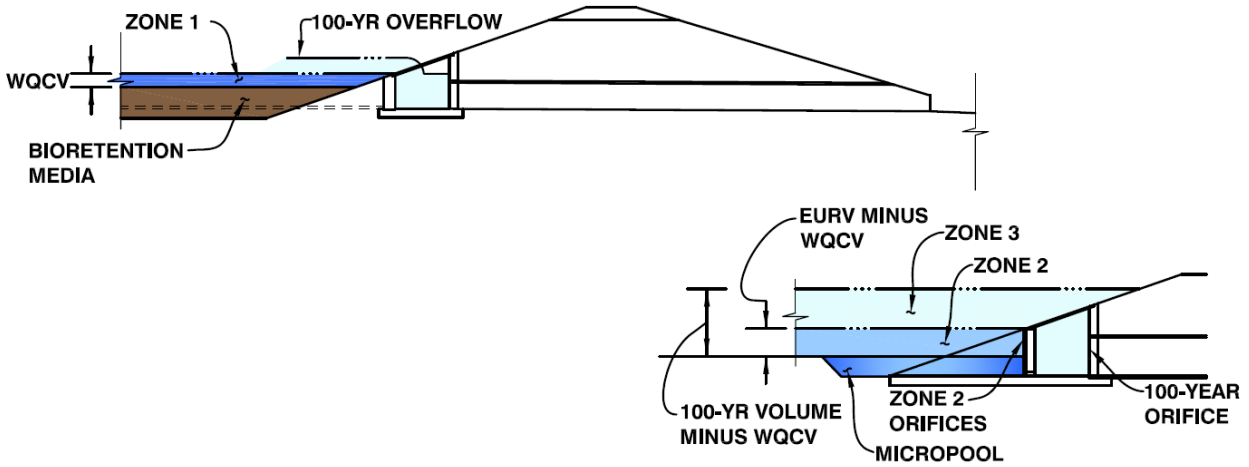

Figure 12-14. Stand-alone bioretention with downstream zone 2/zone 3 basin

Table 12-4. Sand filter or bioretention facility combined with full spectrum detention

Zone	Volume	Drain Time of Zone, hrs	Maximum Release Rate
1	12-hr WQCV	12	Based on drain time
2	EURV minus 12-hr WQCV	12 to 32[1]	Based on drain time
3	100-yr minus EURV	Based on release rate	0.9(predevelopment Q_{100})

[1]Colorado law requires 97% of the 5-year event to drain within 72 hours.

4.0 Sizing of Full Spectrum Detention Storage Volumes

Three methods for sizing full spectrum detention storage volumes are described in the USDCM, as follows:

1. Simplified Equation
2. UD-Detention workbook
3. Hydrograph routing using CUHP and SWMM

The recommended range of application for the methods based on upstream watershed area is shown in Table 12-5. Full spectrum detention facilities may be sized using any of the methods shown in the table for the ranges of watershed area; however, the UD-Detention workbook more accurately represents input variables than the simplified equation and the hydrograph approach provides the most accurate approach. UDFCD recommends the hydrograph routing approach when evaluating multiple full spectrum detention facilities arranged in parallel or series in a watershed. The three sizing methods are described in the following sections.

Table 12-5. Applicability of full spectrum sizing methods based on watershed area

Watershed Properties	Sizing Method		
	Simplified Equations	**UD-Detention[1]**	**CUHP/SWMM Hydrograph Routing**
Less than 10 acre	X	X	
10 to 50 acres		X	X
50 to 130 acres		X	X
130 acres to 1 mile[2]		X	X
Greater than 1 mile[2]		X	X
Multiple detention facilities in parallel or series			X

[1]See Section 4.2 for additional discussion on the use of UD-Detention for the preliminary design and final design of a full spectrum facility.

4.1 Simplified Equations

Simplified equations are provided in this section for determining full spectrum detention design volumes and 100-year release rates. Once these values are determined, a full spectrum detention facility may be designed according to the technical guidance described in Section 5.0.

4.1.1 Full Spectrum Detention Volume

Three different volumes are associated with the design of a full spectrum detention facility, as illustrated in Section 3.4. These are:

1. **WQCV** (Zone 1)
2. **EURV** (Zone 1 plus Zone 2)
3. **100-year volume** (sum of Zones 1, 2, and 3)

Within the ranges identified in Table 12-5, these volumes may be determined using simplified equations, as described below.

WQCV. The water quality capture volume for each of the five types of water quality facilities shown in Section 3.4 can be calculated based on the procedures described in Volume 3 of the USDCM.

EURV. Use equations 12-1, 2 and 3 to find EURV in watershed inches for specific soil types.

$$EURV_A = 1.68i^{1.28} \quad \text{Equation 12-1}$$

$$EURV_B = 1.36i^{1.08} \quad \text{Equation 12-2}$$

$$EURV_{C/D} = 1.20i^{1.08} \quad \text{Equation 12-3}$$

Where:

$EURV_K$ = Excess urban runoff volume in watershed inches (*K* indicates NRCS soils type),
i = Imperviousness ratio (a decimal less than or equal to 1)

The Technical Memorandum entitled *Determination of the EURV for Full Spectrum Detention Design*, dated December 22, 2016 documents the derivation of these equations. This is available at www.udfcd.org. Apply the equations above for each of the soil types found in the watershed and then calculate a weighted average value based on the relative area proportion of each soil type. Convert the EURV in watershed inches to a volume multiplying it by the watershed area.

Whenever NRCS soil surveys are not available for a catchment area, soils investigations are recommended to estimate equivalent soil type.

100-Year Volume. A simplified equation can be used to determine the required 100-year full spectrum detention volume for tributary areas less than 10 acres. This volume includes the EURV (and the EURV includes the WQCV). UDFCD does not recommend adding additional volume above that provided in Equation 12-4. The derivation of this equation is documented in a Technical Memorandum entitled *Estimation of Runoff and Storage Volumes for Use with Full Spectrum Detention*, dated January 5, 2017 (available at www.udfcd.org). If a more detailed analysis is desired, see Table 12-5. The 100-year volume in watershed inches is converted to cubic feet or acre-feet by multiplying by watershed area and converting units.

$$V_{100} = P_1\left[\begin{array}{l}(0.806i^{1.225} + 0.109i^{0.225})A\% + (0.412i^{1.371} + 0.371i^{0.371})B\% \\ + (0.341i^{1.389} + 0.398i^{0.389})CD\%\end{array}\right] \quad \text{Equation 12-4}$$

Where:

V_{100} = detention volume in watershed inches

P_1 = one-hour rainfall depth (inches)

i = imperviousness ratio (a decimal less than or equal to 1)

A%, B%, and CD% = indicates percentage of each NRCS soils type (expressed as a decimal)

4.1.2 100-year Release Rates

The maximum allowable 100-year release rate for a full spectrum detention facility is equal to 90 percent of the predevelopment discharge for the upstream watershed. Modeling has shown that using this release rate for multiple full spectrum detention basins within a watershed is effective in controlling future development peak discharges in the receiving stream to levels below predevelopment conditions for the 2, 5, 10, 25, 50, and 100-year events.

The predevelopment 100-year unit discharge for specific soil types per acre of tributary catchment varies based on the watershed slope and the watershed shape (described as the ratio of the flow length squared to the watershed area). Use Equation 12-5 with coefficients provided in Tables 12-6, 12-7, and 12-8 to calculate the peak unit flow rate based on an assumed predevelopment imperviousness of 2%. When using this equation, UDFCD recommends a sloped value no less than 0.01 and no greater than 0.04 and a shape value no less than one and no greater than six. Multiply the 100-year peak unit flow rate by 0.9 to determine the allowable 100-year release from a watershed.

See the Technical Memorandum entitled *UDFCD Predeveloped Peak Unit Flowrates,* dated December 21, 2016 for documentation of the following equation and tables. This is available at www.udfcd.org.

$$q = P_1 C_1 S^{C_2} \left(\frac{L^2}{A} \right)^{C_3}$$ Equation 12-5

Where:

q = peak unit flow rate (cfs/acre)
P = one-hour precipitation depth (in) from NOAA Atlas 14
S = watershed flow path slope (ft/ft)
L = watershed flow path length (ft)
A = area of tributary (ft^2)
C_1, C_2, C_3 = coefficients dependent on event frequency (see Tables12-6, 12-7, and 12-8)

Table 12-6. Coefficients for NRCS hydrologic soil group A

Return Period →		2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Leading Coeff.	C_1	0.0014	0.0104	0.0208	0.0478	0.2652	0.5622	0.9318
Slope Exp.	C_2	0.1684	0.2065	0.2070	0.2491	0.2056	0.2021	0.1853
Shape Exp.	C_3	-0.3533	-0.4430	-0.4453	-0.4406	-0.4385	-0.4286	-0.3933

Table 12-7. Coefficients for NRCS hydrologic soil group B

Return Period →		2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Leading Coeff.	C_1	0.0285	0.0377	0.3509	0.8566	1.0437	1.2088	1.4061
Slope Exp.	C_2	0.1911	0.1855	0.2069	0.1761	0.1743	0.1677	0.1640
Shape Exp.	C_3	-0.4045	-0.3950	-0.4446	-0.3729	-0.3696	-0.3542	-0.3470

Table 12-8. Coefficients for NRCS hydrologic soil group C

Return Period →		2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Leading Coeff.	C_1	0.0338	0.2418	0.5375	0.9920	1.1614	1.3053	1.4949
Slope Exp.	C_2	0.1869	0.2005	0.1901	0.1720	0.1715	0.1651	0.1623
Shape Exp.	C_3	-0.3946	-0.4280	-0.4055	-0.3641	-0.3637	-0.3490	-0.3438

When multiple soil types exist in the watershed, use the table values for each soil type and calculate a weighted average value relative to the area proportion of each soil type. Use Equation 12-6 to calculate the allowable discharge from the basin.

$$Q = 0.9aq \qquad \text{Equation 12-6}$$

Where:

Q = Allowable 100-year release rate (cfs)
a = Area of watershed (acres)
q = weighted average unit release rate based on relative proportions of watershed soil types (cfs/acre)

Unless otherwise recommended in an approved master plan, the maximum releases rates described in this section are for all full spectrum detention facilities.

4.1.3 Predevelopment Peak Discharges for Various Return Periods

The intent of the UDFCD full spectrum detention policy is to manage developed condition peak flows to levels similar to predevelopment conditions for a full range of return periods in areas serviced by full spectrum detention facilities. To gain a sense for the magnitude of predevelopment peak flow rates for various return rates, see the Technical Memorandum entitled *UDFCD Predeveloped Peak Unit Flowrates,* (MacKenzie and Rapp, 2016). This is available at www.udfcd.org.

4.2 UD-Detention Workbook

Beyond the simplified equation described in Section 4.1, an Excel-based workbook is available to size full spectrum detention basins for the range of watershed sizes identified in Table 12-5. UD-Detention is available at www.udfcd.org. This workbook uses the Modified Puls reservoir routing method to evaluate performance of the facility based on tributary watershed parameters and variables associated with the basin/pond geometry and outlet configuration. It compares calculated release rates to predevelopment discharges for the 2, 5, 10, 25, 50, and 100-year events. UD-Detention allows analysis of any retention pond or detention basin including extended detention, bioretention, sand filters, basins that may or may not be full spectrum, basins that only include one or two controlled zones, or basins having unusual outlet structures.

Section 8.0 of this chapter includes an example problem using each of the workbooks.

4.2.1 Hydrograph Routing using CUHP and SWMM

Hydrograph routing using CUHP and SWMM is a third option for sizing and designing full spectrum detention facilities, based on the watershed properties identified in Table 12-5. This is the only method that is able to assess the performance of multiple detention facilities arranged in parallel or in series in a watershed. Hydrograph routing using SWMM is similar to the evaluation mode of UD-Detention in that

the user needs to input stage-area and stage-discharge information based on a preliminary design and iterations may be necessary to arrive at a final basin and outlet structure configuration that reduces developed condition peak flows to levels equal to or below predevelopment conditions.

The reservoir routing capabilities in SWMM determine a detention basin's outflow characteristics given the stage-discharge relationship for a reservoir outlet link and the stage- area relationship for the reservoir storage node of the model. The stage- area relationship is determined by finding the water surface areas of the basin at different depths or elevations, which are then used by the model to calculate the incremental volumes used as the stage rises and falls. The basin layout and outlet structure are modified as needed after each model run to adjust the corresponding stage-area and stage-discharge data pairs, until the outflow from the basin meets the specified flow limit. No description of the theory of reservoir routing is provided in the USDCM, as the subject is well described in many hydrology reference books (Viessman and Lewis 1996; Guo 1999b).

For full spectrum basins evaluated using hydrograph routing, the EURV portion of the basin still needs to be sized using Equations 12-1 through 12-3 in Section 4.1 and the outlet designed to empty this volume as described in Section 3.4. The 100-year peak flow control volume above the EURV (Zone 3) must be determined, and its outlet designed using full hydrograph routing protocols. The maximum allowable 100-year release rate should not exceed 90 percent of the approved predevelopment release rate determined through CUHP/SWMM modeling of the upstream watershed (this may vary slightly from the predevelopment discharge values presented in Section 4.1.2), or maximum flow rates recommended in an accepted master plan.

5.0 Design Considerations

The design of a detention facility entails detailed hydraulic, structural, geotechnical, and civil design. This includes a detailed site grading plan, embankment design, spillway design, hydraulic and structural design of the outlet works, safety grate design, maintenance access, consideration of sedimentation and erosion potential within and downstream of the facility, liner design (if needed), etc. Collaboration between geotechnical engineers, structural engineers, hydrologic and hydraulic engineers, land planners, landscape architects, biologists, and/or other disciplines is encouraged during the preliminary and final design phases.

It is beyond the scope of the USDCM to provide detailed dam design guidance. There are many excellent references in this regard, such as *Design of Small Dams* (U.S. Bureau of Reclamation 1987). UDFCD urges all designers to review and adhere to the guidance in such references as failure of even small embankments can have serious consequences for the public and the municipalities downstream of the embankment.

As discussed in Section 3.4, full spectrum detention facilities are configured together with one of five types of water quality basins described in Volume 3 of the USDCM. The design of the water quality portion of the facility, illustrated as Zone 1 in Section 3.4, is described in detail in Volume 3. The following guidelines for the design of full spectrum detention facilities apply to Zones 2 and 3 as shown in Figures 12-6 through 12-14.

5.1 General Layout and Grading

Storage facility geometry and layout are often best developed in concert with land planners and landscape architect. Whenever desirable and feasible, multiple uses of a basin should be considered, such as creation of riparian and wetland vegetation, wildlife habitat, paths, and other passive or active recreation

opportunities. If multiple uses are being contemplated, it is recommended that the inundation of passive recreational areas be limited to one or two occurrences a year and of active recreation areas to once every two years. Generally, the area within Zone 1 and Zone 2 is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas, but may be suitable for passive recreation such as wildlife habitat and some hiking trails. It is desirable to shape the water quality portion of the facility (Zones 1 and 2) with a gradual expansion from the inlet and a gradual contraction toward the outlet, thereby minimizing short-circuiting.

Maintenance is also an important consideration with respect to layout and grading. Consider how lower areas of the basin, such as the forebay and micropool will be accessed, and with what equipment.

5.2 Storage Volume

Provide the total 100-year storage volume determined using one of the three methods described in Section 4, along with additional basin storage and depth necessary to contain emergency flows and provide freeboard as described in Section 5.3.

5.3 Embankments

Embankment should be designed to not catastrophically fail during the 100-year and larger storms that the facility may encounter. The following criteria apply in many situations (ASCE and WEF 1992):

- **Side Slopes:** For ease of maintenance, the side slopes of the embankment should not be steeper than 3(H):1(V), with 4(H):1(V) preferred. The embankment's side slopes should have fully vegetated coverage, with no trees or shrubs above the basin floor. Soil-riprap protection (or equivalent) may be necessary to protect it from wave action on the upstream face, especially in retention ponds.

- **Settlement and Compaction:** The design height of the embankment should be increased by roughly 5 percent to account for settlement. All earth fill should be free from unsuitable materials and all organic materials such as grass, turf, brush, roots, and other organic material subject to decomposition. The fill material in all earth dams and embankments should be compacted to at least 95 percent of the maximum density based on the Modified Proctor method of ASTM D698 testing.

- **Freeboard:** The elevation of the top of the embankment should be a minimum of 1 foot above the water surface elevation when the emergency spillway is conveying the maximum design or emergency flow. When the embankment is designed to withstand overtopping of the undetained peak flow without failure, freeboard requirements may be reduced or waived.

Anti-Seepage may also be required. This topic is covered in detail in FEMA's *Technical Manual: Conduits through Embankment Dams* (2005) and NRCS's *National Design Construction and Soil Mechanics Center Technical Note – Filter Diagrams for CO-1 Structures* (2003). Construction of a filter diaphragm will be adequate in most scenarios covered in this chapter.

If the storage facility is determined to be "jurisdictional" per the criteria of Colorado Division of Water Resources (DWR), also known as the Office of the State Engineer, the embankment shall be designed, constructed and maintained to meet DWR's most-current criteria for jurisdictional structures. The design for an embankment of a stormwater detention or retention storage facility should be based upon a site-specific engineering evaluation.

5.4 Emergency Spillways

Provide an open channel emergency spillway to convey flows that exceed the primary outlet capacity or when the outlet structure becomes blocked with debris. When the storage facility falls under the jurisdiction of the DWR, design this bill way based on the storm prescribed by the DWR (DWR 2007). If the storage facility is not a jurisdictional structure, the size of the spillway design storm should be based upon the risk and consequences of a facility failure (e.g., avoidance of a critical facility). Generally, embankments should be fortified against and/or have spillways that, at a minimum, are capable of conveying the 100-year peak runoff from the fully developed tributary area (prior to routing flows though the detention basin). However, detailed analysis and determination of downstream hazards (such as critical facilities) should be performed and may indicate that the embankment protection and/or spillway design needs to be designed for events larger than the 100-year design storm.

An emergency spillway also controls the location and direction of the overflow. Clearly depict the emergency spillway and the path of the emergency overflow downstream of the spillway and embankment on the construction plans and do not allow structures (such as utility boxes) to be placed in the path of the emergency spillway or overflow.

Soil riprap is the most common method for providing embankment protection on a spillway. Although not preferred, baffle chute spillways may also be considered on a case by case basis. Further discussion regarding these two types of embankment protection is provided below.

5.4.1 Soil Riprap Spillway

Soil riprap embankment protection should be sized based on methodologies developed specifically for overtopping embankments. Two such methods have been documented (U.S. Nuclear Regulatory Commission, 1988 and Robinson et al., 1998). See these publications for a complete description of sizing methodology and application information. Figure 12-21 illustrates typical rock sizing for small (under 10-feet high) embankments based on these procedures that may be used during preliminary design to get an approximate idea of rock size. Final design should be based on the more complete procedures documented in the referenced publications. The thickness should be based on the criteria identified in the *Open Channels* chapter for steep channels. For spillway design, it is critical that the soil riprap has an adequate percentage of well-graded rock.

The invert of the emergency spillway is set at or above the 100-year water surface elevation (based on local jurisdiction criteria). A concrete wall is recommended at the emergency spillway crest extending at least to the bottom of the soil riprap located immediately downstream. The top of the crest wall at the sides should extend to the top of the embankment, at least one foot above the spillway elevation.

5.4.2 Baffle Chute Spillway

The USBR has developed design standards for a reinforced concrete chute with baffle blocks on the sloping face of a spillway, commonly referred to as baffled chute drop spillway. The primary reference that is recommended for the design of these structures is *Design of Small Dams* (1987). In addition, *Design of Small Canal Structures* (Aisenbrey, et al. 1978) and *Hydraulic Design of Stilling Basins and Energy Dissipators* (Peterka 1984) may provide useful information for the design of baffle chute spillways.

Photograph 12-3. Baffle chute drop after several decades of service.

The hydraulic concept behind baffle chute spillways involves flow repeatedly encountering obstructions (baffle blocks) that are of a nominal height equivalent to critical depth. The excess energy is dissipated through the drop by the momentum loss associated with reorientation of the flow. *Design of Small Dams* provides guidelines for sizing and spacing the blocks. Designing for proper approach velocities is critical to structure performance. One advantage of this type of spillway is that it does not require any specific tailwater depth. However, the designer does need to consider local flow and scour patterns in the transition back to the channel.

For safety reasons and considerations of appearance, a baffle chute spillway is not recommended for use as a grade control structure in a stream. Caution is advised when using a baffle chute spillway in a high debris area because the baffles can become clogged, resulting in overflow, low energy dissipation, and direct impingement of the erosive stream jet downstream.

A step by step procedure for the design of a baffle chute drop spillway is provided in *Design of Small Dams*. Typical design elements consist of upstream transition walls, a rectangular approach chute, a sloping apron (generally equal to the downstream slope of the basin embankment) that has multiple rows of baffle blocks and downstream transition walls. The toe of the chute extends below grade and is backfilled with loose riprap to prevent undermining of the structure by eddy currents or minor degradation downstream. The structure is effective even with low tailwater; however, greater tailwater reduces scour at the toe. The structure lends itself to a variety of soils and foundation conditions.

The steps involved in the construction of a baffle chute spillway are typical of the construction of any reinforced concrete structure, and include subgrade preparation, formwork, setting reinforcing steel, placing, finishing and curing concrete, and structure backfilling. Baffle chutes generally provide consistent, dependable hydraulic performance and are relatively straightforward to construct. Potential construction challenges include foundation integrity, water control, and managing the multiple phases of formwork, reinforcing, and concrete placement and finishing.

5.5 Outlet Structure

Outlet structures control release rates from storage facilities and should be sized and structurally designed to release flows at the specified rates without structural or hydraulic failure. Sizing guidance is provided earlier in this chapter with additional guidance in Volume 3 of the USDCM.

The most common design consists of a configuration that releases the WQCV (Zone 1) and the balance of the EURV (Zone 2) through an orifice plate (typically a steel plate containing a vertical column of small, equally-spaced orifices. The 100-year volume above the EURV (Zone 3) is then controlled by an orifice at the bottom of the outlet vault structure, or drop box, after spilling over the crest of the drop box. The crest of the drop box acts as a weir and its length, as well as the size of the drop box opening, needs to be oversized to account for flow area reduction by the safety grate bars and blockage by debris. Figure OS-1 in Volume 3 of the USDCM provides guidance for determining initial minimum trash rack sizes for an outlet structure. Values from this figure account for clogging and metalwork losses through the safety grate. In addition to using Figure OS-1, also ensure that the velocity through the grate unhindered by debris blockage does not exceed 2 feet per second.

Drop box Design Considerations

Considerations for the cost and appearance of the structure can limit the size of the drop box. However, it is important to consider maintenance access and ensure that neither the crest of the box nor the safety grate (even when partially clogged) is limiting flow to the 100-year orifice.

Safety considerations (pinning by impingement velocity through the grate) may also dictate a larger structure. Use Figure OS-1 in Volume 3 of the USDCM to size the grate while separately ensuring that velocity does not exceed 2 feet per second through the safety grate in its unclogged condition.

Additionally, UDFCD recommends providing a rail in any location where a drop exceeds 3-feet.

Design procedures for analyzing drop box hydraulics and accounting for debris blockage are described in Sections 5.5.1 through 5.5.4. Additional discussion regarding safety grates and debris blockage can be found in Section 5.6.

The hydraulic capacity of the various components of the outlet works (orifices, weirs, pipes) can be determined using the UD-Detention Excel workbook, or other standard hydraulic equations. A rating curve for the entire outlet can be developed by combining the rating curves developed for each of the components of the outlet and then selecting the most restrictive element that controls a given stage for determining the composite total outlet rating curve. The following sections describe procedures to generate a rating curve for four example types of 100-year drop box outlet structures. See Volume 3 of the USDCM for sizing the water quality orifices and incorporating water quality features into the outlet structure.

5.5.1 Flush Safety Grate

A flush grate drop box is a grate, either bar or close mesh, that is flush with the top of the box opening. The box opening may be horizontal or constructed with the slope of the embankment (as shown in Figure 12-15).

Evaluate the top of the outlet box for both weir (A) and orifice (B) flow at increasing water depths. The lesser of the two calculated flow values will indicate which controls for a given depth. Detailed discussion regarding weir and orifice hydraulics are in Section 5.14. Apply the net weir length and orifice open area, considering blockage by grating and potential debris, as discussed in Section 5.6. UDFCD contracted with Bureau of Recreation (USBR) to construct a physical model to refine weir/orifice calculations for a sloping drop box. Equations within the UD-Detention workbook equations are based on the USBR physical model. Documented at www.udfcd.org.

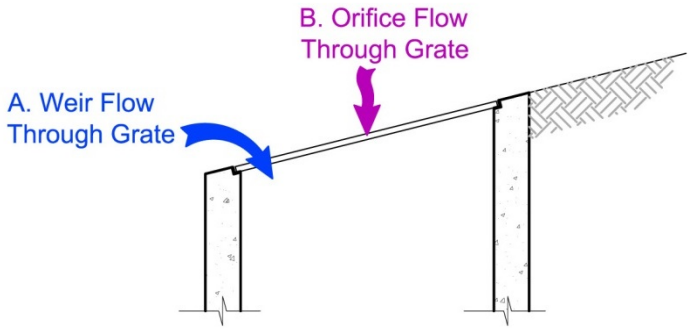

Figure 12-15. Flush grate (sloping drop box shown)

5.5.2 Raised Grate with Multiple Vertical Openings

A raised grate with multiple vertical openings offers improved flow capacity and resistance to debris blockage. It has vertical openings (open bar or close mesh) on two to four sides. See Figure 12-16 for a graphical representation of this grate configuration.

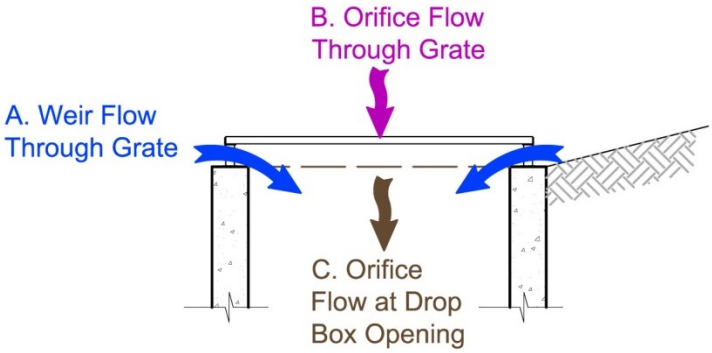

Figure 12-16. Grate with vertical openings (horizontal drop box shown)

This outlet must be evaluated for the two separate flow conditions (listed below and shown in Figure 12-16) to determine which controls at each incremental depth:

- **A. Weir Flow:** Calculate weir flow using the drop box interior perimeter reduced for the vertical grate supports and a 10% perimeter reduction for clogging.
- **B. Orifice Flow:** Calculate orifice flow using the smaller of the interior drop box area or the total grate area reduced for metalwork and debris clogging.

5.5.3 Raised Safety Grate with Vertical Opening

A grate with one vertical opening may also offer improved flow capacity and resistance to debris blockage. Figure 12-17 provides a graphical representation of this grate configuration.

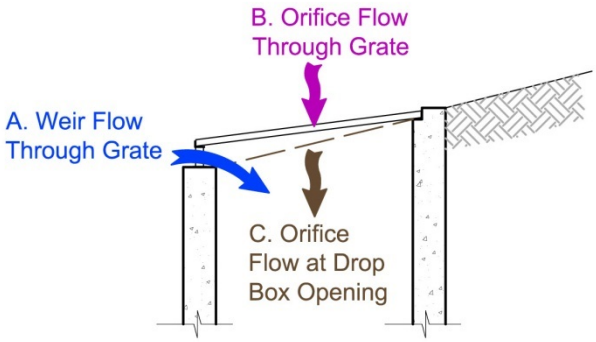

Figure 12-17. Grate with vertical opening (sloping drop box shown)

This outlet must be evaluated for the two separate flow conditions (listed below and shown in Figure 12-17) to determine which controls at each incremental depth:

- **A. Weir Flow:** Calculate weir flow using the average of the net perimeter length (i.e., reduced for metalwork and clogging) calculated from the condition shown in Figure 12-15 and Figure 12-16.

- **B. Orifice Flow:** Calculate orifice flow using the smaller of the interior drop box area or the total grate area reduced for metalwork and debris clogging. To account for clogging, the vertical grate net opening area should be reduced by 10%, while the horizontal grate net opening should be reduced by 50%. To simplify orifice calculations at various stages for a vertical or sloping grate, use the UD-Detention workbook.

5.5.4 Raised Grate with Offset Vertical Openings

A grate with offset vertical openings is a bar or close mesh grate that is elevated and extends beyond the sidewalls of the concrete outlet structure. This results in a vertical and horizontal gap between the grate and the walls of the drop box on all four sides of the structure and provides grate area below floating debris similar to a micropool design (See Volume 3 of the USDCM). Figure 12-18 shows a horizontal grate configuration. The grate could also be sloped.

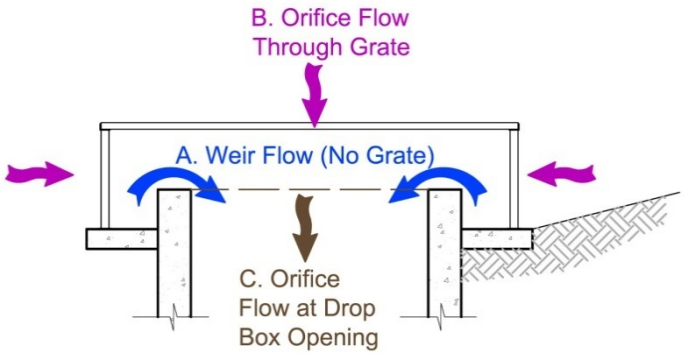

Figure 12-18. Grate with offset vertical panels (horizontal drop box shown)

This outlet must be evaluated for three separate flow conditions (listed below and shown in Figure 12-18) to determine which controls at each incremental depth:

- **A. Weir Flow:** Calculate weir flow over the walls of the drop box using the smaller of the unclogged drop box perimeter or the grate perimeter reduced for metalwork and 10% debris clogging.

- **B. Orifice Flow:** Calculate orifice flow using the smaller of the interior drop box area or the total grate area reduced for metalwork and debris clogging.

5.5.5 Outlet Pipe Hydraulics

Once the hydraulics of the top of a drop box are evaluated using the procedures discussed in Sections 5.5.1 through 5.5.4, the capacity of the outlet pipe and its orifice plate flow restrictor must be determined for increments of increasing water depth. The discharge pipe of the outlet works should be evaluated to ensure it is not under outlet control as a culvert at the 100-year (or design) discharge, and the orifice plate covering the opening of this pipe in the bottom of the drop box should be evaluated to ensure it limits flow to the required release rate. See the *Culverts* chapter for guidance regarding the calculation of the hydraulic capacity of outlet pipes. The UD-Culvert workbook can be used to determine the controlling condition of the culvert downstream of the orifice flow restrictor plate, while the UD-Detention workbook was designed to simplify these tasks.

The stage-discharge relationship of the outlet pipe and orifice is then compared to the controlling stage-discharge relationship for the top of the drop box plus flow through the water quality/EURV orifices may also be added. The ultimate control of the outlet is the smaller value of the flow through the top of the drop box plus water quality/EURV orifices, and the flow through the outlet pipe orifice over the range of stage. The design goal is that the outlet pipe orifice controls flow for the 100-year event, and the grate controls for more frequent return periods.

Determining the final hydraulics of the outlet structure becomes an iterative process. A final stage discharge curve is determined by completing the steps outlined above. This stage-discharge curve and the basin geometry are then input into the UD-Detention workbook or a SWMM model to evaluate hydrograph routing and the associated maximum stage, storage volume, and release rate. Often times it will be necessary to adjust the dimensions of the outlet box or the restrictor plate and orifice area of the outlet pipe to achieve the desired outflow from the basin. The goal is to have the 100-year orifice at the bottom of the box in front of the outlet pipe control the 100-year release rate at the maximum stage, not the hydraulic condition at the top of the outlet box. A final check on the overall safety of the outlet should be made to ensure that the velocity of flow through the grate open area reduced for metalwork but not for clogging does not exceed 2 ft/s.

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5.6 Trash Racks and Debris Blockage

Trash racks should always be installed as part of an outlet structure to reduce safety concerns. Consider maintenance of the structure and potential access by the public when selecting the type of trash rack. For example, a close mesh grate will be more appropriate in high pedestrian traffic but will require more frequent maintenance as it will catch smaller debris. Trash racks of sufficient size should always be provided on an outlet structure so that they do not interfere with the hydraulic capacity of the outlet. See figure OS-1 in Chapter 4 of Volume 3 of this manual for the minimum open area based on the outlet size.

Typically, outlet structure safety grates consist of either a bar grate, a close mesh grate or an open grate as shown in Figure 12-19 below. Close mesh and bar grates can be used for horizontal, sloping or vertical surfaces. Open grates are typically only used along vertical openings, as shown in Figures 12-16 through 12-18 of Section 5.5. Figure 12-19 provides typical dimensions for the three aforementioned grates. The open area of the grate is typically provided by the manufacturer for prefabricated grates. Alternatively, this can be calculated. It is always appropriate to apply a debris blockage reduction. This is typically 50%. In some cases, it may be appropriate to increase or decrease this value based upon the potential for debris at a specific site. Considerations should include land cover and the type of grate at a minimum.

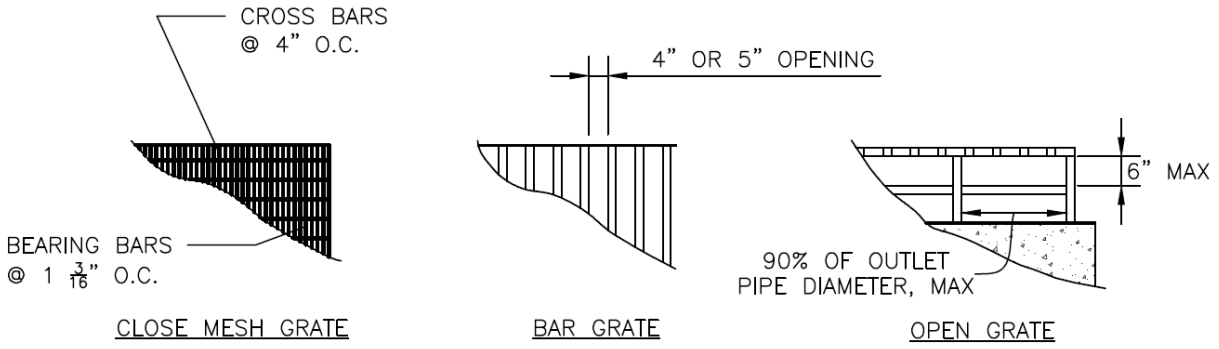


Figure 12-19. Typical grate configurations for outlet structures

5.7 Inlets

Inlets should provide energy dissipation to limit erosion. They should be designed in accordance with drop structure or pipe outlet criteria in the *Hydraulic Structures* chapter of the USDCM, or using other energy dissipation structures as appropriate. Additionally, forebays or sediment traps are recommended to provide a location to remove coarse sediment from the system prior to it being deposited in the vegetated area of the basin. Forebays need regular monitoring and maintenance.

5.8 Vegetation

The type of grass used in vegetating a newly constructed storage facility is a function of the frequency and duration of inundation of the area, soil types, and the other potential uses (park, open space, etc.) of the area. UDFCD recommends use of native grasses to reduce frequency and cost of maintenance and help maintain infiltration rates. See the *Revegtation* chapter for detailed information on establishing vegetation, including soil testing and amendments, seed mixes, and plantings. A planting plan should be developed for new facilities to meet their intended use and setting in the urban landscape. Trees and shrubs are not recommended on dams or fill embankments. However, use of trees immediately outside of detention basins will not interfere with their flood control operation or increase maintenance needs significantly. Also, sparse planting of trees basins may also be acceptable as long as they are not located near inlets and outlet or on the emergency spillway(s) and will not interfere significantly with maintenance or create clogging problems with the water quality screen. On the other hand, use of shrubs on the banks and bottom, while not affecting the flood routing, can increase maintenance significantly by providing traps for a source of debris and obstructing maintenance procedures. Because storage facilities are frequently wet, they are ideal nurseries for invasive and undesirable plants such as Siberian Elms, Russian Olives, Tamarisk, etc. This unplanned vegetation should be removed annually.

5.9 Retaining Walls

The use of retaining walls within detention basins is generally discouraged due to the potential increase in long-term maintenance access and costs as well as concerns regarding the safety of the general public and maintenance personnel. Where walls are used, limit the length of the retaining walls to no more than 50 percent of the basin perimeter. Also, consider potential fall hazards associated with pedestrians, cyclists, and vehicles in determining the appropriate treatment between a sidewalk, path, or roadway and the top of the wall. Considerations include distance from the public to the wall, curvature of the path or roadway, single or terraced walls, surrounding land use, and volume of traffic. Potential solutions include dense vegetation, seat walls, perimeter fencing, safety railing and guardrail. In some cases walls less than 2 feet

will warrant a hard vertical barrier; in other cases a 3-foot wall may be the point at which this barrier is appropriate. Check requirements of the local jurisdiction. UDFCD recommends providing a hard vertical barrier in any location where walls exceed 3-feet.

Adequate horizontal separation between terracing walls should be provided to ensure that each wall is loaded by the adjacent soil, based on conservative assumptions regarding the angle of repose. When determining the separation between walls, consider the proposed anchoring system and the required equipment/space needed to repair the wall in the event of a failure. Ensure that failure and repair of any wall does not impact loading on adjacent walls. Separation between adjacent walls should be at least twice the adjacent wall height, such that a plane extended through the bottom of adjacent walls would not be steeper than a 2(H):1(V) slope. Slope of finished grade between walls should not exceed 4 percent. Wall designs exceeding these criteria or exceeding a height of 30 inches should only be performed by a Professional Engineer and should include a structural analysis for the design, evaluating the various loading conditions that the wall may encounter. Also consider a drain system behind the wall to ensure that hydrostatic pressures are equalized as the water level changes in the basin.

5.10 Access

All weather stable maintenance access shall be provided to elements requiring periodic maintenance. Guidance for equipment access to water quality components is discussed in Volume 3 of the USDCM. This guidance may also be relevant for flood control (only) facilities.

5.11 Geotechnical Considerations

The designer must take into full account the geotechnical conditions of the site. These considerations include issues related to ground water elevation, embankment stability, geologic hazards, seepage, and other site-specific issues.

It may be necessary to confer with a qualified geotechnical engineer during both design and construction, especially for the larger detention and retention storage facilities.

5.12 Linings

Sometimes an impermeable clay or synthetic liner is necessary. Stormwater detention and retention facilities have the potential to raise the groundwater level in the vicinity of the basin. Where there is concern for damage to adjacent structures due to rising ground water, consider lining the basin with an impermeable liner. An impermeable liner may also be warranted for a retention pond where the designer seeks to limit seepage from the permanent pool. Note that if left uncovered, synthetic lining on side slopes creates a serious impediment to egress and a potential drowning hazard. See the Retention Pond Fact Sheet in Volume 3 of the USDCM for guidance and benefits associated with the constructing a safety wetland bench.

5.13 Environmental Permitting and Other Considerations

The designer must take into account environmental considerations surrounding the facility and the site during its selection, design and construction. These can include regulatory issues such as:

- If construction will create disturbance or otherwise modify a jurisdictional wetland,
- If the facility is to be located on a waterway that is regulated by the U.S. Army Corps of Engineers as a “Water of the U.S.”, and

- If there are threatened and endangered species or habitat in the area.

There are also non-regulatory environmental issues that should be considered. UDFCD recommends early discussions with relevant federal, state and local regulators on these issues. Issues may include the following:

- Potential for encountering contaminated soils during excavation,
- Proper implementation of design elements to mitigate mosquito breeding (i.e., a micropool)
- Concern from area residents regarding the disturbance of existing riparian habitat that may be required for construction of the basin, and
- Colorado water rights issues related to large permanent pools or retention ponds.

5.14 Orifice and Weir Hydraulics

The following discussion regarding weirs and orifices is adapted from *Urban Drainage Design Manual*, Hydraulic Engineering Circular No. 22, Third Edition (Brown et al., 2009).

5.14.1 Orifices

Multiple orifices may be used in a detention facility, and the hydraulics of each can be superimposed to develop the outlet-rating curve. For a single orifice or a group of orifices, orifice flow can be determined using Equation 12-7.

$$Q = C_o A_o (2gH_o)^{0.5}$$ Equation 12-7

Where:

Q = the orifice flow rate through a given orifice (cfs)

C_o = discharge coefficient (0.60 recommended for square-edge orifices)

A_o = area of orifice (ft^2)

H_o = effective head on each orifice opening (ft)

g = gravitational acceleration constant (32.2 ft/sec^2)

If the orifice discharges as a free outfall, the effective head is measured from the centroid of the orifice to the upstream water surface elevation. If the downstream jet of the orifice is submerged, then the effective head is the difference in elevation between the upstream and downstream water surfaces.

5.14.2 Weirs

Flow over a horizontal spillway or drop box crest can be calculated using the following equation for a horizontal broad-crested weir. See Figure 12-7 for a graphical representation of weir flow.

Horizontal Broad-Crested Weir: The equation typically used for a broad-crested weir is:

$$Q = C_{BCW} L H^{1.5}$$ Equation 12-8

Where:

Q = discharge (cfs)

C_{BCW} = broad-crested weir coefficient (This ranges from 2.6 to 3.0. A value of 3.0 is often used in practice.) See Hydraulic Engineering Circular No. 22 for additional information.

L = broad-crested weir length (ft)

H = head above weir crest (ft)

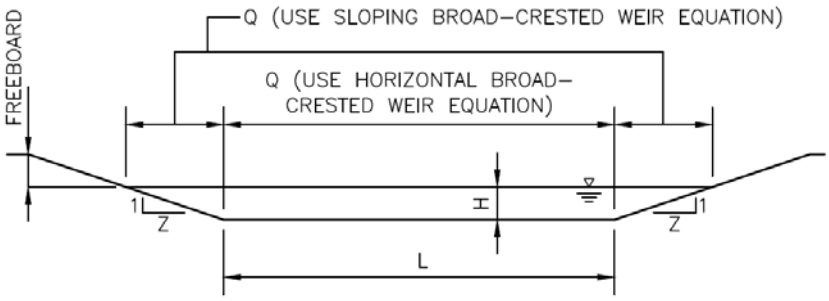


Figure 12-20. Sloping broad-crest weir

Sloping Broad-Crested Weir: Figure 12-20 shows an example of a sloping broad-crested weir. The equation to calculate the flow over the sloping portion of the weir is as follows:

$$Q = \left(\frac{2}{5}\right) C_{BCW} Z H^{2.5}$$ Equation 12-9

Where:

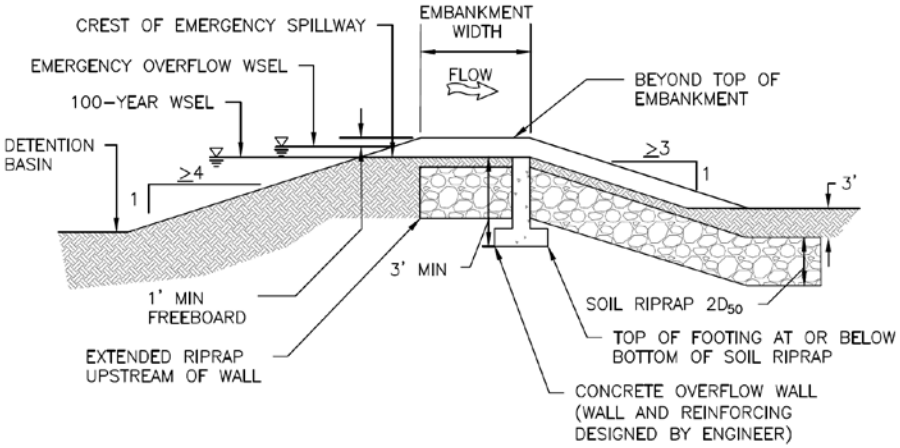
Q = discharge (cfs)

C_{BCW} = broad-crested weir coefficient (This ranges from 2.6 to 3.0. A value of 3.0 is often used in practice.) See Hydraulic Engineering Circular No. 22 for additional information.

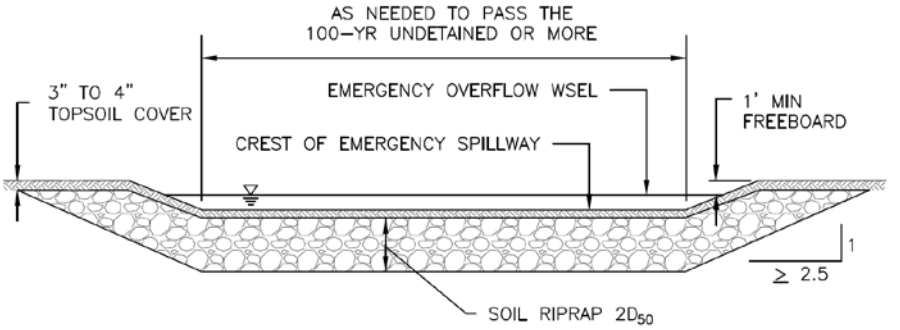
Z = side slope (horizontal: vertical)

H = head above weir crest (ft)

Note that in order to calculate the total flow over the weir depicted in Figure 12-20, the results from Equation 12-8 must be added to two times the results from Equation 12-9.



EMERGENCY SPILLWAY PROFILE



EMERGENCY SPILLWAY SECTION AND SPILLWAY CHANNEL

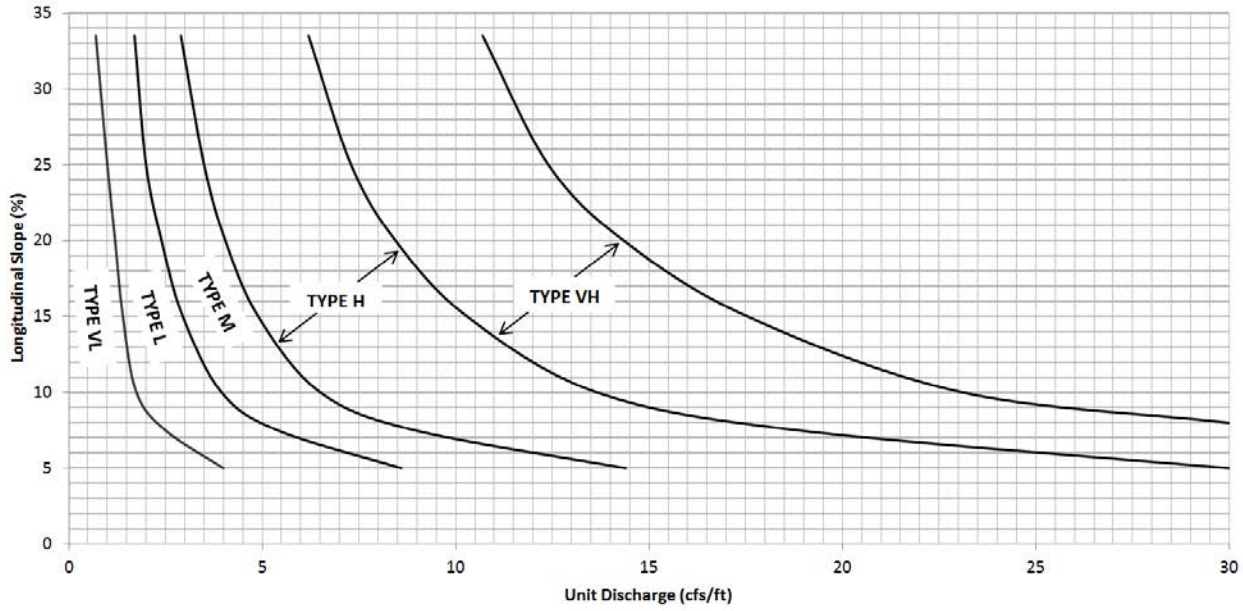


Figure 12-21. Embankment protection details and rock sizing chart (adapted from Arapahoe County)

6.0 Additional Configurations of Detention Facilities

In addition to regional, sub-regional, and onsite full spectrum detention facilities described in Section 2, there are a number of specialized types and configurations for storage that require special considerations.

6.1 Water Storage Reservoirs

Colorado State law specifically exempts the reliance of water storage reservoirs for flood control by downstream properties. If a project developer or local jurisdiction wants to utilize them for detention storage, some form of ownership of the flood storage pool and outlet function must be acquired from the reservoir owner. An agreement with the reservoir owner that ensures the continued existence of the facility or its detention function over time must be reached before relying on such reservoirs. It is also necessary to demonstrate that the embankment and spillway are safe and stable to ensure public safety.

6.2 Upstream of Railroad and Highway Embankments

Storage behind road, railroad, and other embankments can also be lost due to site grading and fill changes and/or the installation of larger culverts or bridges. If the designer intends to utilize roadway, railroad, or other embankments for detention storage, some form of ownership of the flood storage pool and control of the outlet must be acquired. An agreement with the roadway, railroad, or other agency that ensures the continued full flood protection benefit of the facility over time must be reached before relying on the facility. In addition, it is necessary to demonstrate that 1) roadway, railroad or other embankment stability will not be compromised, 2) embankment overtopping during larger storms will not impact upstream or downstream properties, and 3) the storage facility will remain in place as a detention facility in perpetuity.

6.3 Side-Channel Detention Basins

Also referred to as offline detention, this type of storage facility is located immediately adjacent to a stream and depends on a diversion of some portion of flood flows out of the waterway into the detention basin, typically over a side-channel spillway. These facilities can be used to "shave the peak" off of a flood hydrograph and can potentially be smaller and store water less frequently than on-line facilities. These facilities do not include WQCV or EURV and therefore address only flood peak reduction. They generally have limited application, but may be one of the storage alternatives considered during watershed master planning studies.

6.4 Parking Lot Detention

Parking lot islands or adjacent landscape areas can be desirable locations to provide WQCV or even EURV; however, it is recommended that the maximum water surface for WQCV or EURV be kept below the elevation of the pavement surface.

It is more problematic to provide100-year detention within parking lots given the inconvenience imposed by ponding water in areas of vehicle and pedestrians use. If 100-year parking lot detention is allowed by local jurisdictions, depth limitations and signage requirements should be considered carefully.

6.5 Underground Detention

Because of the problems associated with placing detention "out of sight", the difficulty and hazardous nature of access for maintenance, seepage concerns, and uncertain design life for vessels subject to corrosion, underground detention is not recommended by UDFCD. Some local jurisdictions may allow underground 100-year detention in limited high-density urban developments; in those cases, careful consideration must be given to requirements to ensure ongoing inspection, maintenance, and functionality.

6.6 Blue Roofs

A blue roof is a rooftop designed to provide detention. Rooftop detention was removed from this manual as part of a previous update because conventional systems could be easily manipulated by maintenance personal that viewed standing water on a roof as problematic and would make adjustments to the outlet resulting in loss of detention. Depending on the design, blue roofs can be successful in providing storage and slow release of the WQCV or larger events. To ensure long-term maintenance, the design should both appear as an intentional part of the roof design and should not be easily bypassed.

Photograph 12-4. This blue roof system utilizes trays. The design appears as an intentional feature to the lay person. Additionally, the design is such that it cannot be easily manipulated. Photo courtesy of Geosyntec.

6.7 Retention Facilities

Retention facilities (basins with a zero release rate or a very slow release rate) have been used in some instances as temporary measures when there is no formal downstream drainage system, or one that is grossly inadequate, until an adequate system is developed. However, these facilities are problematic on a number of levels. Sizing these facilities for a given set of assumptions does not ensure that another scenario produced by nature (e.g., a series of small storms that add up to large volumes over a week or two) will not overwhelm the intended design. In addition, water rights concerns and problems associated with standing water make these facilities undesirable. For these reasons, retention basins are recommended by UDFCD only as a choice of last resort.

After taking into consideration the concerns summarized above, if a retention facility is to be designed and constructed then UDFCD recommends the following design parameters. The retention facility should be sized to capture, as a minimum, 2.0 times the 24 hour, 100-year storm plus 1 foot of freeboard.

7.0 Designing for Safety, Operation, and Maintenance

Maintenance considerations during design include the following (adapted from ASCE and WEF 1992).

1. Use of mild side slopes (e.g., no steeper than 4(H):1(V)) along the banks and installation of landscaping that will discourage entry along the periphery near the outlets and steeper embankment

sections are advisable. Also, use of safety railings at vertical or very steep structural faces. If the impoundment is situated at a lower grade than and adjacent to a highway, installation of a guardrail is in order. Providing features to discourage public access to the inlet and outlet areas of the facility should be considered.

2. The facility should be accessible to maintenance equipment for removal of silt and debris and for repair of damages that may occur over time. Easements and/or rights-of-way are required to allow access to the facility by the owner or agency responsible for maintenance.

3. Permanent ponds should have provisions for complete drainage for sediment removal (or other means of sediment removal). The frequency of sediment removal will vary among facilities, depending on the original volume set aside for sediment, the rate of accumulation, rate of growth of vegetation, drainage area erosion control measures, and the desired aesthetic appearance of the pond.

4. For multiuse facilities, especially those intended for active recreation, the play area might need special consideration during design to minimize the frequency and periods of inundation and wet conditions. It may be advisable to provide an underground drainage system if active recreation is contemplated.

5. Adequate dissolved oxygen supply in ponds (to minimize odors and other nuisances) may be able to be maintained by artificial aeration.

6. Use of fertilizer, pesticides and herbicides adjacent to the permanent pool pond and within the detention basin should be avoided (this includes EPA-approved pesticides and herbicides).

7. Secondary uses that would be incompatible with sediment deposits should not be planned unless a high level of maintenance will be provided.

8. French drains or the equivalent are almost impossible to maintain, and should be used with discretion where sediment loads are expected to be high.

9. Detention facilities should be designed with sufficient depth to allow accumulation of sediment based on a sustainable frequency of maintenance.

10. Often designers use fences to minimize hazards. These may trap debris, impede flows, hinder maintenance, and, ironically, fail to prevent access to the outlet. However, desirable conditions can be achieved through careful design and positioning of the structure, as well as through landscaping that will discourage access. Creative designs, integrated with innovative landscaping, can be safe and can also enhance the appearance of the outlet and basin. When developing the landscape plan also consider landscape maintenance requirements.

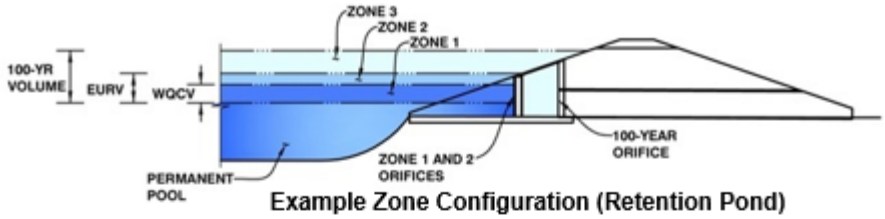
11. To reduce maintenance and avoid operational problems, outlet structures should be designed with no unmonitored moving parts (i.e., use only pipes, orifices, and weirs). Manually and/or electrically operated gates should be avoided unless equipped with remote monitoring and an emergency operation plan. To reduce maintenance, outlets should be designed with openings as large as possible, compatible with the depth-discharge relationships desired and with water quality, safety, and aesthetic objectives in mind. For the 100-year discharge, use a larger outlet pipe and install a restrictor plate (orifice) to reduce outflow rates. Outlets should be robustly designed to lessen the chances of damage from debris or vandalism.

See Volume 3 of the USDCM for additional recommendations regarding operation and maintenance of water quality related facilities.

8.0 Design Examples

8.1 Example - Design of a Full Spectrum Detention Sand Filter Basin using UD-Detention

Determine the required full spectrum detention volume and approximate area for a sand filter basin to receive runoff from 20 acres in Denver. The site is 75% impervious and has NRCS hydrologic soil group C/D. The watershed slope is 0.5% and the length of the watershed is 1300 feet.



Example Zone Configuration (Retention Pond)

Required Volume Calculation

Sand Filter (SF)	SF		
Watershed Area =	20.00	acres	
Watershed Length =	1,300	ft	
Watershed Slope =	0.005	ft/ft	
Watershed Imperviousness =	75.00%	percent	
Percentage Hydrologic Soil Group A =	0.0%	percent	
Percentage Hydrologic Soil Group B =	0.0%	percent	
Percentage Hydrologic Soil Groups C/D =	100.0%	percent	
Desired WQCV Drain Time =	12.0	hours	
Location for 1-hr Rainfall Depths =	Denver - Capitol Building		
Water Quality Capture Volume (WQCV) =	0.399	acre-feet	Optional User Override 1-hr Precipitation
Excess Urban Runoff Volume (EURV) =	1.466	acre-feet	
2-yr Runoff Volume (P1 = 0.83 in.) =	0.977	acre-feet	inches
5-yr Runoff Volume (P1 = 1.09 in.) =	1.406	acre-feet	inches
10-yr Runoff Volume (P1 = 1.33 in.) =	1.776	acre-feet	inches
25-yr Runoff Volume (P1 = 1.69 in.) =	2.434	acre-feet	inches
50-yr Runoff Volume (P1 = 1.99 in.) =	2.945	acre-feet	inches
100-yr Runoff Volume (P1 = 2.31 in.) =	3.557	acre-feet	inches
500-yr Runoff Volume (P1 = 3.14 in.) =	5.040	acre-feet	inches
Approximate 2-yr Detention Volume =	0.917	acre-feet	
Approximate 5-yr Detention Volume =	1.324	acre-feet	
Approximate 10-yr Detention Volume =	1.591	acre-feet	
Approximate 25-yr Detention Volume =	1.878	acre-feet	
Approximate 50-yr Detention Volume =	2.015	acre-feet	
Approximate 100-yr Detention Volume =	2.231	acre-feet	

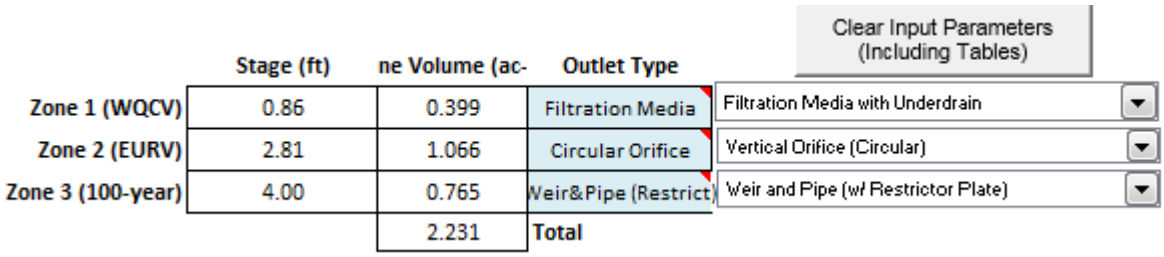
Enter the watershed parameters into the blue user input cells in the *Basin* tab. A drop down box allows the user to indicate the location. Alternatively, the user may enter their own 1- hour precipitation values. The worksheet calculates the runoff and detention volumes and populates the remaining cells, as shown above.

Stage-Storage Calculation

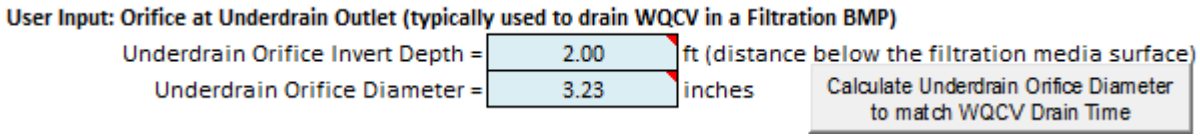
Zone 1 Volume (WQCV)	0.399	acre-feet
Zone 2 Volume (EURV - Zone 1)	1.066	acre-feet
Zone 3 Volume (100-year - Zones 1 & 2)	0.765	acre-feet
Total Detention Basin Volume =	2.231	acre-feet
Initial Surcharge Volume (ISV) =	N/A	ft^3
Initial Surcharge Depth (ISD) =	N/A	ft
Total Available Detention Depth (H_{total}) =	4.00	ft
Depth of Trickle Channel (H_{TC}) =	N/A	ft
Slope of Trickle Channel (S_{TC}) =	N/A	ft/ft
Slopes of Main Basin Sides (S_{main}) =	4	H:V
Basin Length-to-Width Ratio ($R_{L/W}$) =	2	
Initial Surcharge Area (A_{ISV}) =	0	ft^2
Surcharge Volume Length (L_{ISV}) =	0.0	ft
Surcharge Volume Width (W_{ISV}) =	0.0	ft
Depth of Basin Floor (H_{FLOOR}) =	0.00	ft
Length of Basin Floor (L_{FLOOR}) =	196.3	ft
Width of Basin Floor (W_{FLOOR}) =	98.1	ft
Area of Basin Floor (A_{FLOOR}) =	19,258	ft^2
Volume of Basin Floor (V_{FLOOR}) =	0	ft^3
Depth of Main Basin (H_{MAIN}) =	4.00	ft
Length of Main Basin (L_{MAIN}) =	228.3	ft
Width of Main Basin (W_{MAIN}) =	130.1	ft
Area of Main Basin (A_{MAIN}) =	29,702	ft^2
Volume of Main Basin (V_{MAIN}) =	97,168	ft^3
Calculated Total Basin Volume (V_{total}) =	**2.231**	acre-feet

Once the user defines each zone, the available depth for detention, basin side slopes, and length to width ratio (shown above), the workbook calculates the approximate basin geometry and volume and populates stage storage values based on this geometry and approximate routed volume.

Next, use the *Outlet Structure* tab to design outlet control for each zone of the detention basin. The workbook allows for several different outlet configurations. Filtration BMPs (i.e., sand filters and rain gardens) release the WQCV (Zone 1 for this example) through an underdrain. Zone 2 (EURV-WQCV for this example), will be drained through a circular orifice located immediately above the WQCV water surface elevation. Zone 3 (100-yr – EURV) will be released when water overtops the outlet structure (weir) and is restricted at the entrance to the outlet pipe. This example uses a restrictor plate. Selection of the outlet configuration is located at the top of the *Outlet* tab (see the screenshot below).

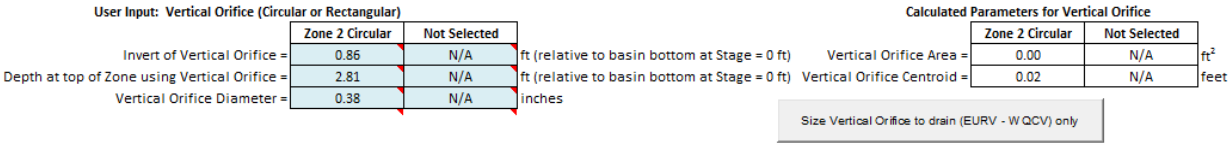


To size the Zone 1 outlet, enter a value for "underdrain orifice invert depth" (depth from the top of the sand bed to the invert of the underdrain at the outlet). Press the "Calculate Underdrain Orifice Diameter to match WQCV Drain Time" button. The underdrain parameters are also calculated and shown below.



(Blue cells in the next section are marked "N/A" because the user did not select this as an outlet type. Skip this section.)

Zone 2 will outlet from the basin through a circular orifice (see screenshot below). This orifice should be located immediately above the WQCV. This zone extends up to the EURV water surface elevation. The workbook pulls both of these values from the *Basin* tab. Note the stage\storage description in the first column of the table in the *Basin* tab. Press the "Size Vertical Orifice to drain (EURV – WQCV) only" and enter a value for the time to drain this volume. For this example, we specify 24 hours. The user can come back to this section any time and modify the drain time. This is typically done to meet desired drain times for various return periods.



Use the next section of the *Outlet Structure* tab to size the overflow weir and restrictor plate. Again, the appropriate overflow weir height populates automatically from the basin tab. This is the elevation of the EURV surface elevation in the basin. Fill in approximate values for the drop box. This example uses a square inside dimension of 4 feet for the drop box and a flat top.

Enter the depth of the invert of the outlet pipe along with reasonable values for the diameter and restrictor plate height. The workbook will resize these as needed to match a release of 90% of the predevelopment 100-year peak runoff rate per USDCM criteria. Press the "Size Outlet Pipe to match 90% of the Predevelopment 100-year Peak Runoff Rate" button. The workbook will adjust the size of the outlet pipe diameter, the height of the restrictor plate, and sizes an emergency spillway. See the screenshot below.

User Input: Overflow Weir (Dropbox) and Grate (Flat or Sloped)

	Zone 3 Weir	Not Selected	
Overflow Weir Front Edge Height, Ho =	2.81	N/A	ft (relative to basin bottom at Stage = 0 ft)
Overflow Weir Front Edge Length =	4.00	N/A	feet
Overflow Weir Slope =	0.00	N/A	H:V (enter zero for flat grate)
Horiz. Length of Weir Sides =	4.00	N/A	feet
Overflow Grate Open Area % =	70%	N/A	%, grate open area/total area
Debris Clogging % =	50%	N/A	%

Calculated Parameters for Overflow Weir

	Zone 3 Weir	Not Selected	
Height of Grate Upper Edge, H_t =	2.81	N/A	feet
Over Flow Weir Slope Length =	4.00	N/A	feet
Grate Open Area / 100-yr Orifice Area =	6.48	N/A	should be ≥ 4
Overflow Grate Open Area w/o Debris =	11.20	N/A	ft^2
Overflow Grate Open Area w/ Debris =	5.60	N/A	ft^2

User Input: Outlet Pipe w/ Flow Restriction Plate (Circular Orifice, Restrictor Plate, or Rectangular Orifice)

	Zone 3 Restrictor	Not Selected	
Depth to Invert of Outlet Pipe =	3.00	N/A	ft (distance below basin bottom at Stage = 0 ft)
Outlet Pipe Diameter =	18.00	N/A	inches
Restrictor Plate Height Above Pipe Invert =	17.00		inches

Size Outlet Plate to match 90% of Predevelopment 100-year Peak Runoff Rate

Calculated Parameters for Outlet Pipe w/ Flow Restriction Plate

	Zone 3 Restrictor	Not Selected	
Outlet Orifice Area =	1.73	N/A	ft^2
Outlet Orifice Centroid =	0.73	N/A	feet
Half-Central Angle of Restrictor Plate on Pipe =	2.67	N/A	radians

User Input: Emergency Spillway (Rectangular or Trapezoidal)

Spillway Invert Stage=	3.80	ft (relative to basin bottom at Stage = 0 ft)
Spillway Crest Length =	16.00	feet
Spillway End Slopes =	4.00	H:V
Freeboard above Max Water Surface =	1.00	feet

Size Emergency Spillway to pass Developed 100-yr Peak Runoff Rate

Calculated Parameters for Spillway

Spillway Design Flow Depth=	0.88	feet
Stage at Top of Freeboard =	5.68	feet
Basin Area at Top of Freeboard =	0.80	acres

The workbook provides output related to the drain time for each storm frequency, the ratio of peak outflow to predevelopment flow, and other pertinent information.

Routed Hydrograph Results

Design Storm Return Period =	WQCV	EURV	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	500 Year
One-Hour Rainfall Depth (in) =	0.53	1.07	0.83	1.09	1.33	1.69	1.99	2.31	3.14
Calculated Runoff Volume (acre-ft) =	0.399	1.466	0.977	1.406	1.776	2.434	2.945	3.557	5.040
OPTIONAL Override Runoff Volume (acre-ft) =									
Inflow Hydrograph Volume (acre-ft) =	0.398	1.465	0.976	1.406	1.774	2.433	2.945	3.556	5.030
Predevelopment Unit Peak Flow, q (cfs/acre) =	0.00	0.00	0.01	0.08	0.23	0.60	0.82	1.12	1.77
Predevelopment Peak Q (cfs) =	0.0	0.0	0.2	1.6	4.6	11.9	16.5	22.4	35.4
Peak Inflow Q (cfs) =	5.4	19.7	13.2	18.9	23.8	32.4	39.1	47.1	66.2
Peak Outflow Q (cfs) =	0.4	0.6	0.5	0.6	2.5	11.5	18.1	20.4	39.1
Ratio Peak Outflow to Predevelopment Q =	N/A	N/A	N/A	0.4	0.5	1.0	1.1	0.9	1.1
Structure Controlling Flow =	Filtration Media	Vertical Orifice 1	Vertical Orifice 1	Vertical Orifice 1	Overflow Grate 1	Overflow Grate 1	Overflow Grate 1	Outlet Plate 1	Spillway
Max Velocity through Grate 1 (fps) =	N/A	N/A	N/A	N/A	0.2	1.0	1.6	1.8	1.8
Max Velocity through Grate 2 (fps) =	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Time to Drain 97% of Inflow Volume (hours) =	12	35	25	34	38	38	37	37	36
Time to Drain 99% of Inflow Volume (hours) =	12	36	26	35	39	39	39	39	39
Maximum Ponding Depth (ft) =	0.69	2.61	1.78	2.51	2.95	3.27	3.45	3.74	4.29
Area at Maximum Ponding Depth (acres) =	0.48	0.59	0.54	0.59	0.61	0.63	0.65	0.66	0.70
Maximum Volume Stored (acre-ft) =	0.318	1.347	0.870	1.288	1.552	1.752	1.861	2.057	2.426

The maximum ponded area for this design example is 0.66 acres, while the maximum volume stored is 2.06 ac-ft.

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Chapter 13
Revegetation

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1.0 Introduction

Revegetation is critical to the proper functioning of detention basins, retention ponds, wetland basins, riparian areas. Revegetation is also necessary to stabilize adjacent areas disturbed during construction. Successful revegetation is required to close-out common regulatory permits associated with working in waterways, including stormwater discharge permits associated with construction activities and U.S. Army Corps of Engineers (USACE) 404 permits. Because of Colorado's semi-arid climate, prevalence of introduced weeds, and difficult soil conditions encountered on many projects, revegetation can be challenging and requires proper planning, installation, and maintenance to be successful.

Urban Drainage and Flood Control District (UDFCD) recommends that engineers include a revegetation specialist (i.e., ecologist, landscape architect, and wetland scientist) who is experienced in restoration ecology and local native plant communities as part of the overall project team to assist with project planning, direction, construction observation, monitoring, and long-term maintenance supervision for revegetation aspects of drainage projects. Early involvement of qualified professionals can help to identify site constraints and site preparation requirements, identify sensitive areas that should be protected during construction, select appropriate plants and installation procedures, and develop plans for continued plant establishment once the construction phase is complete.

This chapter provides guidelines and recommendations for revegetation efforts associated with drainage and water quality facilities. The guidance addresses three habitat types: uplands, riparian areas, and wetlands. For each habitat type, guidance is provided with regard to site preparation, plant material selection and installation, maintenance and post-construction monitoring.

Many municipalities have their own seed mixes and revegetation specifications that apply to development projects. When local guidelines and criteria differ from the criteria in this chapter, the engineer and revegetation specialist should work with the municipality to determine the appropriate revegetation criteria. UDFCD may also specify additional or different site-specific requirements, depending on site-specific considerations.

2.0 Habitat Types

There are three general habitat types or "planting zones" encountered on drainage-related projects: upland, riparian and wetland areas. As shown in Figure 13-1, these habitat types are characterized primarily by moisture and frequency of flooding, which affect the types of vegetation appropriate for each zone. Some streams may include all three habitat types, whereas on other streams some of the habitat types may be narrow or absent.

Basic descriptions of each habitat type are provided in Sections 2.1 through 2.3. It is important to recognize that although the revegetation sequence for each habitat type is similar, each habitat type has unique characteristics requiring somewhat different approaches and challenges to revegetation. For example, proper soil preparation and weed control are particularly important for upland revegetation projects. For riparian areas,

Cross-references to Related Urban Storm Drainage Criteria Manual (USDCM) Revegetation Criteria

- *Open Channels* Chapter: Stream Restoration, Naturalized Channels, and Swales
- Water Quality BMPs: BMP Fact Sheets for swales, buffers, bioretention and others in Volume 3, Treatment BMPs
- Construction Site Revegetation: BMP Fact Sheets for temporary and permanent seeding and mulching in Volume 3, Construction BMPs
- Extensive reference list at the end of this chapter for additional information on revegetation

addressing streambank erosion and properly assessing water levels for installation of cuttings and other plant material are important. For wetlands, adequate assessment of site hydrology to determine whether a site is capable of supporting wetlands is fundamental to success.

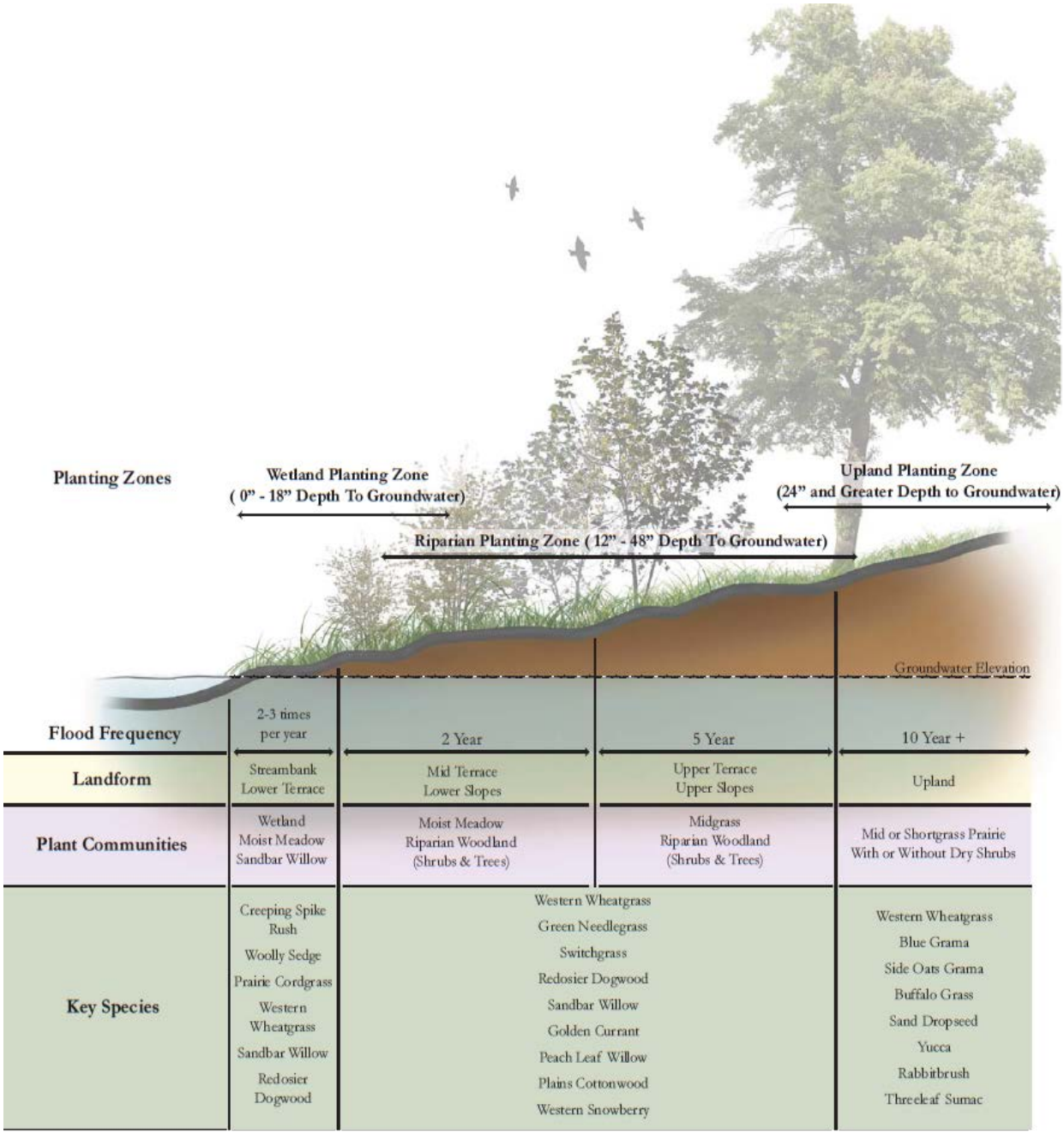

Figure 13-1. Wetland, riparian and upland habitats and planting zones

2.1 Upland

Native upland areas in the UDFCD area include plains grassland, shrubland, and/or woodland/forest. Plains grassland is the dominant upland vegetation type and is characterized by low-growing grasses, forbs, and scattered shrubs. Shrubland and woodland/forest are characterized by upland trees and shrubs. Upland areas can contain a combination of all three habitat types. Native upland vegetation is generally xeric, and these plants are well adapted to the UDFCD region with average rainfall of 15 inches per year. If a site is properly prepared before revegetating and the desired plant palette is correctly selected and planted in the appropriate season, average annual rainfall should be adequate for vegetation establishment (Colorado Natural Areas Program 1998).[1]

Common Front Range upland vegetation includes upland shrubs such as rabbitbrush (*Chrysothamnus nauseousus*), sage (*Artemisia* spp), and three-leaf sumac (*Rhus trilobata*) with an understory of upland grasses and herbaceous species. Trees are less common in the upland zone although there are several native species of both upland deciduous and coniferous trees located in this zone.

2.2 Riparian

Front Range riparian ecosystems are located directly adjacent to rivers, streams, creeks, ponds and other waterbodies. Riparian areas are shaped by the dynamic forces of water and are regularly inundated by rivers and streams. They provide flood control, streambank stability, nutrient cycling, stream food web support, pollutant filtering, sediment retention, and wildlife movement and migration corridors. In addition to these functions, they also provide passive recreational open space areas that are amenities in urban areas.

Photograph 13-1. Revegetation in progress in a riparian area along a recently constructed grade control structure. (Photograph courtesy of WWE.)

The riparian zone is generally flat with layered soils that have been deposited by previous flood events. On average, this zone floods every 2 to 5 years and is generally flat with layered soils that have been deposited by previous flood events. The riparian zone represents a transition from areas supporting water-adapted plant species to those supporting upland plant species. Common Front Range vegetation found in this zone includes an overstory of plains cottonwood (*Populus deltoides*), peachleaf willow (*Salix amygdaloides*), and box-elder (*Acer negundo*) with an understory of sandbar willow (*Salix exigua*), other native shrubs and transitional area grasses and herbaceous species. Large, inflexible trees and shrubs should not be planted in this zone because they may exacerbate flooding during high flow events by catching debris (or becoming debris).

Technically, riparian areas include several different plant communities and types of habitat, but for the purpose of this chapter, discussion of "riparian" areas generally refers to areas within the floodplain that are not wetlands.

[1] Because an "average" rainfall year cannot be assured, supplemental irrigation may be required for germination and establishment of vegetation in drier than average years.

2.3 Wetlands

As defined by the Clean Water Act (40 CFR 230.3(t)), wetlands are "areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas." In lay terms, wetlands can be thought of as transitional areas between open water and dry land. Their unique character allows them to provide an array of valuable functions including water quality improvement, floodwater attenuation and storage, soil stabilization, fish and wildlife habitat, and food web support. In Colorado, creation of wetlands in excess of the wetland area disturbed and creation of wetlands where wetlands did not exist historically requires a water right.

Photograph 13-2. A recently revegetated wetland channel. (Photograph courtesy of Iris Mitigation and Design.)

The wetland zone along stream channels is located between the average water elevation and the bankfull discharge elevation (Figure 13-1). The lower section (near the streambank) is exposed to the highest velocity flows and typically has the highest potential for erosion (NRCS 2001b). The higher section (transitions into the lower riparian zone) is inundated less frequently and is exposed to less erosive forces. In high velocity streams, this zone may be naturally unvegetated. In lower velocity streams, it is often vegetated with water-tolerant herbaceous plant species. Flexible-stemmed willows and low-growing shrubs capable of withstanding frequent inundation should be planted in the lower section of this zone. Common Front Range wetland species include sandbar willow (*Salix exigua*) and redosier dogwood (*Corns sericea*) with an understory of wetland grasses, sedge and rush.

Prior to initiating a wetland revegetation plan, it is important to recognize that different types of wetland projects will require different approaches. Three general types of wetland projects include:

- Created wetlands that are constructed in upland areas that have not supported wetlands historically.
- Restored wetlands that are reestablished where a wetland existed historically but is no longer present.
- Enhanced wetlands that are existing wetlands improved to address degradation (usually human caused). Enhancement may include removing or constructing berms, filling ditches, grading, and/or modifying vegetation communities

3.0 Site Preparation

Initial evaluation of site conditions and appropriate site preparation are fundamental to successful revegetation for upland, riparian and wetland habitat types. Table 13-1 provides a summary of site preparation activities pertinent to each habitat type. Guidelines for each activity are provided in Sections 3.1 through 3.6.

Table 13-1. Site preparation activities for revegetating upland, riparian and wetland habitats

Revegetation Guidance Topic		Applicability to Habitat Type		
Activity	**Chapter Section**	**Upland**	**Riparian**	**Wetland**
Initial Hydrologic Evaluation	3.1		✓	✓
Initial Weed Evaluation and Control	3.2	✓	✓	✓
Topsoil Preservation (including Existing Wetland Soil)	3.3	✓	✓	✓
Soil Testing	3.4	✓	✓	✓
Soil Amendment	3.5	✓	✓	✓
Seed Bed Preparation	3.6	✓	✓	✓
Tree Protection	3.7	✓	✓	✓

3.1 Initial Hydrologic Evaluation

One of the most critical aspects for the successful revegetation of riparian and wetland areas is having sufficient hydrology to support the plants. An initial hydrologic investigation should be performed for both riparian and wetland revegetation efforts. According to Zedler and Weller (1989), understanding hydrology is the most basic and important need for a successful wetland project. During the planning process, the depth to groundwater and fluctuations in the groundwater depths should be monitored for at least one year (preferably longer, if feasible) for both riparian and wetland areas. The installation of monitoring wells and piezometers provides valuable information about groundwater levels. If limited groundwater data are available (i.e., from geotechnical reports or only one year of monitoring), it is very important to understand the data in the hydrologic context (e.g., wet year, dry year) and season in which it was collected.

As part of the wetland planning process, rigorous investigation of potential water sources should take place. Potential sources of water include groundwater, surface water, and precipitation. If the wetland's hydrology is to originate primarily from surface water, such as from a river or stream, water elevations near the proposed wetlands should be measured repeatedly during the active growing season (approximately April through September). Typically, multiple years of data are needed to make reliable determinations on water availability, since any given year may be wetter or drier than average. Groundwater levels adjacent to the stream or river should also be assessed to determine whether the river or stream is a gaining or losing system (i.e., either supplemented by the groundwater or losing water to the groundwater, respectively). In conjunction with detailed land surveys (preferably 1-foot contours), known groundwater levels and surface water levels can help to assess whether the final wetland grade will provide the hydrology necessary for supporting wetland vegetation. It is also important to consider temporary and/or periodic activities that may influence groundwater, including nearby wells, construction dewatering and/or plans for future buildings nearby that may require subterranean dewatering. Long-term monitoring wells, which may be used to collect groundwater data required for design, will require a separate state well permit.

For riparian area planning, it is important to recognize that plantings must have contact with groundwater to survive. In the semi-arid West, groundwater often fluctuates throughout the year. If the depth to groundwater precludes planting/seeding species that require more available moisture, upland (also known as xeric) plant species may need to be seeded/planted instead of riparian plant species.

3.2 Initial Weed Condition Evaluation and Control

Weed infestations and, in some cases, non-native aggressive grasses that prevent the establishment of the desired native vegetation should be controlled. Ideally, weed control should be considered a year or more prior to soil disturbance. Weed control requirements should be evaluated for upland, riparian and wetland areas. For proven treatment methods and recommended treatment timing of common Front Range annual and perennial weeds, see Table 13-2. The listed weeds may be found in the habitat zone indicated and in other zones as the micro-ecology permits.

If a site has annual or perennial weed growth, weed management before revegetation is crucial for minimizing weeds and weed seed and to allow for desirable species establishment. Removing the weed seed source will help to reduce competition for soil moisture during desirable plant species establishment. Implementing weed control practices prior to and/or during construction can reduce the level of effort required for weed control later as new vegetation is becoming established. While construction activities are still on-going, maintaining weed control over the entire site, including on the topsoil stockpile, will reduce weed density once the topsoil is replaced and revegetation commences. Weed control strategies prior to construction for annual and perennial weeds are slightly different and are discussed separately in Sections 3.2.1 and 3.2.2. Weed control strategies during and following construction are included in the maintenance discussion in Section 7.4.

Table 13-2. Proven treatment methods and timing of treatment for common front range weeds
(Source: Weed Research and Information Center, University of California-Davis 2013)

Common Name	Scientific Name	CO Weed List Rating	Spring Treatment	Summer Treatment	Fall Treatment
Wetland Weeds					
Canada thistle	*Cirsium arvense*	B	H,MM	MM	H, MM
Common teasal	*Dipsacus fullonum*	B	H		H
Eurasian watermilfoil	*Myriophyllum spicatum*	B	BI, H	MP	MP
Purple loosestrife	*Lythrum salicaria*	A	MD, MP, H, BI		
Tamarisk	*Tamarix ramosissima*	B	BI, H[1]	H[1]	H[1]
Riparian Weeds					
Leafy spurge	*Euphorbia esula*	B	BI, H		H
Poison hemlock	*Conium maculatum*	C	HP, H	HP	H
Quackgrass	*Elymus repens*	B			H
Russian olive	*Elaeagnus angustifolia*	B	H[1]	H[1]	H[1]
Upland Weeds					
Bindweed	*Calystegia sepium*	NL	BI, MP[2]	H	H
Bouncingbet	*Saponaria vaccaria*	B		H	H
Bull thistle	*Cirsium vulgare (Savi) Tenore*	B	MP[2], BI, H, BG[3]	MM, BG[3]	H, BG[3]
Chinese clematis	*Clematis orientalis*	B	BG, MP	H	
Common burdock	*Arctium minus*	C	MP[2], MM, H, BI	MM	MM, H
Common mullein	*Verbascum Thapsus*	C	H		H
Dalmation toadflax	*Linaria dalmatica*	B	BI, MP[2], H		H
Diffuse Knapweed	*Centaurea diffusa*	B	MP[2], BI, H	MM, MC, H	H
Downy brome (Cheat grass)	*Bromus tectorum*	C			H
Kochia	*Kochia scoparia*	NL	MP[2]	MM, H	
Myrtle spurge	*Euphorbia myrsinites*	A	H	H	H
Musk thistle	*Carduus nutans*	B	BI, MP[2], MC, H, BG[3]	MM, BG[3]	H, BG[3]
Perennial pepperweed	*Lepidium latifolium*	B	MP[2], H, BG		
Plumeless thistle	*Carduus acanthoides*	B	BI, MP[2], H,MC, BG[3]	MM, BG[3]	H, BG[3]
Puncturevine (Goathead)	*Tribulus terrestris*	C	MP[2], BI, H	MD, H	
Redstem filaree	*Erodium cicutarium*	B	MP[2], H		H
Russian knapweed	*Acroptilon repens*	B	H		H
Russian thistle	*Salsola tragus*	NL	MP[2], BG, H	H	
Scotch thistle	*Onopordum acanthium*	B	MD, MP[2], H, BG[3]	MM, BG[3]	BG[3], H
Yellow starthistle	*Centaurea solstitialis*	A	MP[2], MM, BI, BG, H		
Yellow toadflax	*Linaria vulgaris Mill*	B	MP[2], BI		H
Whitetop (Hoary cress)	*Cardaria draba*	B	MM, H		H

Table Notes: [1]Grazing with sheep, goats and horses- no cattle. [2]Pull young seedlings. [3]Cut and treat stump if large plant or spray foliage if small plant.
Seasons: Spring = Sp, Summer = Sm, Fall = Fa. Mechanical Methods: Mowing = MM, Pulling, = MP, Cutting = MC, Digging = MD. Biological Methods: Insects = BI, Grazing animals = BG. Chemical Methods: Herbicides = H.

If herbicides will be needed to control weeds at the site, a certified applicator should be used. A copy of the applicator's license should be obtained and records should be kept of all applications that occur on the site. Only herbicides rated as aquatic safe should be used in riparian and wetland areas. A key consideration in herbicide selection should be how long the herbicide remains active in the soil (residual soil activity). No chemical residue should remain in the soil at seeding time, which could reduce desirable species germination.

In 2013, the Colorado Water Quality Control Division issued a Colorado Discharge Permit System (CDPS) General Permit for Discharges from Application of Pesticides, modeled after the U.S. Environmental Protection Agency's general permit issued in 2011. A Compliance Certification may be required for certain types of herbicide applications in Colorado.

Weed Control Considerations

- Consider weed control prior to construction to reduce competition with desirable vegetation during establishment.
- The label is the law! Follow herbicide label directions provided by the manufacturer.
- Controlling weeds by spot spraying and backpack applications is best for precise weed control treatments.
- Check to be sure that the county or other agency jurisdiction does not have the area designated as part of their weed control area – boom spraying may wipe out a revegetation effort.
- Cross-boundary weed control agreements may be needed with adjacent land management teams for more effective weed control in an area.

3.2.1 Control of Annual Weeds

Weed management is especially useful where annual weeds are abundant. Some common annual weeds such as kochia (*Bassia sieversiana*) and cheatgrass (*Anisantha tectorum*) have short-lived seed. If weed seed production can be prevented during the year prior to revegetation of a site, it will help reduce future weed growth. Be aware that a late summer mowing of untreated annual weeds followed by plowing and seeding generally results in a rebound of many of the weedy species, so proper weed management is important prior to seeding.

For mild to moderate weed infestations, a broad-spectrum herbicide treatment may be sufficient to control weeds before revegetating the site. Be sure to check herbicide labels regarding timing of treatments because a month or more may be needed between herbicide treatments and revegetating the site (seeding) to reduce residual impact of the chemicals.

If the site has heavy annual weed growth, the soil may be deeply plowed and turned over to bury weed seed. The plowing can then be followed by disking to level the area. Once remaining weeds geminate, an application of a broad-spectrum herbicide will kill establishing weedy species. Since some topsoil is lost with this method, deep plowing to bury weed seed should only be used in an area with adequate topsoil or on historic agricultural fields. Chiseling the deep plowed area should create a level seedbed. Seedbed preparation can begin in August, prior to the fall when seeding is recommended.

3.2.2 Control of Biennial and Perennial Weeds

Seeding Failures

"Inadequate weed suppression causes more seeding failures than any other single factor."

--NRCS, 1997

Ideally, control of biennial and perennial weeds should also begin a year or more prior to seeding a site to reduce competition with the seeded species. If project timing does not allow for weed control to precede construction, it may be implemented as the site is being prepared for revegetation, and weed control may still be necessary even if it is initiated prior to construction. Spring and fall are good times for spot herbicide treatment of developing rosettes (first year stage) of many biennial species and some perennials weeds. Spring and fall are especially good for common regional weeds including Canada thistle (*Cirsium arvense*), musk thistle (*Carduus nutans*), scotch thistle (*Onopordum acanthium*), common teasel (*Dipsacus fullonum*) and knapweed (*Centaurea diffusa*). Always follow herbicide label recommendations for best treatment times and chemical mixtures for specific weed species.

3.2.3 Additional Weed Control Guidance for Wetland Areas

Cattails are native wetland plants which can form dense stands. If required for maintenance, deeply rooted cattails (*Typha latifolia* and *T. angustifolia*) may be controlled by fall application of aquatic labeled glyphosate followed by cutting the plant after the plant has died.

If an existing wetland is to be enhanced, elimination of undesirable species, such as reed canarygrass (*Phalaris arundinacea*) may be necessary. Herbicide application is generally the most effective means to eliminate a weedy species prior to planting. In wetland areas supporting weedy species, an EPA-approved aquatic use herbicide (such as glyphosate without polyethoxylated amine (POEA) surfactant) may be spot applied by a licensed applier prior to planting and seeding. Repeat application of herbicide every two weeks on remaining green growth. Allow two to three weeks after the last application prior to planting.

3.3 Topsoil Preservation

In undisturbed upland areas along the Front Range of Colorado, native topsoil depths vary. During construction activities, topsoil should be stripped and stockpiled separately from either sub-soil or wetland soil. In order to preserve soil microbs, which are helpful with plant establishment, it is best to limit topsoil stock piles to a height of 10 feet. Topsoil also supports mid and late seral species and can therefore promote the transition from an early, weed-dominated stage to a later, native-dominated stage (Goodwin et al. 2006). Once stockpiled, the topsoil may be seeded with a sterile non-native grass or a native seed mix, depending on how long it will remain. Use native seed when the stockpile will remain for over one year. Temporary vegetation will assist in stabilizing the topsoil to reduce erosion and weed infestations. Exotic perennial grasses such as smooth brome (Bromus inermis), crested wheatgrass (Agropyron cristata) and intermediate wheatgrass (Thinopyrum intermedium) should not be used for temporary cover on topsoil stockpiles because they will be difficult to eradicate later. Other aggressive non-native grass species to avoid include timothy (Phleum pratense), orchard grass (Dactylis glomerata), tall fescue (Schedonorus arundinacae) and meadow fescue (Schedonorus pratense). These exotic species are competitive and difficult to control when revegetating a project. Any soil containing weeds, such as reed canarygrass (Phalaris arundinacea) and Canada thistle (Cirsium arvense), will require great effort to control, and if possible should not be used (NRCS 2001a).

Once construction is complete, the topsoil can be spread before re-seeding and/or planting. Protecting the native topsoil is important because importing topsoil later is both labor intensive and expensive. If

stockpiling of topsoil is not possible, subsoil can be amended and decompacted before the site is revegetated (Colorado Natural Areas Program 1998). While this is an option, the seeding results will likely be less successful as those where topsoil is available.

Topsoil may be salvaged from a wetland that will be destroyed (on-site or at another location). A study by Brown and Bedford (1997) showed that wetlands with transplanted wetland soil exhibited higher plant cover and greater diversity than areas that did not receive transplanted wetland soil. Wetland topsoil contains seeds, roots, rhizomes, tubers and other fleshy propagules that can aid in revegetation. The top 8 to 10 inches should be scraped with a front-end loader and transported to the site where it will be applied. Ideally, the topsoil should be spread out on the new wetland immediately, to a depth of no more than 6 inches. Although wetland topsoil can be stockpiled for short periods, it will lose viability. Stockpiles should be kept for less than 4 weeks, should measure less than 3 x 3 feet (height/width) (NRCS 1997). Wetland topsoil should not be stockpiled during the summer because it will compost, and the seeds and propagules will be killed.

3.4 Soil Testing

Soil testing of both native and imported topsoil is recommended to select appropriate plant species for a site and to determine what types of soil amendment are required, if any. Soil samples can be delivered to a local soil testing laboratory, agricultural extension service, or university service for analysis. A standard agronomic test (e.g., nutrients, organic matter, and salinity), as well as full textural analyses, should be required for all topsoil fractions imported or salvaged from the site. Table 13-3 provides general guidance for viable topsoil composition for the establishment of native plants in upland areas in Colorado.

For upland areas along the Colorado Front Range, soil textures vary greatly. Soil texture characterizes a soil based on the size of particles found in a particular sample. Soil texture is described as sand, clay, and/or silt based on particle sizes (Figure 13-2). A U.S. Department of Agriculture (USDA) soil texture triangle diagram shows the types of soil texture combinations that are possible. Knowing the soil texture on a site will help with appropriate plant selection (Colorado Natural Areas Program 1998) and evaluation of potential for soil moisture retention. Plants are generally adapted to certain soil types although some plants can establish in a combination of soil types.

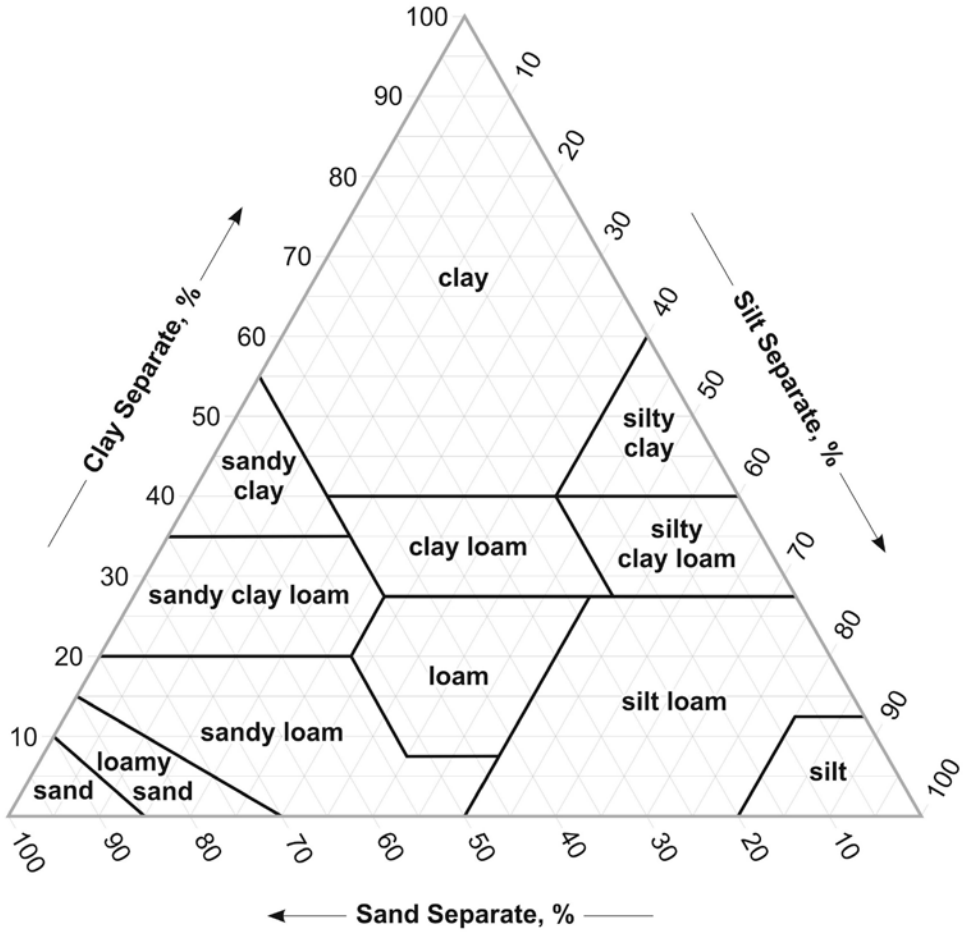

Figure 13-2. Soil textural triangle

When collecting soil samples and reviewing analysis results, follow these guidelines:

- Soils should be evaluated during design (visually and by lab analysis). Observation of soil prior to salvage may help determine quality of the soil to support herbaceous growth and presence of noxious weeds. Soils tests (both agronomic and full textural analyses) should be obtained during construction because grading activities and the process of stripping and stockpiling can result in very different conditions.

- The revegetation specialist and the contractor should work together to identify soil sampling locations based on planned earthwork. It is advisable for the contractor to visit the site with the revegetation specialist to understand the depth and character of the topsoil to be stockpiled. Observation of the soil source areas in the field is necessary to assist with determination of quality of the soil as a topsoil source.

- Salvage piles should be labeled and not mixed or moved until just before reapplying.

- In some cases, the subsoil should also be tested for suitability as a plant growth medium. In general, shale or weathered clay stone should be exported from the site and should not be within 18 inches of the surface. At least 18 inches of suitable subsoil and topsoil should be provided in areas that will be revegetated.

- If topsoil is to be imported from an off-site location, it is best to test it separately before it is brought on-site to be sure that it is good quality topsoil for the project. Soil amendments may still be (and often are) needed once a topsoil is brought on-site and reapplied to the existing subsoil.

- Soil test recommendations are usually geared toward agricultural crops, which may require substantially more soil amendments than what are necessary for native plant establishment. When submitting the samples, be sure to inform the testing laboratory that the soil testing is related to native plant establishment and that recommendations on soil amendments should be geared for this type of plant establishment.

- Soil test results should then be reviewed by a revegetation specialist who is familiar with the project so that the proper soil amendments are applied for the type of vegetation that will be seeded/planted.

- Saline soil conditions require special attention to plant species selection. When soil electrical conductivity is greater than 3 to 6 mmhos/cm, then saline soil conditions may be problematic (sensitivity also depends on plant species) (Swift and Koski 2007; Cardon et al. 2007). This condition commonly occurs in clay soils where the natural leaching of salts is limited. Both the surface and subsoils should be tested for salinity. If the soils are found to be highly saline, plant species should be chosen that are adapted to these conditions. CSU Cooperative Extension has developed lists of salt tolerant plants (Swift 1997; GreenCO 2008). Other research is ongoing to test the salinity tolerance of a range of riparian plant species (Goodwin et al. 2006). Native grass seed mixes of species that can tolerate more saline soil conditions are provided in Appendix A of this chapter.

Table 13-3. Viable topsoil composition for Colorado native plant establishment in upland areas

Chemical Attributes	**Preferred Range**		**Additional Description**
pH	6.0-7.5		A pH < 6 indicates possible acid problems, and pH > 8.0 indicates an alkaline soil. A pH> 8.5 indicates possible sodium problems. Most nutrients are most available to plants around a pH of 6.5.
Organic Matter	1-3%		Desirable range for good topsoil is a minimum of 1%.
Salinity	EC < 3 - 6 mmhos/cm		The desired EC varies depending on the plant selected, but EC values >2 mmhos/cm could indicate a problem for germination.
Sodium Absorption Ratio (SAR)	<6		SAR provides an indirect measure of percent exchangeable sodium on the soil colloid.
Free Lime	<10		Free lime represents the carbonates of calcium and magnesium which are not combined in the soil. Values > 10 may indicate a high amount of "lime", poor soil structure, and an increase in water and wind erosion susceptibility. Plant-available phosphorus may be reduced because of this condition.
Cation Exchange Capacity (CEC)	12-25		Exchangeable cations include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}).
Saturation Percentage	> 25 and <80		Saturation percentage is the amount (percentage by weight) of water needed to saturate a soil. Values >80 may indicate high montmorillonite clay content and/or high quantities of exchangeable sodium, whereas values < 25 may indicate coarse soil materials with a low water-holding capacity. The full soil textural analyses may also report the clay content directly.
Minimum ammonia DPTA (chelate) Extractable Nutrients			Nitrogen (N) – Phosphorus (P) – Potassium (K): ratio of important elements in a fertilizer or soil amendment. Nitrogen is responsible for strong stem and foliage growth. High nitrogen levels favor quick-growing invasive weeds, while low nitrogen levels favor slow-growing, late-seral species (Goodwin et al. 2006). Phosphorus aids in healthy root growth and flower and seed production. Potassium improves overall health and disease resistance.
Nitrogen	5 ppm air dried basis		
Phosphorus	5-12 ppm		
Potassium	20-50 ppm		
Iron	3-5 ppm		
Texture Class	**% of Total Weight**	**Average %**	Soil Texture by Hydrometer Method provides the percentages of sand, silt, and clay in the soil. There are 12 textural designations (excluding modifiers such as very fine, cobbley, etc.) which can appear on a soil report. Each of these designations has a range of percentages of sand, silt, and clay, which could apply. Suitable soil textures for good topsoil material are silt loam, loam, silty clay loam, very fine sandy loam, and fine sandy loam. Soil textures with greater amounts of clay or sand can be problematic for achieving revegetation success.
Sand (0.05-2.0 mm diameter)	25 to 65	5	
Silt (0.002-0.05 mm diameter)	20 to 50	30	
Clay (<0.002 mm diameter)	20 to 30	25	

3.5 Soil Amendment

Depending on the results of soil tests, soil amendments may be required, particularly when test results fall outside of desired ranges in Table 13-2. Wetland areas typically do not require soil amendments. Soil amendment for upland and riparian areas is discussed in Section 3.5.1 and conditions where wetland soils may require amendment are discussed in Section 3.5.2.

3.5.1 Soil Amendment for Upland and Riparian Areas

Once the soils have been tested, amendments may be needed to improve soil conditions (e.g., nutrients, soil chemistry) or texture prior to revegetating the site, particularly for upland and riparian sites. The revegetation specialist should review the soil test results and identify soil amendments that may be needed. As long as the proper soil-specific seed mixtures are used, most native topsoil can be revegetated with little or no amendment beyond the addition of a slow-release organic fertilizer.

Fertilizers may have a positive, negative, or neutral effect on the survival and growth of planted species (NRCS 2001a). Nitrogen fertilizers should be used only when soil tests show a gross nitrogen deficiency because they can stimulate annual weeds and may pollute waterbodies if applied in lower riparian zones. In some cases, nitrogen fertilizers can decrease valuable mycorrhizal activity (Goodwin et al. 2006). Nitrogen is rarely needed for native species, which have evolved in low nutrient environments characteristic of prairie grasslands. If fertilizer is expected to have a beneficial effect on seeded species, it should be added shortly before or shortly after seeding (Goodwin et al. 2006) and in accordance with soil test results.

If the original topsoil from a site is stockpiled and then replaced, soil amendments may not be required to successfully revegetate the site. If amendments are needed based on the soil test, amendments may include a slow-release organic fertilizer (such as 4-6-4 or 7-2-2 N:P:K), compost, peat, humates, sulfur, gypsum, lime, wood chips and soil micro-organisms. Application of chemical fertilizers should be avoided as this can stimulate annual weeds and may contaminate water bodies if applied in lower riparian zones.

For upland sites, most sites with low organic matter (including overworked agricultural soils, steep slopes, and sub-soils) will benefit from the addition of between 800 to 1200 pounds per acre of a slow-release organic fertilizer. This organic fertilizer is often granular and low in phosphorus. Organic fertilizers are useful for high-use areas such as park sites, along roads, and highly visible native turf areas. Chemical fertilizers generally have higher phosphorus and nitrogen levels, which encourage weedy growth that may compete with the desirable planted/seeded species. Chemical fertilizers or fertilizers produced from poultry waste are often fast-release, which encourages weed establishment. The applicator should understand the quantities/rates of fertilizer needed to avoid over fertilizing an area. Soil amendments should be applied prior to the final tilling of the soil, and should be incorporated at least 6 inches into the soil.

Soils which are low in organic matter can be amended with an approved composted material to improve soil texture. Manure is usually not recommended (NRCS 2001a). Usually, 2 cubic yards of quality compost per 1000 square feet is adequate to improve the organic content of poor soils for native revegetation. (If the revegetation effort will be in a manicured area where turf will be installed, 3-5 cubic yards per 1000 square feet is recommended. See GreenCO [2008] for more information on turf areas.) Organic matter should be incorporated at least 6 inches into the soil by tilling the soil 8 to 12 inches until no clumps or areas of thick compost remain on the surface. Table 13-4 summarizes the characteristics of mature compost that are suitable for organic matter soil amendments.

Table 13-4. Characteristics of mature compost suitable for soil amendment

Maturity Indicator	Desired Result
Ammonia N/Nitrate N Ratio	<6
Carbon to Nitrogen Ratio	<18
Percentage of Germination and Vigor	80% or more for both germination and vigor
pH	5.5-8.0
Soluble Salts Concentrations	2.5 dS (mmhos/cm) or less preferred
Particle Size	Pass through 1-inch screen or smaller
Moisture Content	35% - 55%
Maturity/Growth Screening	Demonstrate ability to enhance plant growth
Stability	Stable to highly stable, providing nutrients for plant growth
Organic Matter Content	30% - 70%

In upland and riparian areas, the addition of soil microorganisms can aid the establishment of native vegetation. Soil microorganisms process mulch and dead plant material into nutrients that are available for plant uptake. Common microorganisms present in soil include bacteria, protozoa, and mycorrhizal fungi. Mycorrhizal fungi adhere to roots and develop a beneficial relationship with the plant by improving nutrient uptake, drought tolerance, and pathogen resistance (Goodwin et al. 2006). They are plentiful in the litter layer of established plant communities. For riparian areas, if an adjacent riparian area has a rich layer of litter and a lack of weeds, some of the litter can be collected and mixed in with the seed mix to be applied to the riparian area to be revegetated. Mycorrhizal fungi are also available commercially.

Other amendments, such as polymer and vermiculite root dips are generally not necessary and may be detrimental (NRCS 2001a). Similarly, special treatments for willow and cottonwood cuttings (such as rooting hormones and fungicides) are unnecessary (Hoag 1998). These cuttings root easily without special treatments.

3.5.2 Soil Amendment for Wetland Areas

In general, wetland revegetation projects do not require soil amendments. Wetland plants can successfully establish in a wide range of soil textures, from heavy clay with no organic matter to coarse gravels (NRCS 2011). In particular, the use of mulch is not recommended (EPA 1994), and fertilizers are rarely necessary or helpful (Colorado Natural Areas Program 1998, NRCS 2003). The addition of fertilizers may be especially detrimental by favoring the growth of weed species in the wetland and contributing to nutrient overloads already present in many waterways. However, each site is unique. To determine whether specific fertilizers may be necessary for a given project, the soil should be tested and compared with the optimum nutrient conditions for the species to be planted (Colorado Natural Areas Program 1998).

A notable exception to this generalization includes wetland creation projects in which the topsoil is removed (excavated) to reach the appropriate grade and the subsoil is exposed without replacing the topsoil. In these situations, virtually all of the naturally-occurring nutrients have been removed. Unless water entering the wetland has a high nutrient load, fertilization will probably be necessary (NRCS 2003). Not surprisingly, studies have shown that without suitable soil conditions, wetland creation projects tend to provide lower functions than natural wetlands (Bruland and Richardson 2005). In particular, soils in created wetlands tend to have a lower organic content than natural wetlands (Fajardo 2006).

3.6 Seedbed Preparation

When seeding is used to revegetate a site, then seedbed preparation is required and generally consists of decompacting the soil, adding soil amendment (if needed), and then firming the soil surface prior to seeding.

Cultipacker

A cultipacker is an agricultural implement used to crush dirt clods, remove air pockets, eliminate cracks, and bury small stones to form a smooth, firm seedbed. The cultipacker is used after ripping or disking the soil as a secondary tillage. It can be used either before or after seeding to firm the seedbed and to eliminate air pockets. After broadcast seeding the cultipacker can be used to gently firm the soil around the seeds, ensuring shallow seed placement and excellent seed/soil contact.

3.6.1 Addressing Soil Compaction

Soil compaction in upland, riparian and wetland areas is a common problem for revegetation. Seedbed preparation (tilling) is crucial before revegetating a site. Compaction can be found in naturally occurring soils with high clay content or can result from heavy equipment at construction sites, cattle grazing, working soils when wet, and other causes. When soil is compacted, seeds and plant roots and rootlets cannot penetrate through the hard surface and less oxygen is available for plant establishment and growth. Less water is available for plant establishment due to the hard compacted soil surface, and the site may be vulnerable to excessive runoff due to less water penetration. Microorganisms may be inhibited due to both a lack of oxygen and large pore space needed to survive. Loss of microorganisms leads to a further degraded soil unsuitable for plant growth and affects the nutrient cycling in soils (Natural Resources Conservation Service [NRCS] 1998).

Decompaction will allow water to more easily penetrate into the soil where it can be used by roots and will enhance infiltration on the site, reducing the potential for runoff, especially during smaller, frequent events. Special attention should be given to staging areas, roads, and other high traffic areas that are severely compacted. Decompaction should occur in two steps:

- Before the topsoil is replaced, the sub-soil should be ripped to a depth of 12 inches. This can be accomplished by disking, ripping, plowing, and rototilling, made more effective by ripping in two directions perpendicular to each other. An effective method to reduce soil compaction in created and restored wetlands is to use a chisel plow to mechanically rip both the topsoil and subsoil layers prior to planting (Bantilan-Smith et al. 2009). This process is more difficult to complete on slopes greater than 3:1. On steeper slopes, a track hoe and with a ripper tooth can be used to decompact soil to the proper depth.

- Once the sub-soil is ripped and the topsoil is replaced, soil amendments should be added, if needed per the soil test and habitat type, then the soil should be tilled to 6 inches, leaving no clod over 3 inches in diameter.

These two processes will allow for a total of 18 inches of decompaction, thus providing a better growing medium for native vegetation.

3.6.2 Seedbed Firming

Once the final tilling is completed, fine grading will ensure a smooth seeding/planting surface. The soil surface should be relatively firm as described for each habitat type:

- For upland and riparian areas, the soil surface should then be prepared for seeding so that a footprint will imprint between ¼ to ¾ inch only (NRCS 2011b).

- For wetland areas, the surface is considered firm enough when a person's footprint penetrates ¼ to ½ inch deep (NRCS 1997). Some newly created wetlands may be very difficult to firm. If necessary and when possible, firming of wetlands may be achieved by disking followed by rolling or harrowing just prior to seeding (NRCS 2008).

Firming of the seedbed soil should be performed prior to seeding, particularly if seeding in late spring or summer. Natural precipitation can sometimes be heavy enough to settle the worked soil, but waiting for such rainfall may not be realistic. If soils are sandy and contain a small amount of moisture already, a cultipacker can be used to firm the seedbed soil. Soils that are wet or silt loam to clay loam should not be cultipacked because they can become too firm, making drill seeding or crimping much less successful. Chiseling after plowing may adequately firm finer textured soils. It is also possible to firm the soil with irrigation following seeding and mulching.

3.7 Tree Protection

Protection of existing trees is an important aspect of site preparation, which should occur at the beginning of the construction phase. Figure 13-3 provides a detail for installation of construction fencing to protect existing trees.

4.0 Plant Material Selection

Appropriate plant selection is crucial in successful native revegetation of upland, riparian and wetland sites. A site plan should be created by a revegetation specialist trained in native vegetation restoration. A variety of plant materials can be used to revegetate a site. The materials used will depend greatly on budget as well as the schedule and goals of the project. Generally, these materials include seed, plugs, containerized plant material, balled and burlapped (B&B) trees and shrubs, cuttings, and transplanted plants (particularly in the case of wetlands). Table 13-5 identifies plant materials typically used in each habitat type, followed by guidance related to plant selection, seeding, and trees and shrubs.

Table 13-5. Plant material for revegetating upland, riparian and wetland habitat types

Revegetation Guidance Topic		Applicability to Habitat Type		
Plant Material	**Chapter Section**	**Upland**	**Riparian**	**Wetland**
Seed (permanent and temporary)	4.2	✓	✓	✓ **(limited)**
Plugs	4.4.1	✓	✓	✓
Containers	4.4.2			
Bare Root	4.4.3	✓	✓	✓
Balled and Burlapped (B&B)	4.4.4	✓	✓	✓
Cuttings	4.4.5		✓	✓
Wetland Sod, Rhizomes, Tubers	4.5			✓

4.1 Plant Selection Guidance for Habitat Types

Plant selection guidelines for upland, riparian and wetland areas differ somewhat and are discussed separately below. See Figure 13-1 for a summary of planting zones within each habitat type.

4.1.1 Plant Selection for Upland Areas

When present, a nearby reference site with similar conditions (soils, slope, and aspect) should be examined to assist with plant selection for upland areas.

Photograph 13-3. An upland area vegetated with native grasses along a riparian corridor in open space area. (Photograph courtesy of Iris Mitigation and Design.)

Upland sites are generally revegetated by seeding with a native seed mixture selected based on the soil texture and to a lesser extent, chemistry. Seeds are best obtained from a local nursery and regional seed mixtures have been found to be successful in most of the soil conditions which occur in the Colorado Front Range. Sites with sandy soils or elevated salinities (EC> 3) should use alternative seed mixtures for those soil conditions.

Plant materials used to revegetate upland areas may include also include grass and herbaceous species plugs, containers, bare root, B&B plants, and cuttings. Regardless of the plant material selected, several general principles should be considered. First, the genetic source of the plant material may affect the long-term revegetation success. Plant material that originates in proximity to the revegetation project will be better adapted to the local area's environmental conditions, may be more resistant to pests, and may exhibit more robust growth over the long term. Similarly, plant species should be chosen that closely match the environmental conditions at the project site. Such plant species are typically adapted to water availability, salinity, elevations, and soil conditions.

Seeding is generally not feasible for establishing trees and shrubs. However, containers, and bare root plant material can be good options for both herbaceous and woody plant species.

4.1.2 Plant Selection for Riparian Areas

Evaluating reference sites on the same watercourse at a similar elevation may be particularly useful when revegetating riparian areas. However, many urban streams are degraded, and healthy native vegetation useful for reference areas may not be present nearby. When good reference sites exist, these areas should be assessed for the species present, the types of plant forms present (herbaceous, shrubs, or trees), and the location of species and plant forms relative to the stream. In the absence of a nearby reference area, it is possible in to rely on a proven regional riparian plant palette for most projects because riparian areas along the Front Range are typically very similar in species composition.

Unlike riprap and other inert materials, riparian plants are able to bend during high flow events and/or regenerate following flooding or other natural disturbances. This means plant selection is particularly important when revegetating riparian areas. If the appropriate species are chosen and planted in the proper locations, the entire project can be "self-healing" following disturbance (NRCS 2005b).

A primary limiting factor in semi-arid environments is water availability. This is particularly true in riparian areas where the soil moisture varies dramatically with the distance from the watercourse. Vegetation plans should reflect a gradient of vegetation from the streambank/wetland edge to the upper stream terrace areas. Use at least two seed mixtures to cover this gradient and plant woody species where they are best adapted to the hydrology.

Although it is rare in riparian areas, when soil tests reveal that the area is excessively saline, choose species that have adapted to these conditions. Similarly, if herbivore predation has been demonstrated to be problematic, species can be chosen that are thorny or otherwise unpalatable. Grazing should also be limited during establishment with the use of enclosures.

4.1.3 Plant Selection for Wetland Areas

A wide variety of plant material is available for revegetating wetlands, as summarized in Table 13-5. Wetland and stream edge areas are generally revegetated with a combination of wetland seed mixtures, herbaceous wetland plugs, dormant woody cuttings and some potted woody plants. Ultimately, plant selection should be based on:

- Elevation of the planting area above normal water elevation (hydrology).
- Frequency of flooding.
- Permit requirements.
- Soil type.

Photograph 13-4. A Front Range creek restored with a gradient of vegetation types, including wetland plants. (Photograph courtesy of Iris Mitigation.)

Regardless of the plant material selected, several general principles should be considered to improve chances for success:

- The genetic source of the plant material may affect long-term revegetation success. Native woody nursery stock produced from locally collected plant materials, local dormant cuttings, and regional seed sources will be better adapted to local climatic conditions.
- Plant species should be chosen that closely match the existing environmental conditions, especially the hydrology.
- Some plant species may also be adapted to particular soil types (EPA 1994, Colorado Natural Areas Program 1998) and elevations.
- Only native species should be used.
- Common cattail (*Typha latifolia*) and reed canarygrass (*Phalaris arundinacea*) should not be seeded or planted in wetlands because they tend to be invasive.

Good reference sites with conditions similar to the project area are also a valuable tool in determining appropriate plant species, densities, distribution, abundance and diversity and should be considered when available.

4.2 Seeding

Guidance for permanent seed selection for each habitat type is provided below, followed by guidance for temporary seeding. Seed mix tables are provided in Appendix A. Local jurisdictions may require alternative seed mixes and/or require that the seed mix used for the project be approved prior to use.

4.2.1 Seeding Upland Areas

Seeding is the most common and least costly method of revegetation for upland areas. Seed is usually obtained from a commercial seed supplier. Grasses, forbs (wildflowers), and certain shrubs can all be seeded. Basic upland seed mixes are provided in Appendix A to this chapter. Wildflower species can be omitted if not available or another recommended wildflower seed can be increased. Seed mixtures provided in Appendix A are appropriate for most of the typical site conditions and can be mixed upon request by commercial seed companies. Pre-mixed "native" mixtures of grasses or wildflowers offered by seed companies can contain non-native aggressive and even weedy species which are not well suited to revegetation of regional upland areas. It is better to select a mixture provided in Appendix A which contains native species well suited to the task of providing erosion protection in this high plains area.

Fall is the preferred time for non-irrigated seeding. Late summer seedbed preparation followed by installation of the seed in the fall (October) allows winter months for additional firming of the seedbed before spring and germination. Fall seeding benefits from winter and spring moisture and usually assures maximum soil moisture availability for establishment.

Late winter to early spring (February to early April) is typically the next favorable time period for seeding. Winter and early spring seeding should not be conducted if the soil is frozen, snow covered, or wet (muddy). Although of greater risk, spring seeding (mid-April into early June) can be successful, especially during moist spring years. Mid- to late-summer seeding can be successful, with adequate precipitation and/or irrigation to wet and settle the seed bed. Firming of the seedbed following seeding will improve results during dry or warm seeding times.

4.2.2 Seeding Riparian Areas

Seeding is a good option for revegetating the herbaceous understory of a riparian plant community. Seeding timeframes for riparian areas are similar to those described for upland areas. Most native seed mixes (see Appendix A) are commercially available.

4.2.3 Seeding Wetland Areas

The least expensive wetland plant material is wetland seed (NRCS 1997). Often revegetation of wetlands is done through a combination of seeding and plugs which can add to the overall species diversity of a wetland and provides additional root structure and above-ground biomass (NRCS 2003). With proper seedbed preparation and use of blanket protection, UDFCD has observed a high rate of success.

4.2.4 Temporary Seeding

Temporary seeding is an erosion control best management practice (BMP) that prevents soil erosion on a construction site, soil stockpile, or other disturbed site prior to final site stabilization and helps to control weeds. Typically it is appropriate to utilize this practice when the disturbed area will not be finally prepared and seeded for a month or more (depending on local requirements).

The soil may be temporarily stabilized with sterile non-native annual or perennial grasses or native perennial grasses. The selected grass species for this temporary seeding, if non-native, should be either an annual grain or a sterile wheat/wheatgrass hybrid. Sterile grass will not re-seed and compete with more desirable native plantings. Annual grains should be selected depending on the time of year when they will be seeded. Oats, spring wheat, and spring barley are seeded in the spring, followed by millet from May through July. Winter wheat or winter barley may be seeded in the fall and winter months. These annual crop grasses allow for approximately 12 months of coverage. For a slightly longer period of

annual grass coverage, a sterile short-lived perennial wheat/wheatgrass hybrid may be seeded.

Perennial, faster-growing, native grasses can also be seeded as a cover crop. (See the Temporary Native Seed Mixes in Appendix A). However, non-native perennial grasses should never be seeded for temporary cover because they are difficult to eradicate later. Non-native perennial fast-growing grasses to avoid include smooth brome, timothy, orchard grass, crested wheatgrass, tall and meadow fescue, and intermediate wheatgrass.

See the Temporary Seeding Fact Sheet in Volume 3, Chapter 7, Construction BMPs for more information.

4.3 Trees and Shrubs

4.3.1 Upland Trees and Shrubs

Table 13-6 summarizes native upland trees and shrubs that are generally appropriate for planting at an upland revegetation site. Containerized plants, bare root or B&B trees and shrubs can be used. A revegetation specialist must determine which of these native trees and shrubs are appropriate for the specific upland site. Each tree and shrub species listed requires different amounts of sunlight, soil condition and moisture in order to establish and thrive. Temporary irrigation is recommended for tree and shrub establishment.

4.3.2 Riparian Trees and Shrubs

The riparian ecosystem is a transition area between wetland and upland ecosystems and is dominated by large cottonwood (*Populus* spp.) and peachleaf willow (*Salix amygdaloides*) trees with an understory of willow (*Salix* spp.), other woody riparian shrubs, transitional area grasses and herbaceous species. The riparian vegetation has varying widths from the edge of the waterbody depending on factors including: geology, topography, elevation, soil type, hydrology, and upstream and upgradient build-out. Trees and shrubs depend on access to water but can handle occasional dry periods once established.

The cottonwood tree is a relatively short-lived species (80-100 years), and fallen cottonwood make excellent wildlife habitat. It is important to allow for cottonwood and willow regeneration in the riparian zone for replacement species. Cottonwood and willow will regenerate naturally in the riparian zone. The riparian vegetation provides flood control, nutrient cycling, stream food web support, pollutant filtering, sediment retention, and wildlife movement and migration corridors. Healthy riparian vegetation provides streambank stability and erosion control. However, vegetation in this zone can also reduce flood capacity when it's not managed. Non-native riparian species such as the crack willow (*Salix fragilis*) should be avoided as this fast growing and aggressive species has fragile branches which break off along with root mass and cause further erosion issues.

Table 13-7 provides a list of common Front Range native riparian trees and shrubs appropriate for the revegetation of riparian areas.

Table 13-6. Upland trees and shrubs for revegetating sites on the Colorado front range

Upland Trees	
Common Name	**Scientific Name**
Ponderosa pine[1]	*Pinus ponderosa*
Rocky Mountain juniper[1]	*Juniperus scopulorum*
Pinyon pine[1]	*Pinus edulis*
One-seeded juniper[1]	*Juniperus monosperma*
Hackberry[1]	*Celtis laevigata*
Upland Shrubs	
Common Name	**Scientific Name**
Big sagebrush	*Artemisia tridentata*
Yucca	*Yucca glauca*
Sand sagebrush	*Artemisia filifolia (sandy soils only)*
Fringe sagebrush	*Artemisia frigida*
Common juniper[1]	*Juniperus communis*
Winterfat	*Krascheninnikovia lantana*
Western sandcherry	*Prunus pumila*
Smooth sumac	*Rhus glabra*
Mountain mahogany[1]	*Cercocarpus montanus*
American plum	*Prunus americana*
Wax currant	*Ribes cereum*
Wood's rose	*Rosa woodsii*
Rabbitbrush	*Chrysothamnus nauseosus*
Threeleaf sumac	*Rhus trilobata*
Snowberry	*Symphoricarpos occidentalis*
Gambel oak[1]	*Quercus gambelii*
Fourwing saltbush	*Atriplex canescens*

[1] Temporary irrigation is recommended for establishment

Table 13-7. Common Colorado front range native riparian trees and shrubs

Common Name	Scientific Name	Plains	Foothills
Riparian Trees			
Aspen	*Populus tremuloides*		X
Boxelder	*Acer negundo*	X	X
Colorado blue spruce	*Picea coloradensis*		X
Narrowleaf cottonwood	*Populus angustifolia*	X	X
Plains cottonwood	*Populus deltoides*	X	X
Peachleaf willow	*Salix amygdaloides*	X	X
River birch	*Betula*		X
Rocky Mountain maple	*Acer glabrum*		X
Thinleaf alder	*Alnus incana*		
Riparian Shrubs			
American plum	*Prunus americana*	X	X
Bebb's willow	*Salix bebbiana*		X
Bluestem willow	*Salix irrorata*		X
Chokecherry	*Prunus virginiana*	X	X
Drummond's willow	*Salix drummondiana*		X
Geyer's willow	*Salix geyeriana*		X
Golden currant	*Ribes aureum*	X	X
Redosier dogwood	*Cornus sericea*	X	X
River hawthorne	*Crataegus rivularis*		X
Rocky Mountain willow	*Salix monticola*		X
Sandbar willow	*Salix exigua*	X	X
Skunkbush sumac	*Rhus triobata*	X	X
Snowberry	*Symphoricarpos occidentalis*	X	X
Wax currant	*Ribes cereum*	X	X
Wood's rose	*Rosa woodsii*	X	X

4.3.3 Wetland Tree and Shrub Plantings

Riparian woody plant materials (trees and shrubs) are also appropriate for planting around the edge of wetland areas. Seeding is generally not appropriate for revegetating trees and shrubs. If possible, woody plants that are pre-inoculated with my corrhizal fungi, nitrogen-fixing bacteria, and/or other beneficial microbes should be requested (NRCS 2001). The following types of riparian woody plant material are commercially available for wetlands: B&B, plugs, bare root, and containers. Cuttings are the least expensive way to easily install riparian trees and shrubs and generally include cottonwoods (*Populus* spp.) and willows such as the sandbar willow (*Salix exigua*). Willows can be planted around the perimeter of wetland areas while riparian trees and most other riparian shrubs are planted adjacent to the wetland area but away from standing water so that the plants roots are not in fully inundated water conditions.

4.4 Types of Tree and Shrub Plant Material

Types of tree and shrub material include plugs, containers, B&B material, and cuttings.

4.4.1 Plugs

Plugs, typically used for wetland revegetation and enhancement, are long, cylindrical or square planting tubes, measuring 22 in^3 or less, that contain stems, roots, underground perennial parts, and soil (Colorado Natural Areas Program 1998). Plugs are available for both herbaceous and woody plant species.

Wetland plugs may be obtained at a local wetland nursery. Determine availability early in the planning/design phase. Wetland plugs are sometimes grown specifically for a project so ordering them 6 months to a year in advance may be required. Revegetating wetlands with nursery-grown plugs has demonstrated a much higher establishment rate than with seeding or transplanted plants (NRCS 2003). In general, a project should purchase the largest plugs afforded by the budget (NRCS 2003). The plants should be free of injuries, wounds, or insect damage. The above-ground and underground material should have approximately the same density. Additionally, the roots should extend to the bottom of the tube but should not wind around the tube (i.e., not "root bound"). Figure 13-6 provides a detail for wetland plug planting.

4.4.2 Containerized Material

Containerized plant material is typically grown from seed or cuttings at a nursery and is available in various container sizes, such as 4-inch, 6-inch, 1-gallon, 2-gallon, and 5-gallon pots. An advantage of using containerized stock is that it can be stored (under proper conditions) for a moderate period prior to installation.

When inspecting containerized material, look for well-proportioned above-ground plant material that is not excessively large or small for the container. Also, the roots should exhibit development throughout the soil but should not be growing through the bottom of the container or around the periphery of the container.

4.4.3 Bare Root

Bare root plant material consists of the entire plant (upper plant parts and root systems) without a container or soil. These plants are typically dug up and sold when they are dormant and are commonly available for woody plant species. Because they are less hardy than containerized material, bare root plants tend to have a lower survival rate than containerized stock (Colorado Natural Areas Program 1998). However, they are also less expensive. Because bare root plants lack a container and soil, care should be taken to either install them immediately or carefully store them. In general, bare root seedlings should have a top length of at least 18 inches, a collar of at least 3/8 inch, and well developed terminal buds. The roots should also be well developed, should not be pruned, and should be highly fibrous (NRCS 1997).

4.4.4 Balled and Burlapped

Balled and burlapped (B&B) trees and shrubs are grown in nurseries, dug out with the soil intact, wrapped in burlap, and tied with twine. Most plants sold as B&B are relatively large plants and may be cost prohibitive for some projects. When used, B&B trees may be planted in the upland transitional planting zone to achieve a forested component relatively quickly. The most important aspect to evaluate when inspecting a B&B plant is whether the root ball is moist and intact. If it is not intact or has dried out, the plant may not survive.

4.4.5 Cuttings

Live cuttings are a cost effective way to install woody riparian species such as cottonwood trees. When properly installed, the cuttings can establish readily. The costs for obtaining cuttings will consist primarily of labor costs associated with collecting, storing, and transporting the cuttings. Although inexpensive on a unit basis, costs per square foot can be somewhat high because cuttings are typically densely installed in large quantities. The overall success rates and low establishment costs lower the final cost per plant.

Collecting cuttings from the vicinity of the revegetation project allows for securing locally-adapted, native plant material. When possible, cuttings should be collected from areas that are similar to the area to be revegetated and be collected from multiple locations to provide genetic diversity (NRCS 2005b). It is important to make sure that the native stands used as donor sites are not destroyed by the collection.

Collect cuttings when dormant, preferable from late winter to early spring (prior to bud swell). In Colorado, the most successful time to collect cuttings is in early spring before the buds leaf out (usually between February 1st and April 15th). Cuttings may be classified as willow stakes, willow fascines, willow bundles, and cottonwood poles. Cuttings have varying diameters and lengths and can be grouped into bundles, fascines (wattles), brush layering, brush mattresses, etc. Cuttings are most often obtained from nurseries or from donor sites and are collected during the dormant season. In general, the larger the diameter of the cutting, the more successful it will be (Hoag 1995). Species most often used for cuttings along the Colorado Front Range include coyote or sandbar willow (*Salix exigua*) and plains cottonwood (*Populus deltoides* subsp. *monlifera*).

Table 13-8 presents a common classification system for cut woody plant material. Other classifications may also be found.

Table 13-8. Classifications and typical sizes of woody plant material cuttings

Classification	Size
Willow Stakes	24 to 30 inches long 0.5 to 1.0 inch diameter
Willow Fascines and Bundles	3 to 5 feet long 0.5 to 1.0 inch diameter
Cottonwood Poles	10 to 15 feet long 2 to 4 inch diameter

Although Table 13-8 specifies a range of lengths for willow cuttings and cottonwood poles, the final length of all cuttings will be determined by the depth to groundwater. In lower to middle terraces of riparian areas, the water table is expected to be relatively high. Consequently, cuttings do not need to be installed as deeply as in drier habitats. Regardless, cuttings should be installed to extend approximately 6 inches into the water table and should be tall enough to avoid shading by herbaceous vegetation (Hoag 1995). In general, willow species tend to be adapted to wetter environments than cottonwoods. Consequently, willows are commonly planted nearer to the streambanks and on the lower terraces, whereas cottonwoods are planted in slightly drier areas (higher middle to upper terraces). Planting holes for live stakes can be prepared using rebar and small sledge hammers, pry bars, or drills fitted with larger drill bits. Larger cottonwood poles can be planted using 4 to 8 foot augers. Allow time for the groundwater to fill the hole prior to installation, to ensure adequate depth for the cutting. The higher on the bank, the longer the cuttings will need to be.

All cuttings should be collected from insect-free and rot-free live woody vegetation. In general, collect green wood rather than older more mature wood (Hoag 1998). Do not collect cuttings with thick, cracked bark or suckers because they do not have the energy reserves necessary to consistently sprout. Collection guidance includes:

- **Willow Cuttings**: Live stakes should be cut with sharp pruning shears or a weed cutter with a saw blade near the ground surface to 10 inches above. Cuts must be clean, without stripping the bark or splitting the wood. The top should be cut straight across and the base cut should be cut at an angle. This will allow the cutting to be more easily installed and also differentiates the tip from the base. Another technique to help identify the correct ends of the cutting is to dip the upper part (angled end) in paraffin wax or another sealing substance (such as a non-toxic latex paint). For willow stakes and bundles, all side branches and leaves of a cutting should be trimmed. Branches should be left on cuttings for willow fascines. Live cuttings can be bound together with twine at the collection site for ease of handling and protection during transport.

- **Cottonwood Pole Cuttings**: Live poles should be pruned from live cottonwood trees at an approved harvest site. Cuts must be clean, without striping the bark or splitting the wood. The best cottonwood pole cuttings are those from trees less than 18 inches in diameter. The base cut should be at a 45-degree angle and all the side branches trimmed off. The terminal bud (end of branch) must remain intact.

Immediately after cutting, all live stakes and poles should be carefully protected from desiccation by keeping the ends in water (tanks, buckets, or streams) at all times. During transportation, the cuttings should be placed in an orderly fashion in containers with water at least one foot deep and covered with tarp or burlap to prevent damage from the wind and to facilitate handling. If cuttings are collected in the late fall, they may be dry-stored in a cooler (kept at 29 to 34 degrees Fahrenheit) for up to 6 months (Hoag 1998). This should only be when necessary to extend dormancy. One method that may help initiate the growth process on the willow cuttings is to soak the bottom half of the cuttings in water for 2 to 7 days prior to installation (Hoag 1998).

4.5 Wetland Sod/Rhizomes/Tubers

The least costly means for using existing wetland plant materials is to direct haul them in a wetland topsoil salvage operation. It is also possible to cut and transfer salvaged wetland plants. This plant material includes partial or entire plants, rhizomes, tubers, seeds, and sod mats. Salvaged plant material has the advantage of having local genetics and allowing the use of plant material that would otherwise be destroyed. These activities should take place only when the donor wetland (or portion thereof) will be destroyed as part of an activity permitted under a Section 404 permit.

Photograph 13-5. Installation of wetland sod along a reconstructed channel.

Wetland sod refers to large pieces of wetland plants and substrate that can be rolled up or placed flat for transport. Wetland sod should be collected from weed-free areas and ideally, should be collected when the soils are moist but well drained. A wetland sod mat is cut from a wetland with shovels and a front-end loader that is modified with a sharp-edged steel blade. The sections can then be placed on flat-bed trucks and transported to the wetland to be revegetated.

Commercially produced wetland sod grown in coir can be a cost effective means to reestablish protective shoreline wetland vegetation very quickly. Sod should be placed on the day of delivery to the site into the prepared planting locations with 1 to 2 inches of water to cover the roots of the vegetation in the coir. Cost for wetland sod is comparable to installing wetland plugs 12 inches on center. Wetland sod provides excellent erosion protection for the shoreline once staked in place. It requires anchoring except in backwater areas (see Figures 13-4 and 13-5). Check with commercial nurseries early to determine timeline of species and sod availability. Wetland sod is sometimes grown specifically for a project so ordering it six months to a year in advance may be required. If a donor site can be utilized, wetland plants can be harvested from an existing wetland at almost any time of the year (NRCS 2003). A rule of thumb for collecting herbaceous transplants from donor sites is to remove no more than 1-square-foot of plant material from a 4-square-foot area (NRCS 2003). This allows the remaining plants to rapidly fill in the harvest hole while still providing adequate transplant material. A depth of 5 to 6 inches of root and soil removal is adequate and will include beneficial organisms on the roots of the plants that will greatly aid the new wetland. At the new wetland site, the 1-square-foot transplant may be separated into four to five individual plants, depending on the species.

Rhizomes and tubers from existing remaining wetland areas may also be harvested. Rhizomes are underground stems that are capable of re-sprouting into new plants. Many bulrush species have large rhizomes containing a large amount of stored reserves. With significant stored reserves and local genetics, these large rhizomes tend to be more vigorous than relatively small nursery plugs. Many sedge species also have rhizomes. Rhizomes can be dug from donor sites and divided into sections that contain at least one viable growth point or node (NRCS 2003). Rhizomes should be collected in the spring before plants break dormancy and can be transplanted immediately or temporarily stored in sand or peat moss in a shaded, cool area.

Tubers may also be obtained from donor sites and occasionally from nurseries. Tubers are underground storage organs produced by some plants such as arrowhead (*Sagittaria* spp.), yellow pond lily (*Nuphar lutea*), and flatsedge (*Cyperus* spp.). Like rhizomes, tubers contain significant stored reserves and can be dug up from a donor site or purchased from a nursery and transplanted to a new wetland.

5.0 Plant Installation

Proper installation of plants is critical to successful revegetation. Installation methods depend on the type of plant material selected, as well as the habitat type. Installation methods generally include various seeding methods, installation of plug, containerized, B&B and bare root stock, and cuttings, as summarized in Table 13-9.

Table 13-9. Installation methods for revegetating upland, riparian and wetland habitat types

Revegetation Guidance Topic		Applicability to Habitat Type		
Installation Method	Chapter Section	Upland	Riparian	Wetland
Seeding (multiple methods)	5.1 & 5.2	✓	✓	✓
Herbaceous Plug, Containerized, B&B, and Bare Root Stock Installation	5.3	✓	✓	✓
Cutting Installation	5.4		✓	✓
Transplanting Wetland Plants (Wetland Sod, Rhizomes, Tubers)	5.5			✓

The most important consideration is placement Install each individual plant in its favored microhabitat areas as well as in the appropriate planting zone for the habitat type (Figure 13-1). A revegetation specialist or wetland scientist should be present before and/or during planting to mark the installation locations for each plant (for example, using colored pin flags to represent each species).

Along the Colorado Front Range, the generally accepted planting window in upland and riparian areas for seeding, containerized tree and shrub stock, grass and herbaceous plug, and B&B plants is similar. The planting window for wetland plants is generally longer, given available hydrology and precipitation (NRCS 2003). Planting wetland plugs in the fall and winter can result in frost heave whereby the plug is pushed out of the ground. Spring planting can have slower initial growth but allows the plant to have a long establishment period before winter dormancy. Along the Colorado Front Range, the generally accepted planting window for upland, riparian, and wetland areas is summarized in Table 13-10. Irrigation will assist with plant establishment.

Table 13-10. Planting/seeding schedule

Type of Plant	Time to Plant/Seed
Wetland and Riparian Species	
Riparian Containerized Trees and Shrubs	Spring[1]/Summer/Fall[1]
Wetland and Riparian Grass and Herbaceous Plugs	Spring[1]/Summer/Fall
Wetland and Riparian Bare-root Plants	Spring[1]/Summer
Wetland Seeding	Spring[1]/Summer/Fall
Riparian Area Seeding	Spring[1]/Summer/Fall[1]
Willow Stakes	Late Fall/Winter/Early Spring[1]
Cottonwood Poles	Late Fall/Winter/Early Spring[1]
Upland Species	
Upland Containerized Trees and Shrubs	Winter/Spring[1]/Fall
Upland Grass and Herbaceous Plugs	Spring[1]/Summer/Fall
Upland Bare-root Plants	Spring[1]/Fall
Upland Seeding	Spring[1]/Summer/Fall[1]

[1]Preferred Season

5.1 Seeding Upland and Riparian Areas

Once the soil has been decompacted and amended based on the soil test and the seed bed has been adequately prepared, the site is ready for seed application. Seeding can be completed with a drill, broadcast spreader, or through hydroseeding (when allowed by the local jurisdiction). Interseeding may also be used in upland areas. (Seeding methods are described in Sections 5.1.1 through 5.1.4.) Seeding is best achieved on a roughened seed bed with soil clods no greater than 3 inches.

Seeding rates are determined by the method of seeding, selected grass species, and also the purity of the seed. Seed mixes should only be developed based on pure live seed (PLS) to account for species that have low germination rates or mixes that would otherwise have a high amount of inert material, including dirt or other plant parts. The seed tag from the supplier should be inspected before planting to ensure the seed mix is of high quality and contains the correct percentage of PLS.

To determine the pounds of seed per acre, determine the amount of seeds per square foot desired and the amount of seeds per pound of each species selected. A revegetation specialist can assist in determining the correct amount of seed per acre to be used on the site; however, local jurisdictions often specify seeding rates. On average, seeding rates for upland areas are approximately 18-25 lbs of seed per acre (or approximately 3,500,000 to 5,000,000 seeds per acre, depending on seed size).

Timing of seeding is an important aspect of the revegetation process. For upland and riparian areas on the Colorado Front Range, the suitable timing for seeding is from October through May (NRCS 2011b). The most favorable time to plant non-irrigated areas is during the fall, so that seed can take advantage of winter and spring moisture. Seed should not be planted if the soil is frozen, snow covered, or wet. Proper seeding time is dependent on adequate moisture for germination and seedling growth as well as adequate soil temperatures (Colorado Natural Areas Program 1998).

5.1.1 Drill Seeding

Drill seeding is the most commonly used mechanism for planting seed in the ground, if the site is large enough, has 3:1 slopes or flatter, and is not rocky. The seeding depth will vary based on seed selected but, on average, 1/4-inch to 1/2-inch seeding depth will suffice. Another method of determining seed depth is 2.5 times the width of the seed (NRCS 2011b). Seeding parallel to the contours of the site will reduce erosion caused by water flowing down drill furrows (Colorado Natural Areas Program 1998). Since the size and texture of seed for warm and cool season grasses differ, the drill seeder should have boxes for both warm and cool season seed applications or agitators for mixing the fluffy and smaller seeds (Colorado Natural Areas Program 1998). Warm season seed is usually fluffier than cool season seed and tends to get stuck in the box without the right type of agitator and picker wheel.

Native grass drills should also be equipped with Coulter wheels, adjustable depth bands, and drill row spacing of 7 inches or less. Drilling the seed in two directions perpendicular to one another will improve coverage and establishment. If seeded in only one direction, drilling should follow the contour to reduce a tendancy for rilling down furrows. Partial broadcasting with some of the seed prior to or during drilling operations can also improve results, especially for finer seeded species.

5.1.2 Broadcast Seeding

Broadcast seeding consists of spreading the seed onto the surface of the soil by hand or with a hand spreader (also known as a belly grinder) or a mechanized rotary or cyclone seeder. Broadcast seeding may be cost effective in small areas and may be necessary in areas that are inaccessible to seeding equipment, such as rocky slopes, slopes steeper than 3:1, and areas without roads or other vehicular access.

Broadcast seeding is best completed after the ground has been raked or harrowed. This preparation will allow for better seed/soil contact than a hard-packed surface. Broadcast seeding is less reliable than drill seeding, so the seeding rate will need to be doubled or even tripled to achieve the recommended amount of seed at the desired depth. After seeding is complete, the seed should be raked or harrowed in to provide better seed to soil contact. After the seed has germinated, it may be necessary to spot-seed areas that did not establish. On-going spot seeding may be needed to revegetate bare areas.

Inaccessible small, steep, or soft seedbed areas may be broadcast seeded and harrowed or raked to cover the seed. Broadcast seeding rates of 35 to 45 pounds PLS per acre are adequate for most dryland broadcasting, depending on the plant species in the mix. To improve site diversity, hand-collected native seed can be broadcast before, during or after the main seeding operation. Stream edge seeding rates can be up to 50 to 60 pounds per acre to assure faster establishment or erosion protection.

5.1.3 Hydroseeding

Hydroseeding consists of a slurry of seed, fertilizer (if necessary), wood fiber mulch, water, and other additives (such as mycorrhizal fungi) that is blown onto the surface of an area to be seeded. It is mixed in a tank-mounted truck and is applied from the truck through long hoses. On steep slopes, a tackifier (a chemical compound that helps the material adhere to the slope) is often added. The term hydroseeding is sometimes mistakenly used interchangeably with the term hydromulching, which does not typically include seed.

The wood fiber mulch portion of the slurry is usually dyed to show which areas have been seeded. Hydroseeding provides for a single application of all additives, including seeds and mulch and can be used on steep slopes where it can help prevent erosion.

Hydroseeding is generally not recommended unless the slope is too steep to safety walk on (1.5:1) because it provides less soil to seed contact compared to other methods. If desirable, it may be used in flatter areas when the area is raked following hydroseeding. Some local jurisdictions do not allow hydroseeding due to low success rates on previous projects.

Hydroseeding is best achieved in three steps:

1. Soil preparation.

2. Application of the seed and water slurry. (The hydoseeder is constantly agitated so that the seed and water mixture is consistent.) Where site conditions permit, the seed should be raked into the soil.

3. Mulching.

5.1.4 Interseeding

Relatively weed-free sites with some residual native prairie species may be interseeded with a rangeland-type drill to minimize disturbance to existing grass cover. Interseeding directly into these areas without plowing or chiseling is preferable. A rangeland drill will cut furrows and place the seed at the proper depth. Weed seeds present on the site will be stimulated by interseeding and will probably result in additional annual weeds for a year or two after seeding. Mowing during establishment will help reduce competition from these weeds. Interseeding is an excellent way to enhance an existing upland field that has established vegetation but needs additional cover and possibly species diversity.

5.2 Seeding Wetland Areas

Seeding wetlands can be successful in shoreline areas where the seed will be raked to cover and blanketed immediately. Seed will germinate on muddy surfaces but tends to float in standing water. Once seeded, germination should occur in a week or two.

Wetland plants establish best in fluctuating water conditions, such as those found in nature (NRCS 2003). Where possible, it may be beneficial to manipulate the water levels during establishment. Water can be lowered to expose at least some muddy surfaces so that floating seed will drift into muddy areas. The water level can remain low until muddy areas begin to dry, and then water can be returned to re-wet these surfaces, then drawn down again to allow further growth of the seedling plants. NRCS outlines a detailed hydrologic regime to stimulate wetland plant establishment in *Riparian/Wetland Project Information Series Number 22* (NRCS 2007).

Along the Colorado Front Range, the window for seeding wetland species is in the spring, summer, or fall, depending on hydrological conditions on the site.

5.3 Plug, Containerized, B&B, and Bare Root Stock Installation

The density of plantings, especially when installing nursery stock, will greatly influence the overall cost of the project. In addition to the project's budget, careful consideration must be given to the character of the area to be revegetated when determining planting density. For riparian areas, use of cuttings (Section 5.4) may substantially lower the cost, allowing for higher planting densities.

5.3.1 Wetland Plugs

Wetland plugs should be planted 18 to 24 inches on center (NRCS 2003). Plantings at a wider spacing

exhibited less overall success, perhaps due to plant exposure. If the project budget does not allow 18- to 24-inch spacing, it is better to install plugs in patches at the proper spacing, separated by approximately 10 feet. Over time, plants will spread into the bare areas. As the hydrology within the cross-section changes and distance from the stream increases, species composition should change and spacing can widen to up to 2-3 feet depending upon erosion hazard and budget.

Each flat or rack of wetland plugs should come from the nursery clearly labeled by species. They should be wet upon transfer to the contractor and maintained with consistently moist soil in a shaded area until planted. This can sometimes be better accommodated at the contractor's yard than on site. Plugs delivered to the site should be planted the same day. When planting each plug, dig a generously-sized hole that allows the plug to be planted at the proper depth – not too shallow and not too deep. Avoid "J-rooting" the roots (bending into a "J" due to inadequate hole size). Also be sure to fill in air pockets near the roots to prevent the roots from drying out. Topping the surface of the plug with 1/2 to 2 inches of native soil can help to prevent desiccation. In areas where waterfowl grazing is possible, a 6- to 8-inch steel landscape staple can be used to secure each plant. Staples rust quickly and prevent the plants from being pulled up by the grazing birds.

5.3.2 Containerized, B&B, and Bare Root Stock

Guidelines for planting container stock, B&B plants, and bare roots are similar to the guidelines for planting plugs, described above. As with plugs, be sure to keep the plants moist and cool in the shade at the site. Keeping the plant containers buried in damp wood chip mulch or placing them under a reflective blanket or shade cloth can also prevent desiccation (NRCS, 2001a). Check moisture frequently. If the container and plant are not large and the substrate is easily worked with (such as deep friable soils), the hole may be dug with a shovel. In contrast, if the plant is large and/or the substrate is rocky, planting hoes (hoedads) or small backhoes may be advantageous. Because B&B plants tend to be larger, special equipment may be necessary for their installation. A relatively large hole should be dug enabling the soils around the newly installed plant to be effectively tilled and loosened, providing a medium for the new roots to grow into. Each hole should be filled in soon after digging to prevent the soil from drying out, and the soil should be firmly tamped down around the new plant after the hole is filled. For additional details on tree and shrub planting, see Figures 13-7 through 13-13.

Do not pick up plants, especially trees, by the trunk or upper parts, but by the container. B&B plants should be carried by the root ball.

Seedlings, and especially tree saplings, that have been grown in a greenhouse are highly susceptible to both drought and freeze damage (NRCS 1997). These plants should be "hardened" for a few days prior to planting by placing them in an enclosure that is several degrees above freezing, and they should be watered only sparingly before planting. Because bare root nursery stock is dormant, no hardening is necessary prior to planting.

Each plant should be mulched and deeply watered soon after installation. In relatively dry areas, watering tubes or hydrogel packs can be installed with the plant to provide additional moisture after installation. These allow a temporary source of moisture to the new planting. Although container stock will be more resistant to desiccation during the planting process, bare root plants should be carefully protected from desiccation during the planting process. These can be kept in 5-gallon buckets of water until ready for planting.

5.4 Cutting Installation

Cuttings are commonly installed in riparian and wetland areas. Installation guidance for each habitat type

is discussed separately below.

5.4.1 Installing Cuttings in Riparian Areas

Willows should be installed in the bank riparian planting zone where they can function to stabilize the bank. Cottonwoods should be planted in either the higher reaches of the overbank zone or the transitional zone (Figure 13-1). Regardless of the planting zone, cuttings need to be installed deep enough to contact groundwater year round. In areas with significant fluctuations in seasonal groundwater levels, cuttings will need to be installed deeper to ensure that they contact groundwater even during the driest season. Ideally, cuttings will be installed at least 6 inches into the lowest water table of the year with three to four buds above the ground surface (also includes the terminal bud on cottonwoods). Preferably, two-thirds (or at least half) of the length of the cutting should be in the ground (Hoag 1998). In areas with high erosion, cuttings should be installed 3 to 4 feet into the ground with the buds up.

Installing cuttings in riparian areas can be challenging depending on the substrate present. Cobbles can be impossible to auger, while holes dug in dry sands and gravels often collapse in on themselves (Los Lunas Plant Materials Center N.D.). Depending upon the substrate and the depth to groundwater, the following tools and equipment may be necessary to install cuttings: planting bars, augers, backhoes, rotary hammer drills, stingers, or post-hole diggers. The most important consideration when planting willow cuttings and cottonwood poles is to use equipment that will allow the cuttings to be planted at the depth that provides a constant water source (Hoag 1995). Additionally, the installation must result in good contact between the soil and the cutting.

Installation guidelines for willow stakes and bundles as well as cottonwood poles are provided within the details included in the chapter. Willow fascines can also be used, although UDFCD has observed this technique to be less successful than the above listed technics. For this reason a detail is not provided. See Hoag (2002) for installation guidance for willow fascines.

Recommended planting densities for cuttings include:

- When planting shrubby-type willows, such as coyote (sandbar) willows, a recommended planting density is 1 to 3 feet apart.
- When planting tree-type growth forms, such as cottonwoods and larger willows, a recommended planting density is 6 to 12 feet on center (Hoag 1998).
- If erosion is a concern in a portion of the project, plant shrubby-type willows 1 foot apart (Hoag 1998).

5.4.2 Installing Cuttings in Wetland Areas

Installing wetland shrubs such as sandbar willow within or adjacent to wetlands will most likely include the installation of willow cuttings, which may be installed individually or in bundles. If water erosion is anticipated, willow fascines, stakes, or the somewhat sturdier willow logs or biologs, may be installed along the water's edge. Regardless of the size or assemblage of the cuttings, they should be installed while dormant (after leaf abscission and before bud break), which extends from winter through early spring.

The equipment needed to install the cuttings will depend on the number of cuttings to be installed, size of the cuttings, and on the substrate they are to be placed in. A relatively low number of small cuttings can usually be installed with a planting bar. Larger cuttings, such as poles, may be installed with hand or

power augers. Wheel mounted augers on all-terrain vehicles can be extremely useful when planting thousands of cuttings. When planting in riprap or steep cut-banks, backhoes may be used. The most important consideration when planting cuttings of any size is to use the equipment that will allow the cuttings to be planted at the depth that provides a constant water source (Hoag 1995).

Cuttings should be installed to a depth that allows the end of the cutting to be in contact with groundwater throughout the growing season, even if the water table drops. Assessing groundwater depths prior to planting is highly recommended (Los Lunas N.D.). The basic technique to install a cutting, regardless of its size, is to auger or punch a hole into the substrate (to the appropriate depth) and then place the cutting in the hole. The soil should then be tamped down around the cutting to remove all air pockets. All cuttings, whether stakes or poles, should be planted with the buds pointed up and at least one healthy bud above the ground surface. Smaller cuttings should be installed to approximately three-quarters of their total length (NRCS 1997). In areas where the groundwater is relatively low (such as in adjacent upland or riparian areas), poles or posts may be installed 2 to 7 feet deep (Hoag 1995). For additional information on willow and cottonwood pole cuttings, see Section 4.4.4.

5.5 Transplanting Wetland Plants

Plugs, whole plants, rhizomes, and tubers salvaged from a donor wetland site are most easily transplanted when the site is slightly saturated. All plant material should be reinstalled in the same hydrologic zone that it was removed from. If 1-square-foot plugs are to be transplanted, they may be separated into smaller plantings. Use a small saw or shovel to chop them into smaller pieces (NRCS 2011). Both rhizomes and tubers should be placed in holes dug in the mud. Rhizomes should be planted just below the soil surface and tamped in to ensure good soil contact. Tubers should be placed in a hole that is approximately twice the size of the tuber (NRCS 1997). When transplanting shrubs or trees, the plant should be placed directly to the new location from the equipment used to dig it out. Ideally, a spade machine would be used to remove larger plants and would be sized to match the plants being removed (Colorado Natural Areas Program 1998). To avoid desiccation, trees and shrubs should be transplanted when dormant.

When donor topsoil is obtained from a wetland for its seed bank, it should be spread carefully over the new wetland at a thickness of 6 inches or less (NRCS 1997, Colorado Natural Areas Program 1998). Care should be taken to avoid damaging the plants and propagules that are present within the topsoil. The soils should be spread in the same hydrologic zone from which it was taken. Similarly, wetland sod that is obtained from a donor site should to be placed in the hydrologic zone matching the one from which it was taken. If several pieces of sod are available, they should be placed together in a bricklaying fashion on the soil surface and secured with wooden stakes (NRCS 2011). Gaps between the mats should be avoided to the extent practical.

6.0 Mulching

Mulching is the practice of applying a protective layer of material onto the soil surface of individually planted trees and shrubs or a broadly seeded area. Mulching is important in both upland and riparian areas but should not be conducted in wetland areas (EPA 1994). Mulching can be achieved through straw, hydromulch, or rolled erosion control product (RECP) installation. Applying mulch provides many benefits such as:

- Decreases germination of many weed seeds.
- Moderates soil temperatures.

- Retains soil moisture during dry weather (i.e., decrease evaporation).
- Increases infiltration.
- Decreases erosion.
- Adds organic matter to soil.
- Protects soil from "crusting" caused by raindrops on bare soil.
- Reduces compaction caused by heavy rains.

Mulching practices differ for individually planted trees and shrubs and seeded areas, as described below.

6.1 Mulching Individually Planted Trees and Shrubs

Individually planted trees and shrubs should be mulched immediately after planting. Mulch should be thickest at the edge of the planting saucer and taper to a zero depth at about one inch from the shrub/tree. Too much mulch can be smothering or produce excess moisture that could cause disease. Appropriate mulch includes straw, wood and bark chips, grass clippings, leaves, compost, wood and straw pellets, and inorganic material such as rock.

Mulching with wood and bark chips is less effective per unit weight than mulching with straw (NRCS 2005a). Additionally, it may discourage plant growth if applied at excessive rates. Wood and bark chips tend to have high carbon to nitrogen ratios. Additionally, nitrogen gets tied up during the breakdown of wood and bark making it less available for plants. This may actually provide a slight benefit for natives over weed species, which have higher nitrogen needs. A different form of wood and bark mulch is pellets. Wood and straw can be partially chemically digested and the "mash" formed into pellets. These pellets can be easily broadcast over a site (NRCS 2005a) but should not be used on slopes where they could readily slide downhill.

Photograph 13-6. Crimped straw mulch. (Photograph courtesy of David Chenowith.)

Although often overlooked, rock is excellent inorganic mulch (NRCS 2005a). It holds up well and doesn't float. The biggest constraints are its heavy weight and cost to transport. It may also require greater attention to weed control.

6.2 Mulching Seeded Areas

In seeded upland and riparian areas, one of the most important functions of mulching is to reduce erosion. Because riparian areas are often located on slopes draining into waterways, they are prone to erosion and may increase sediment loading to streams. Because upland seeded areas are often located on open dry areas, they establish better and more rapidly if mulched. Many materials are available for use as mulch on seeded areas, including but not limited to straw, wood and bark chips, grass clippings, leaves, compost, wood/straw pellets, blankets and netting, and inorganic materials such as rock. The more common materials are discussed below.

6.3 Types of Mulch

6.3.1 Straw Mulch

Straw mulch is the most widely used product for upland and riparian area seeding because it is cost-effective, readily available and conveniently packaged in bales. Straw mulch can be spread and crimped successfully on slopes of 4:1 or less. Steeper slopes may require a different type of mulch. Straw is fairly durable, easily applied, and provides excellent erosion protection.

Although straw includes the stalks of plants without the seed heads, some seeds may be present. Straw mulch containing weed seeds can drastically alter the success of revegetation on a site (Kruse et al. 2004). Using non-certified mulch may introduce noxious weeds and undesirable plant species onto the site. Additionally, many agencies require the use of certified weed-free mulch.

Long straw is appropriate for straw mulching but fragmented straw should be avoided. At least 50% of the straw mulch should be a minimum of 10 inches long for stability once crimped. The straw mulch can be applied by hand in small areas or by a chopper/spreader or blower in larger areas. The NRCS-recommended application rate is between 1000 to 8000 pounds of straw mulch per acre (NRCS 2005a). In general, the more straw used, the better the erosion protection. However, a high application rate may interfere with seedling emergence. A good rule of thumb when mulching over a seeded area is to mulch to a density where some soil is visible beneath the straw (between 2 to 2.5 tons of straw per acre is a recommended rate in Colorado).

The disadvantage of straw mulch is that it is highly susceptible to blowing away, so it must be anchored or crimped. The straw should be crimped into the soil to a depth of 2 to 3 inches with a crimping tool. The straw can also be anchored with a roller or empty drill (with heavy press wheels) pulled behind a tractor (NRCS 2005a). Disks and chisels should not be used to crimp because they will cut the straw, allowing it to blow free. If the slope is too steep for equipment access, a tackifier may be blown on top of the mulch by a hydromulching/hydroseeding truck. A tackifier should be applied at a rate of 150 pounds per acre. In cases where extra care is needed to avoid straw mulch blowing away, crimping and tackifier may both be utilized.

Because hay includes the entire plant including seed, mulching with hay will actually seed the site during mulching activities with non-native grass species and should be avoided. Alternatively, native grass species of hay may be purchased, but are difficult to find and expensive. Purchasing and utilizing a certified weed-free straw is an easier and less costly mulching method.

6.3.2 Rolled Erosion Control Products

Rolled Erosion Control Products (RECPs) include a variety of temporary or permanently installed manufactured products designed to control erosion and enhance vegetation establishment and survivability, particularly on slopes and in channels. For applications where natural vegetation alone will provide sufficient permanent erosion protection, temporary products such as netting, open weave textiles and a variety of erosion control blankets (ECBs) made of biodegradable natural materials (e.g., straw, jute, coconut) can be used. See the RECP fact sheet in Chapter 7, Construction BMPs, of Volume 3 for more information on appropriate uses and installation guidance for RECPs.

Although RECPs can be expensive, they are often the best approach for facilitating revegetation on steep slopes (such as 3:1 or steeper). For purposes of revegetation, it is best to avoid thick straw or excelsior blankets because they can impede grass establishment. RECPs must be installed correctly to be effective.

RECP Recommendations

- UDFCD recommends only biodegradable RECPs because plastic netting products may trap snakes, deer and other wildlife.
- Heavy woven coconut fiber blankets (coir) are preferable on stream edges due to strength, flexibility and relative durability of the blanket.
- Coir, non-woven coconut blankets or biodegradable coconut straw composite blankets can be used in biologs and willow log construction.
- UDFCD uses coir mat placed over straw to hold topsoil and seed in place. See details located at the end of this chapter.
- Non-woven coconut blankets can be used on streambanks where less intense flows occur.
- Areas that are not as frequently inundated can use biodegradable coconut straw composite blankets. These blankets and straw blankets tend be stiffer and not drape as well. Jute netting is soft and drapes very well, but is typically limited to a 4-foot width.

6.3.3 Hydromulch

Hydromulch is a slurry of water, wood fiber or recycled paper mulch, and an organic tackifier that is mixed in a large tank (mounted on a truck) and applied with a pump and hoses. It is a more expensive but can be an effective erosion control method that is used in areas where blowing loose straw may not be suitable (such as in established neighborhoods and along roadsides). Because the hydromulch holds the seed in place (with the tackifier), it is especially beneficial when applied to a slope that has been broadcast seeded (Goodwin et al. 2006). It is also valuable for stabilizing soil on steep slopes that cannot readily hold straw mulch. Hydromulch is a sterile product without weed seed concerns and should not be confused with hydroseeding, which combines seed with hydromulch.

Hydromulch should be specified to be “mechanically defibrated virgin wood fiber” and should be applied at a rate of 2000 to 3000 pounds per acre (NRCS 2005a). Approximately 2500 pounds of mulch and 150 pounds of organic psillium derived tackifier per acre is a recommended rate for Colorado. At the rate specified, 95% of the soil surface should appear covered after it dries. For every 500 pounds of wood fiber, 1000 gallons of water is needed. Accessibility to the site by the hydromulching truck and availability of water at the site, via a waterway (with water rights for the activity) or water truck, are essential. Because the hydromulch is applied through hoses, vehicular access throughout the entire site is not necessary provided that the hoses can reach all of the areas to be mulched. Always check installation rates, areas and quantities to be sure that the specified rate has been applied. Most failures result from low application rates.

6.3.4 Compost

Compost is a mulch option that may be considered for use in upland and riparian areas. Compost consists of decomposed organic material and therefore has higher nutrient availability than other mulch materials (NRCS 2005a). This is a potential disadvantage in riparian areas where it could wash into waterways and impact downstream water quality. In contrast, in riparian areas where the topsoil has been completely removed, compost may be appropriate. On seeded upland and riparian areas, compost may also be a more costly mulching alternative because of the quantity required. However, in upland areas where the topsoil has been completely removed, compost may be a beneficial mulching alternative.

7.0 Maintenance

To achieve successful revegetation, the project's resources and budget must extend beyond the active construction phase to include maintenance for several years following construction. A maintenance and management plan should be completed for the site to include the following activities:

- Weed control and long-term management.
- Replanting dead trees and shrubs.
- Reseeding bare areas where grasses did not establish.
- Repairing ECB or other erosion control fabrics, if applicable.
- Stabilizing eroded areas, particularly following large storm events.
- Installing protection from animal damage.
- Temporary or permanent irrigation, as needed.
- Debris removal.
- Installing and/or repairing temporary fencing to control foot traffic, particularly in heavily used park areas.

Wetland areas have some additional unique maintenance requirements, which are discussed separately in Section 7.6.

7.1 Irrigation

When selection of plant species is based on the available moisture and soil conditions at a given site, the plants should thrive once established without the need for long-term irrigation. Temporary irrigation can be helpful for initial establishment, especially when seeding occurs in mid-summer or in a drought. In warmer urban settings, periodic supplemental irrigation can be helpful because heat from roads and buildings tends to warm and dry adjacent areas. Temporary irrigation of native species may not be necessary after initial watering, depending on the site and the hydrologic conditions during establishment.

When provided, temporary irrigation should be applied only during the plant establishment period, usually the first growing season. This is the period when seedling roots are near the surface and can benefit from occasional irrigation. Because frequent supplemental irrigation can encourage shallow rooting, irrigation should progress to less frequent and deeper (longer duration) irrigation (Table 13-11).

If irrigating from the adjacent stream, be sure to obtain water rights or do this during "free river" conditions. If water rights are not available, use a water truck.

Irrigation can occur through any of a combination of the following methods:

- Hand watering.
- Water truck.
- Water tubes or hydrogel packs (needs to be closely monitored and eventually removed).
- Drip system irrigation.
- Spray head irrigation.

The type of revegetation project may guide the type of irrigation necessary for the site. If, for example, the project is a U.S. Army Corps of Engineers 404 permit related project, longer-term permanent irrigation is not favored and should be avoided. (Irrigation is not allowed during the three to five year monitoring period for such projects.)

7.1.1 Seeded Area Irrigation

Properly designed and installed seeded areas can be expected to germinate and establish with natural precipitation in average or wetter than average years. Even a single heavy precipitation event can be adequate to stimulate germination. If seeding is done during a drought season, or during the summer, some initial irrigation can assist with germination and establishment.

Monitoring of irrigation is a critical management activity that should occur if irrigation is to be used on a site. Either too much water or too little water can be detrimental to the survival of newly planted seedlings and plantings. Soil type will also influence the amount of irrigation needed since clay soils require less water to remain moist than do sandy soils. Moist soils in April encourage cool season native species to grow, whereas warm season grasses start to grow when soil is warmer with adequate moisture in mid to late May.

In order for native seed to germinate, the top 1 to 2 inches of soil should be moist, but not saturated. Initial irrigation should maintain moist soil in the seed bed, watering up to twice a day. Use of mulch or landscape fabric will reduce the frequency of irrigation required to maintain surface moisture. Once the grasses begin to establish, the roots will penetrate into the soil more deeply and irrigation should be reduced to three or four times a week, but for a longer duration, to allow for up to 6 inches of moisture in the soil. Irrigation should then be curtailed to one to two times per week later in the summer until the fall months when irrigation would cease to allow the plants to harden for the winter months. Table 13-11 provides a sample irrigation schedule for establishing native areas. Mulching/crimping/hydromulching seeded areas is also crucial to keep moisture in the soil.

Where an access road is available near the seeded area, a water truck can be used to spray-irrigate seeded areas on the same time basis as described above. The labor costs for using a water truck may eventually outweigh the costs of installing a more permanent irrigation system, depending on the site logistics.

Table 13-11. Sample irrigation schedule for establishing native areas

Time Of Year	Frequency	Time of Day	Soil Moisture Depth
Mid-April (Cool Season) Mid-May (Warm Season)	1-2 times per day until temperatures reach 80 degrees	Once in early morning once in late evening	Maintain soil moisture to 2-inch depth
Early June to July	Every other day or more if temperatures are above 90 degrees	Early morning or late evening	Maintain soil moisture to 6-inch depth Cycle and soak technique may be used to reach 4 inch-depth[1]
July to Mid-August	One application per week	Early morning or late evening	Maintain soil moisture to 6-inch depth
Mid-August to Mid-September	One application every other week	Early morning or late evening	Maintain soil moisture to 6-inch depth
Mid-September and on	Withhold watering to allow plants to harden for winter	NA	NA

[1] To maintain soil moisture in soils that are finer in texture, a cycle and soak technique of water application may need to be used. A cycle and soak technique is performed by watering in short durations, with multiple applications. This allows the water to infiltrate the soil rather than run off the site.

7.1.2 Tree and Shrub Irrigation

When properly located and planted, native trees and shrubs should be fairly self-sustaining with limited initial watering. Deep planting of trees and shrubs (which places the base of the root ball at the top of the ground water level, dormant season planting (before leaf out), and use of smaller nursery stock (which requires less water to establish) all can help reduce watering requirements for woody vegetation. All containerized plants should be well watered at installation time. When leafy plants are installed later in the spring or summer, a more prolonged irrigation program may be necessary.

Trees and shrubs should be deeply watered when first planted so that the entire root ball and soil around the root ball are inundated. Depending on the species selected, available soil moisture, and available precipitation, the trees and shrubs should be watered at least once a week during the first growing season. The need for a second growing season of irrigation can be monitored and assessed the following year. Monitoring the trees and shrubs is essential in order to be proactive with temporary irrigation before plants begin to stress and then die.

7.2 Replacing Dead Trees and Shrubs/Spot Reseeding of Bare Areas

Routine maintenance in establishing upland areas generally includes reseeding of bare areas and replacing dead, diseased, or dying planted trees and shrubs. At least some replacement of dying plants is typically required in riparian areas. If diversity is limited, additional species should be planted to add diversity to the establishing upland plant community. If a significant number of plants are diseased or infested by insects, a fungicide or insecticide application may be warranted.

In riparian areas, although newly establishing willows need relatively little maintenance, several maintenance activities will improve the riparian plant community's functions. As willows age, some may

need to be trimmed or cut down to stimulate smaller, denser growth (Hoag 1998). This should be completed in the dormant season. Similarly, on river floodplains no longer exposed to historic flooding (due to irrigation withdraws, dams, etc.), cottonwood and willow trees will no longer naturally replace themselves. These larger riparian species evolved to regenerate with natural cycles of intermittent flooding. When these cycles are disturbed, the larger riparian species are eventually replaced by a xeric plant community (Los Lunas Plant Materials Center 2005). Preserving these riparian plant communities will require ongoing planting and management.

In both riparian and upland areas, bare areas that were seeded will need to be weeded and spot-seeded/mulched annually until the bare areas fill in. In some cases, additional soil sampling and application of soil amendments in perpetual bare areas may be warranted. Irrigation concerns may need to be addressed in the bare areas until the grasses establish.

7.3 Vegetation Protection from Animal Predation

Additional maintenance often required for establishing upland and riparian plant communities includes replacing or installing fencing and protection to minimize animal damage. General browse protection can be provided by flexible tube tree protectors that trap moisture and protect the tree from browsing animals, wind desiccation, small rodents, and insects. They can be obtained in various thicknesses and heights. Rigid seedling protector tubes are plastic-like mesh tubes that protect young woody plants from browsing by larger animals. Metal deer fencing can also be installed around larger plantings to protect them from browse by deer. Deer may also be discouraged by bud caps (pieces of paper that hide buds from deer). Where voles are a concern, wrap the base of the planted tree twice with 6- to 8-inch-wide strips of tinfoil. This can be effective for up to two years (NRCS 2001a).

When in an area heavily populated by prairie dogs, it is not always realistic to keep all prairie dogs out of the newly planted area. Use a perimeter fence to deter prairie dogs from entering the area of construction and consider a more permanent fence during the time of plant establishment. This can be constructed using a wire mesh that is buried 3 feet into the ground and extends above ground 3 feet. Alternatively, the buried portion of the fence could be placed horizontally and just buried a couple inches (in an "L" formation). Attach silt fence onto the upper portion to limit visibility to the protected area. This fence will require maintenance and should remain in place for 1 to 2 years. Fumigation may also be beneficial during this time.

Photograph 13-7. Prairie dogs will attempt to dig under the fence. Bury the wire mesh portion vertically (shown) or in the form of an "L" to deter prairie dogs from burrowing under the fence.

If beavers are a concern, new plantings can be protected by 5-foot-high wire tree guards. This should be done with the understanding that the beaver will look for other (mature) trees. Unlike prairie dogs, when the project requires removal of beaver (although rare), there are typically landowners that will accept them. An experienced trapper can live-trap and safely relocate beaver to a new location.

Geese can cause significant damage to a newly planted wetland. Waterfowl may mouth the plants looking for seed and uproot the planted material. Wetlands often need waterfowl predator control through the placement of a grid of T-posts installed 10 foot on center with wire strung between the posts (see Figure 13-16). Brightly colored flagging is then tied onto the wire. This grid of predator control will

reduce waterfowl landing in the newly planted area. Alternatively a 6- to 8-inch steel landscape staple can be used to secure each seedling. Staples rust quickly and prevent the plants form being pulled up by the grazing birds.

7.4 Weed Management

Control of weeds, especially noxious weeds, is a critical component of maintaining establishing upland and riparian areas. Any weeds on the Colorado Noxious Weed "A List" should be promptly and aggressively treated. Similarly, areas with infestations of Colorado Noxious Weed "B or C List" species with more than 10% cover should be promptly addressed; however, a tolerable range of what species can be present and/or the cover of an individual species can vary by state or local jurisdiction and by specific permitting requirements for an individual project. Using GPS to mark the locations of noxious weeds may be beneficial for both short and long-term management. Developing an integrated weed management plan is highly recommended for most newly revegetated sites. Integrated weed management is defined as using a variety of techniques to control weeds (Colorado Natural Areas Program 1998). Techniques that may be used include mowing, herbicide application, rotational grazing, biocontrol, and hand-removal or cutting. The integrated weed management plan should evaluate the weed species found at the site and determine the best combination of control strategies for each species. Note that newly seeded plants will be especially vulnerable to all herbicides; therefore, herbicides should not be applied to newly-seeded areas until the plants are relatively hardy [when the plants have four to six blades (Goodwin et al. 2006)]. Following the initial years of intensive management, a long-term commitment for spot-spraying of re-sprouting weeds must be part of any control plan. The herbicide label should be read to determine when to re-seed because the time an herbicide remains active in the ground differs for each herbicide.

Newly seeded areas can be very weedy during the first year of growth. Annual weed seeds are abundant in most topsoil and germinate readily. It is critical that annual weeds be mowed when they are in flower and before they produce seeds. Two or three mowing operations in the first year of growth can generally address most of the annual weeds on a site. UDFCD has also found that starting weed control one to two years prior to construction can be beneficial in controlling new weeds following seeding. Biennial and perennial weeds can be spot-treated by a certified weed control specialist with approved herbicides by mid-summer or when the seeded grasses have three to four leaves. A boom sprayer should not be used during the first summer after seeding.

Weed control of established seeded areas during the second growing season may involve a combination of techniques including spot spraying weedy areas. However, herbicide applications should be closely managed and herbicide selection, method of application, times and rates should be chosen carefully and recorded based on the type and amount of weeds present. A certified applicator should be used for all herbicide applications. A copy of their applicator license should be obtained and records should be kept of all applications that occur on the site. A Compliance Certification for the CDPS General Permit for Discharges from Application of Pesticides may be required for herbicide applications exceeding certain thresholds.

A seeded area without shrubs may be mowed during the first year of establishment as a good early weed control method. Weedy areas should be mowed 6 to 8 inches when they exceed 12 inches in height or just begin to produce seed. A small or tandem wheeled tractor is appropriate for this type of mowing. Mowing should not be used to limit plant height. A low-growing grass seed mix should be used if shorter grasses are desired. The normal mowing height for established grasses should be no less than 6 inches because mowing too low is detrimental to grass establishment.

Additional natural weed control methods have a variety of levels of success depending on the species of weed. These include goat/sheep temporary grazing, insect releases, rotational grazing, hand

cutting/pulling, spot seeding, and other natural methods. These methods can be integrated with herbicide treatments and mowing for best results. Spot seeding bare areas with desirable grass and/or planted species once weeds are controlled is highly encouraged so that the bare areas do not become established with additional weedy species.

7.5 Managing Erosion in Riparian Areas

Riparian areas commonly require maintenance to address erosion. The site should be inspected closely for signs of erosion. If necessary, install additional erosion control measures such as erosion control blankets or consider the need for other bioengineered solutions (see the Bioengineered Channels section of the *Major Drainage* Chapter for further detail on bioengineered bank stabilization methods). Existing erosion control matting, netting, or blankets should be repaired or replaced as required and in areas where it is still needed. In locations where major erosion is occurring and cannot be controlled with bioengineering techniques, other types of engineered structural measures may be necessary.

7.6 Maintenance for Created, Restored and Enhanced Wetland Areas

A maintenance plan should be part of the wetland creation, restoration and enhancement project. A maintenance plan should include periodic observations of the wetland area during the growing season to observe existing hydrological conditions, wetland establishment, weed control, spot revegetation and other maintenance needs at the site.

During the maintenance visit, it is important to observe and document existing hydrologic conditions for wetland establishment as designed. Hydrologic observations should include these conditions:

- Standing water.
- Subsurface water through digging of soil pits.
- Observation of established wetland vegetation.

If wetland plants are not fully established, but adequate hydrologic conditions exist, one can assume that the plants will eventually establish throughout the area. Additionally, in areas where water control is possible, wetland plant growth can be stimulated by alternating flooding and drawdown in the wetland. If wetland plants are not establishing and there is a lack of adequate hydrologic conditions, additional excavations, water diversion, or grading may be warranted. If the water depths are too deep for wetland plant establishment, additional fill, water diversion, water pumping, or outlet reconfiguration may be warranted. Once appropriate hydrological conditions have been achieved, additional spot seeding/planting of wetland plant material may be necessary.

A weed management plan is an important part of wetland area design before the seeding/planting occurs. Observation and documentation of weedy species establishing in and around the wetland area is an important first step in weed control. Weeds are controlled through the following actions:

- Applying EPA-approved aquatic herbicides (application at the correct time of year for the targeted weed).
- Hand-pulling of weed species.
- Hand mowing or weed cutter (avoid large vehicles that will damage vegetation).
- Using biological controls (insects other natural control).

- Coordination of weed control planning with adjacent property managers.
- Additional spot seeding/planting of wetland plants may be needed to fill in areas where volunteer weed species may again become established.

Other maintenance activities should include:

- Flood debris (natural and human origin) can create a smothering buildup in riparian wetland areas. If left for long periods of time, it will encourage invasion by weeds from seeds carried by the high water. Sediment deposits on newly seeded areas can sometimes be raked or shoveled off in the first few days following a flood to allow recovery of the young vegetation. If the sediments are deep, they may require additional seeding and possibly mulching. Seed mixtures can be selected based on the texture of the flood-deposited sediment. Biweekly to monthly inspection and removal should continue throughout establishment when regular flows are anticipated (April through September).
- Planted woody trees and shrubs should be observed and documented for wildlife damage such as browse, trunk damage and other physical damage. If wildlife damage is observed, protection should be installed.
- Beaver protection installed at the time of installation may require straightening and debris removal after high water event. Over the long-term, beaver cages will require loosening or enlarging around growing trees to prevent loss of the trees from strangulation by the fencing.
- Irrigation of seeded/planted material during the early establishment period may be needed during especially hot summer drought periods.
- Social walking/biking trails through wetland areas should be discouraged through piling dead wood, boulders, and/or appropriate signage.
- Repair perimeter fencing, signage, and vandalism that may occur.

8.0 Post-construction Monitoring

Post-construction monitoring of revegetation progress is essential for determining the appropriate maintenance and corrective measures that may be required during establishment of vegetation at a site. The results of the monitoring provide the information necessary for adaptive management, which is key for effective revegetation due to climatic variability and other uncontrollable factors. Research has shown that if a revegetation project has problems, they typically show up in the first couple of years after plant installation (NRCS 1997).

A trained professional should conduct and evaluate monitoring recognizing that the site will progress through intermediate stages prior to full revegetation. A variety of techniques and methods for assessing revegetation are available, ranging from simple photo documentation, to comparison to reference sites, to more rigorous ecological evaluations, particularly for wetland sites. See BLM (1999) and Faber-Langendoen et al. (2006) as two resources for monitoring approaches at revegetation sites.

For upland and riparian areas, post-construction monitoring may be required from a federal, state, or local agency depending on project permits. If monitoring is required, the agency may have specific success criteria to meet. For wetland areas, post-construction monitoring is usually required as a condition of the Clean Water Act Section 404 permitting process. A permit granted by the USACE authorizing fill in wetlands or other waters typically specifies a series of performance measures (also referred to as success criteria or performance criteria) that the mitigation area must meet in order for the permit conditions to be

met.

Because of the importance of monitoring, adequate funding must be set aside during project development to support this phase of the project. Otherwise, the project may fail to comply with permit conditions (particularly 404 and stormwater construction permits, which require follow-up monitoring and reporting) and/or failure on-the-ground through lack of appropriate adaptive management.

The following post-construction monitoring phases are typical:

Should the contractor be responsible for the success of the vegetation?

Warranties are typically used to hold the original contractor responsible for the ultimate success of the vegetation. However, this is not necessarily the best or even the most cost effective method to ensure success. UDFCD will typically have the contractor perform initial efforts to vegetate the disturbed area. If these efforts turn out to be unsuccessful, UDFCD will work directly with a landscape specialist/contractor in an effort to reach adequate coverage of vegetation as quickly as possible.

- **Warranty Period Monitoring**: Warranty period monitoring of sites with substantial completion by early spring should begin in late May or early June to determine initial seedling establishment and composition and density of weed species. Monitoring in May can help determine a variety of conditions: whether seedling establishment is proceeding; whether the specified seed mix was in fact installed correctly at the proper rate; what the weed species are and when they are likely to require early summer mowing or later spot herbicide treatment; whether the bank protection measures are holding and establishing woody and herbaceous growth; whether the woody containerized vegetation appears to be healthy or in need of watering; and whether the trees and shrubs which were planted still appear to be the proper species as they leaf out. Evaluation of establishment at this time can sometimes lead to early corrective measures, such as reseeding of bare areas or rilling, mending or correcting poorly installed RECPs. Early growth of noxious biennial species which will flower in June or July should be noted and weed control efforts planned at this time.

  A second key warranty monitoring period typically occurs in August, when the area can again be checked for continued successful herbaceous establishment, woody vegetation survival and growth, and whether occasional watering and weed control efforts are being made. Plans can be made at this time for late season mowing and spot herbicide treatments, fall re-seeding and other corrective measures.

  Final warranty period inspection should occur at the end of warranty (1 year after substantial completion of construction and planting). At this time the site should be evaluated to determine if establishment meets the contract specification and plans. All temporary erosion control fencing, straw bales, tree protection or other temporary protective measures should be removed and disposed of offsite. Bare areas should be seeded with the seed mixture specified for that area in the plans.

- **Long-term Monitoring**: The next phase includes longer-term monitoring, typically by a revegetation specialist or wetland scientist with reporting to regulatory authorities. Monitoring methodologies may range from a quick visual inspection to an in-depth study of species composition, distribution, and density based on quantitative sampling techniques (Colorado Natural Areas Program 1998).

Representative issues that may need to be addressed during the course of post-construction monitoring include:

- Noxious weeds—weeds on the Colorado Noxious Weed A List should be noted and promptly and aggressively treated. Similarly, areas with infestations of Colorado Noxious Weed B or C List species with more than 10% cover should be promptly addressed; however, a tolerable range of what species can be present and/or the cover of an individual species can vary by state or local jurisdiction and by specific permitting requirements for an individual project. Using GPS to mark the locations of noxious weeds may be beneficial for short- and long-term monitoring.
- Browse damage (i.e., impacts from animals grazing on plants).
- Streambank or shoreline erosion.
- Irrigation needs or adjustments (irrigation is typically not needed for long-term maintenance of native areas).
- Replacement plantings.
- Water management in wetlands (if feasible).
- Removal of previously installed browse protection or temporary irrigation.

If animal damage or weed infestations appear to be significant issues, management plans can be prepared to address the problems over the long term.

9.0 Conclusion

Successful revegetation requires a multi-phase effort targeted to the relevant habitat condition. Drainage projects along the Front Range may encounter upland, riparian, and wetland habitat types, each having unique revegetation considerations. Successful revegetation projects will address proper site preparation, plant material selection and installation, mulching, maintenance and post-construction monitoring. Early involvement of a revegetation specialist can help improve the likelihood of a successful revegetation effort. Additionally, post-construction monitoring can help to identify problems that can be corrected while they are at a more manageable stage.

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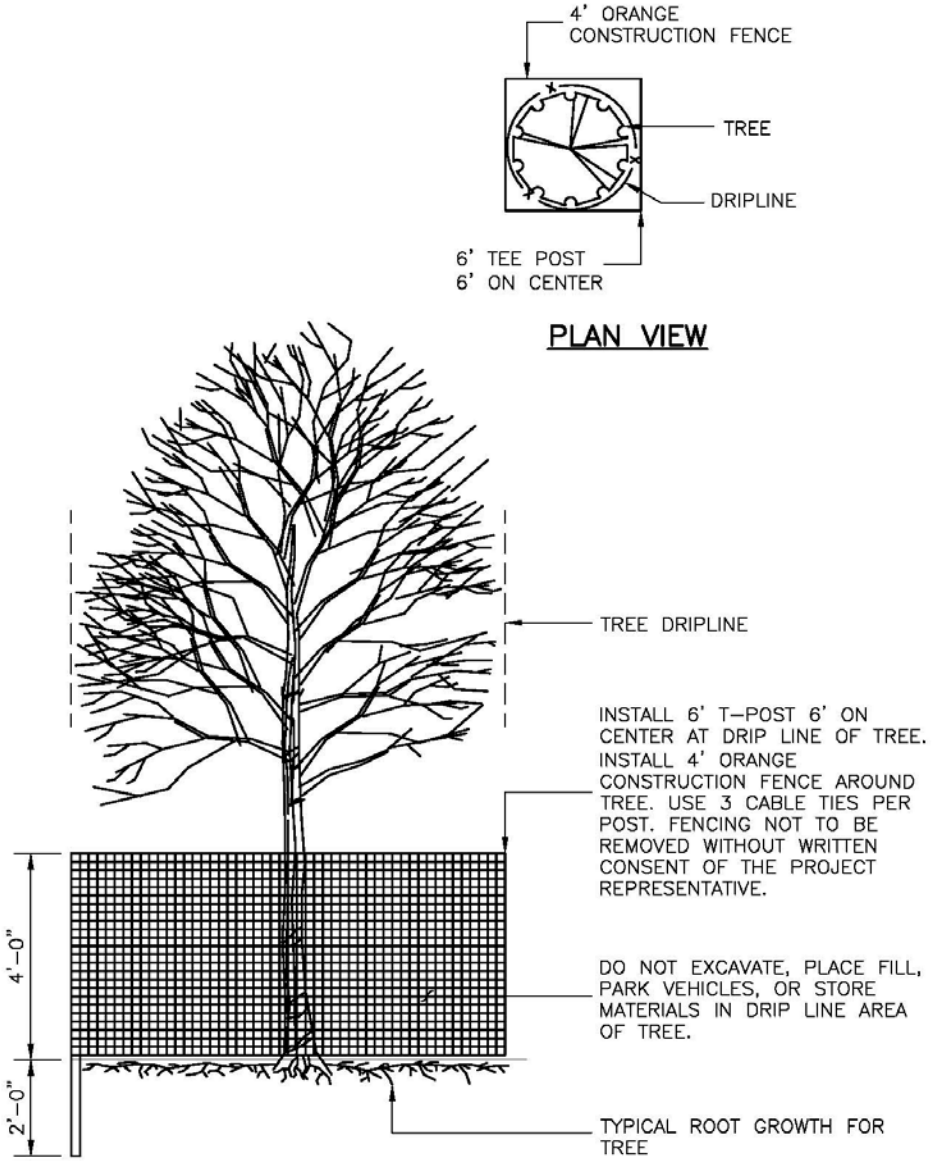
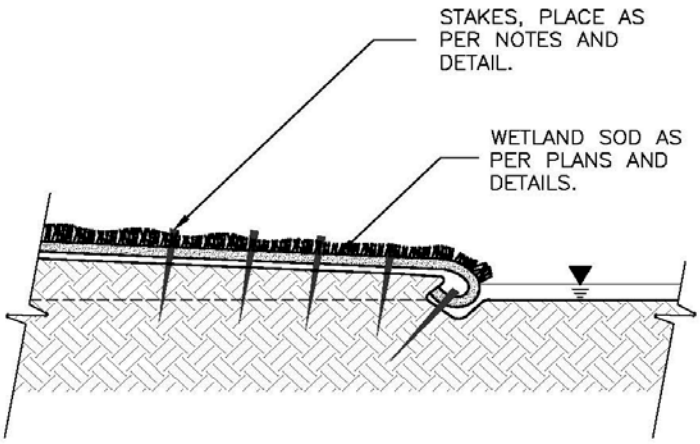
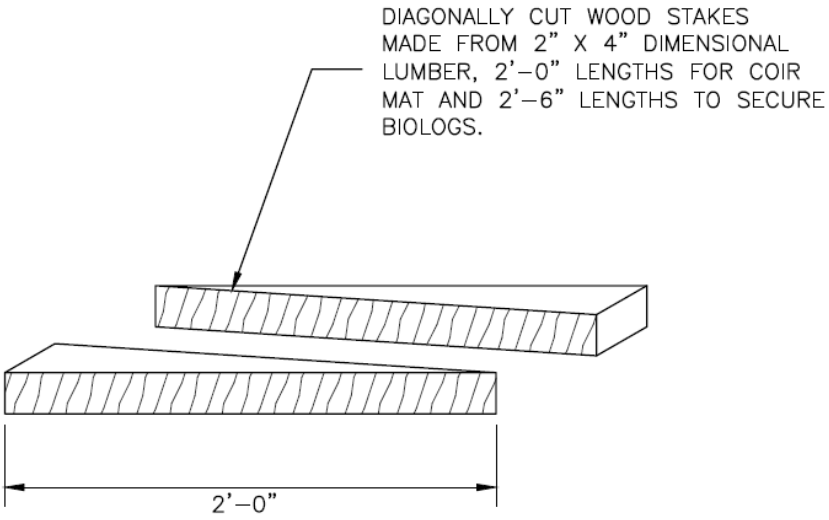


Figure 13-3. Tree protection

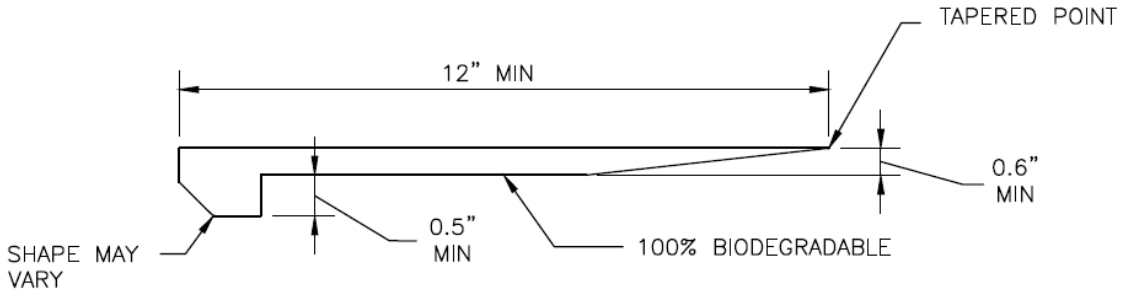


NOTES
1. KEEP ALL WETLAND SOD MOIST AND SHADED UNTIL INSTALLED.
2. FOLLOW FINAL GRADING AND TOPSOIL PLACEMENT.
3. INSTALL FABRIC (4M COIR MAT) AND ANY WILLOW LIVE STAKES PER PLAN.
4. APPLY WETLAND SOD AS SOON AS IT IS AVAILABLE FROM SUPPLIER.
5. ABUT EDGES OF SOD SECTIONS AND SECURELY PIN IN PLACE WITH 8" STEEL LANDSCAPE STAPLES IF NEEDED TO SECURE UNTIL STAKED.
6. STAKE SOD 18" O.C. ON ALL EDGES AND THROUGHOUT THE BODY OF SOD WITH WOODEN STAKES. LEAVE 2–3" OF THE STAKE SHOWING ABOVE THE MAT.
7. ANY PREVIOUS STAKES IN SOD AREA TO BE POUNDED DOWN TO SURFACE PRIOR TO SOD PLACEMENT AND STAKING.
8. IN BACKWATER AREAS AND OTHER AREAS (NOTED ON PLAN) WHERE VELOCITIES APPROACH ZERO, STAKES MAY NOT BE NECESSARY.

Figure 13-4. Wetland sod installation with staking

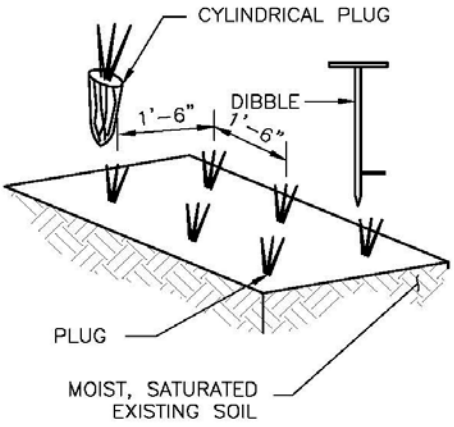


CUT WOOD



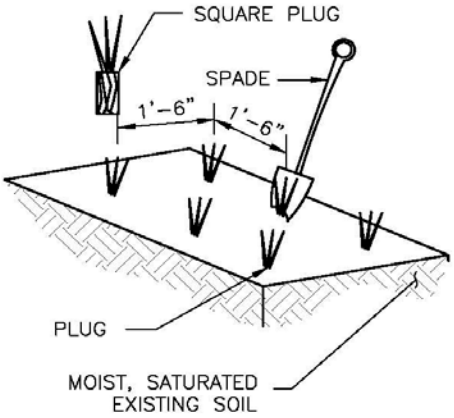
PROPRIETARY

Figure 13-5. Stakes



NOTES
1. DROP WOODEN DIBBLE STICK WITH APPROPRIATELY SIZED STEEL END INTO SOIL APPROXIMATELY 1'-6" FROM OTHER PLUGS.
2. STEP ON STEEL FOOT PLATE TO CREATE DEEPER HOLE. REMOVE DIBBLE STICK.
3. REMOVE WETLAND PLUG FROM CONTAINER AND PLANT ROOTS DOWN.
4. TAMP ON SOIL AROUND PLANT TO SECURE.

CYLINDRICAL CONTAINER PLUGS



NOTES
1. DROP SPADE INTO SOIL APPROXIMATELY 1'-6" FROM OTHER PLUGS.
2. STEP ON SPADE AND MOVE BACK AND FORTH TO CREATE AN OPEN POCKET LARGE ENOUGH FOR THE ROOT MASS TO BE INSTALLED FULLY WITHOUT HAVING TO BEND THE ROOTS.
3. REMOVE WETLAND PLUG FROM CONTAINER AND PLANT ROOTS DOWN SO THAT THE TOP OF THE ROOTS ARE JUST BELOW THE SOIL SURFACE IN THE HOLE.
4. TAMP ON SOIL AROUND PLANT TO SECURE.

SQUARE CONTAINER PLUGS

NOTES
1. UPON ARRIVAL CHECK THAT WETLAND PLUGS ARE HEALTHY, MOIST, AND FREE OF INJURIES OR INSECT DAMAGE.
2. KEEP WETLAND PLUGS MOIST AND SHADED BEFORE PLANTING.
3. SOILS SHOULD BE MOIST TO SATURATED BEFORE PLANTING.
4. WATER THE PLANTED AREA AFTER PLANTING IF NEEDED.
5. INSTALL WATERFOWL PREDATION CONTROL AS NEEDED.

Figure 13-6. Wetland plug planting

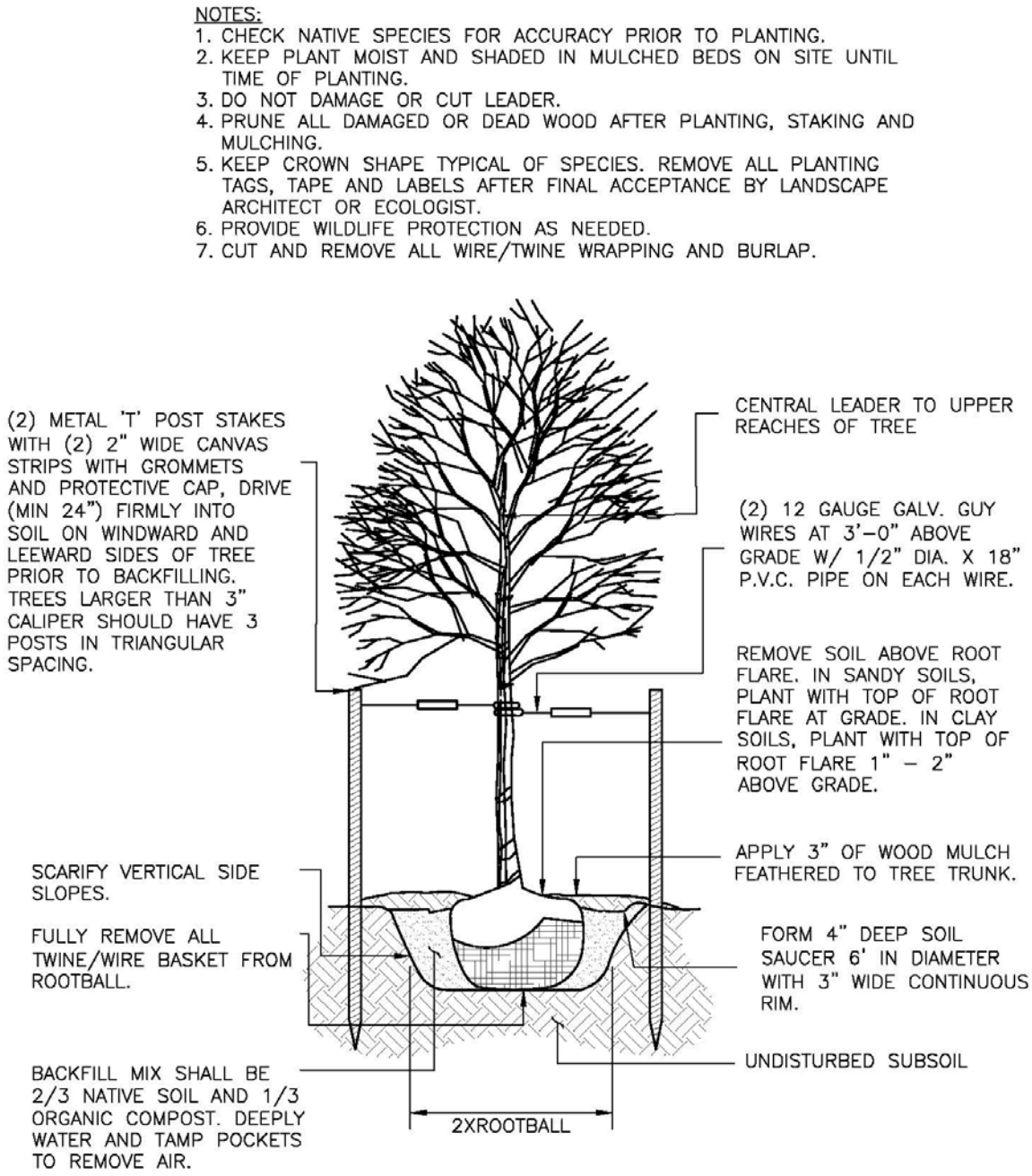


Figure 13-7. Deciduous tree planting

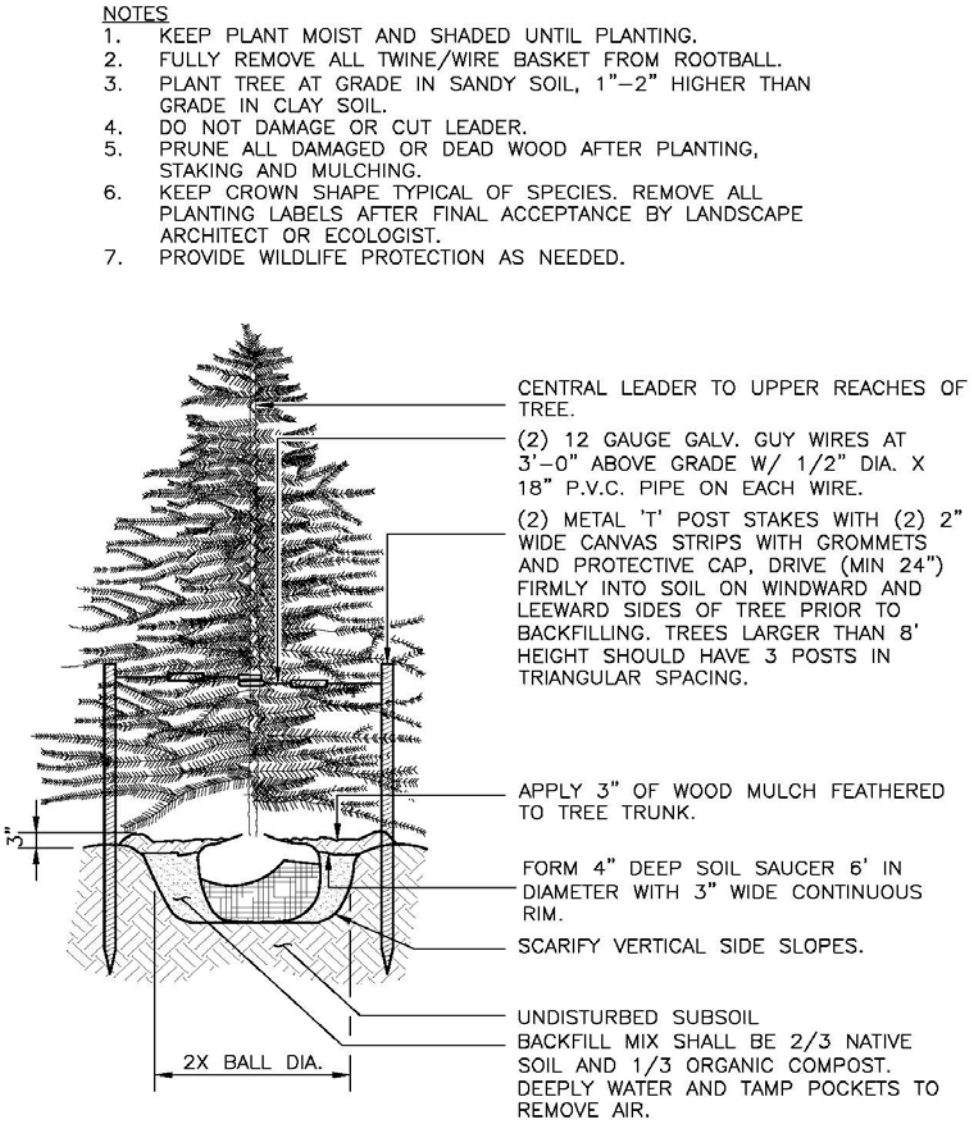


Figure 13-8. Upland evergreen tree planting

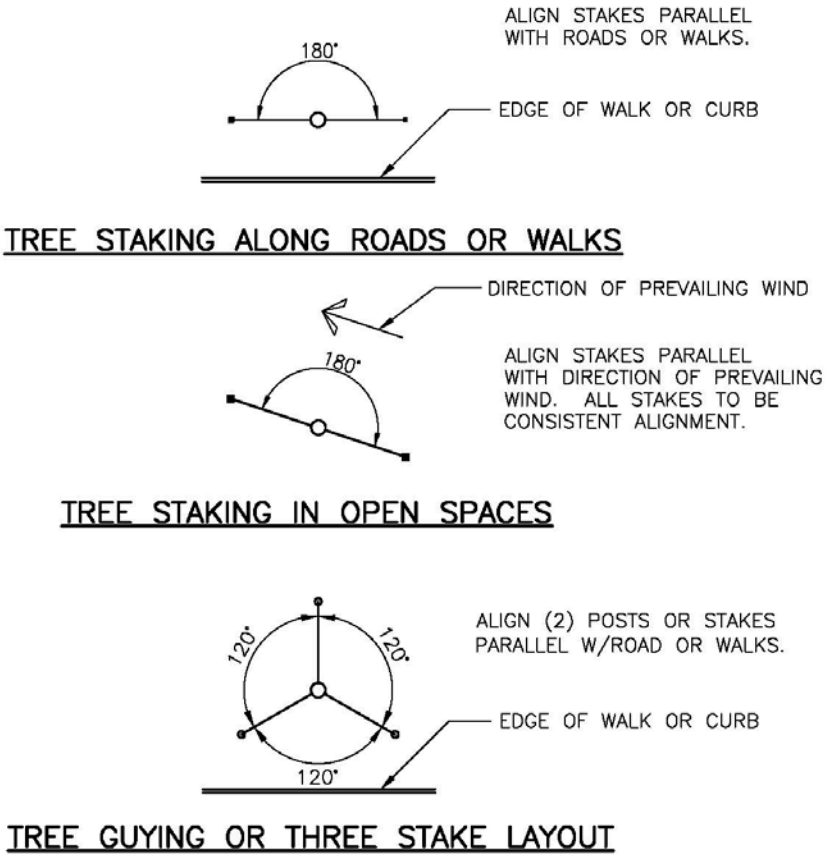


Figure 13-9. Tree stake layout

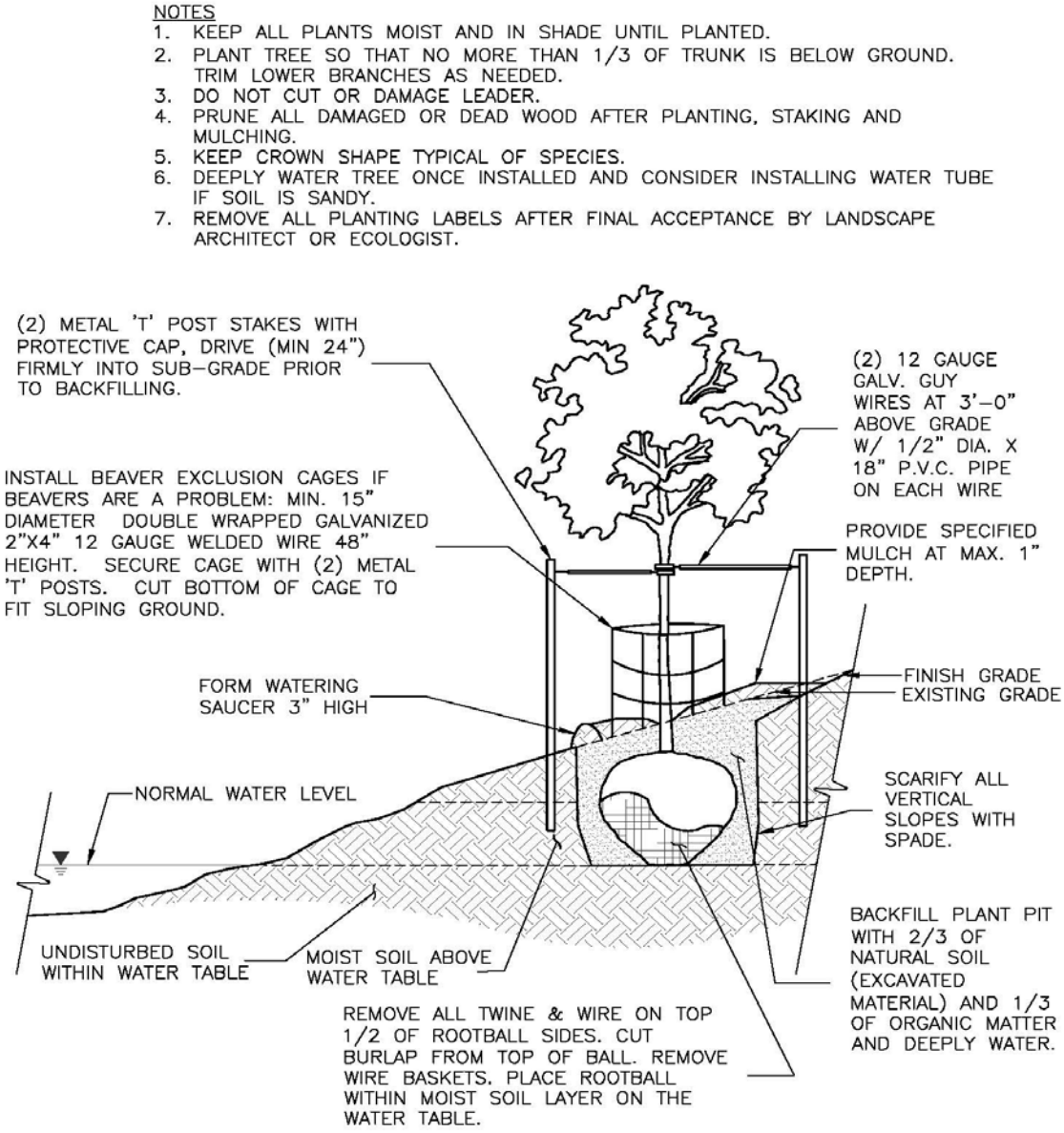


Figure 13-10. Deep tree planting for B&B cottonwood species

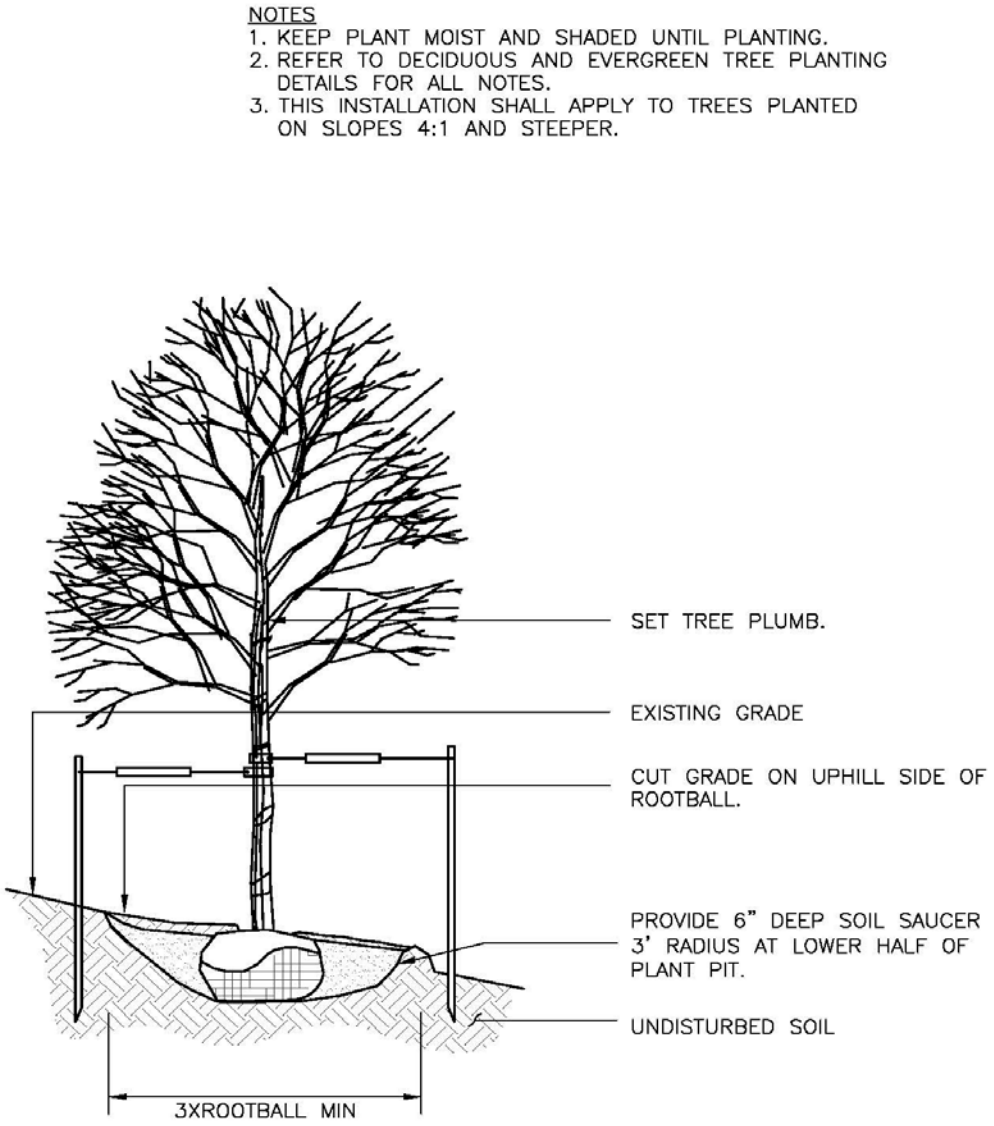


Figure 13-11. Tree planting on slope

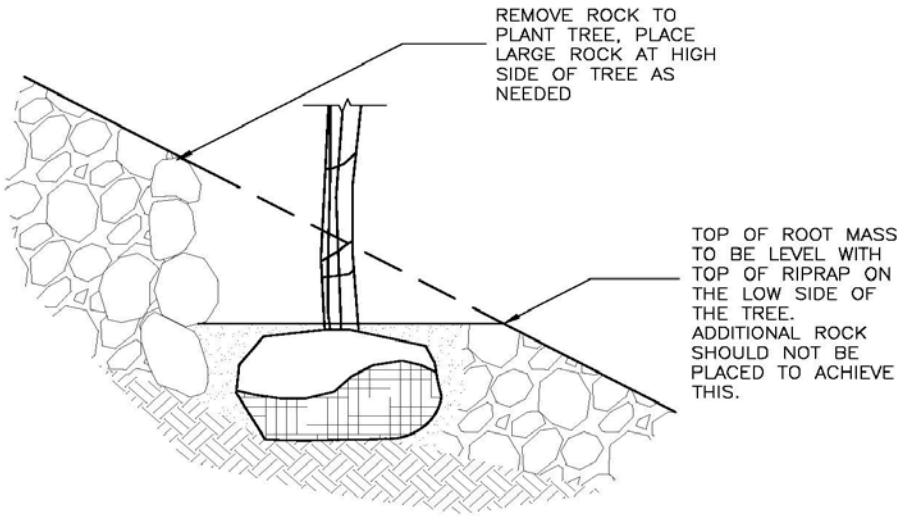


Figure 13-12. Tree planting on riprap slope

NOTES
1. KEEP PLANT MOIST AND SHADED UNTIL PLANTING.
2. FOR ROOT BOUND CONTAINER PLANTS, MAKE 4–5" DEEP VERTICAL CUTS INTO ROOT BALL EDGE AND PLANT IMMEDIATELY.
3. DO NOT CUT LEADER, PRUNE ALL DAMAGED OR DEAD WOOD AFTER PLANTING, STAKING AND MULCHING, KEEP CROWN SHAPE TYPICAL OF SPECIES, REMOVE ALL PLANTING LABELS AFTER FINAL ACCEPTANCE BY LANDSCAPE ARCHITECT OR ECOLOGIST.
4. PROVIDE WILDLIFE PROTECTION AROUND PLANTED SHRUB AS NEEDED.

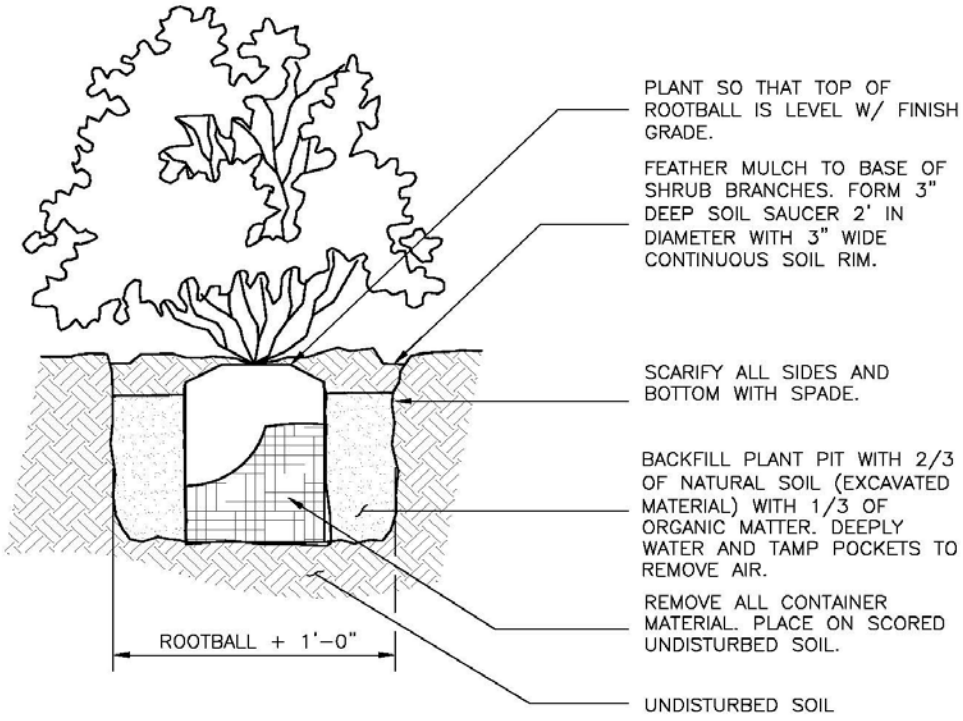
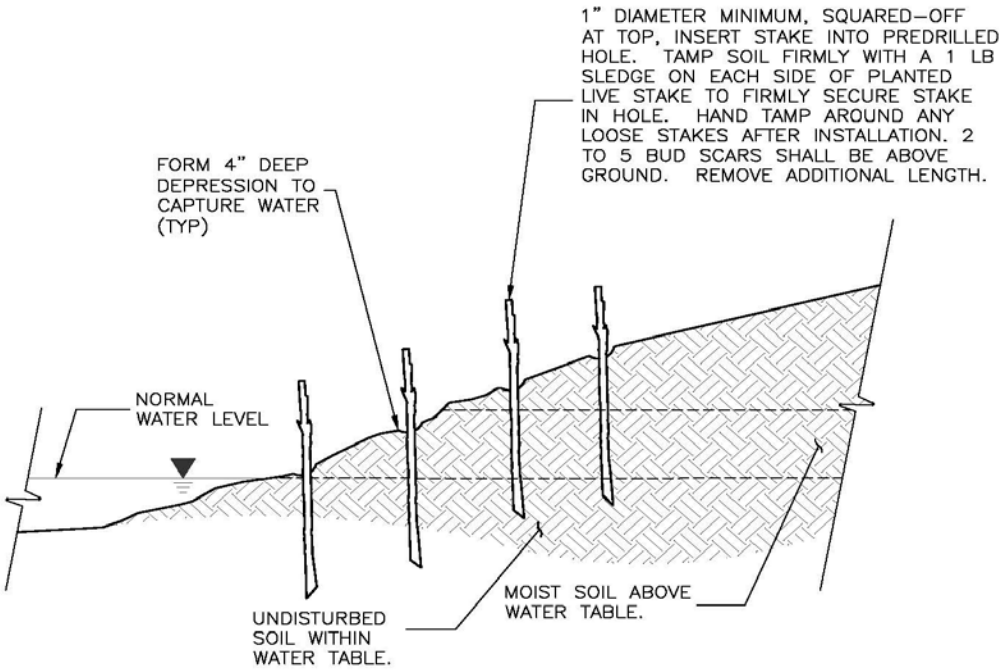


Figure 13-13. Shrub planting container



NOTES
1. HARVEST AND PLANT WILLOW LIVE STAKES DURING DORMANT SEASON
2. WILLOW STAKE SHALL HAVE CUT END ON AN ANGLE TO SIGNIFY PLANTING END.
3. USE HEALTHY, STRAIGHT, AND LIVE WOOD AT 2 TO 3 YEARS OLD.
4. MAKE CLEAN CUTS AND DO NOT DAMAGE STAKES OR SPLIT ENDS.
5. PLACE CUTTINGS IN WATER IMMEDIATELY AFTER HARVESTING.
6. SOAK CUTTINGS FOR 24 HOURS (MIN.) PRIOR TO INSTALLATION.
7. STORE CUT WILLOWS WITH LOWER ENDS IN WATER FOR NO LONGER THAN 7 DAYS BEFORE PLANTING.
8. LENGTH OF STAKES SHALL BE 2' (MIN.). PRE–DRILL HOLES WITH STEEL REBAR.
9. PLANT AT LEAST 3/4 LENGTH OF STAKE INTO MOIST SOIL.

Figure 13-14. Willow live stakes planting

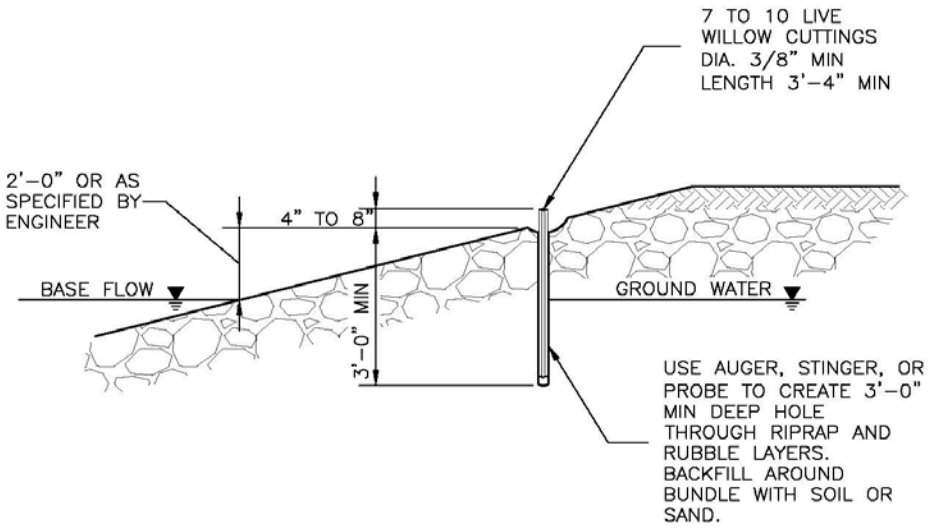


Figure 13-15. Willow bundle installation

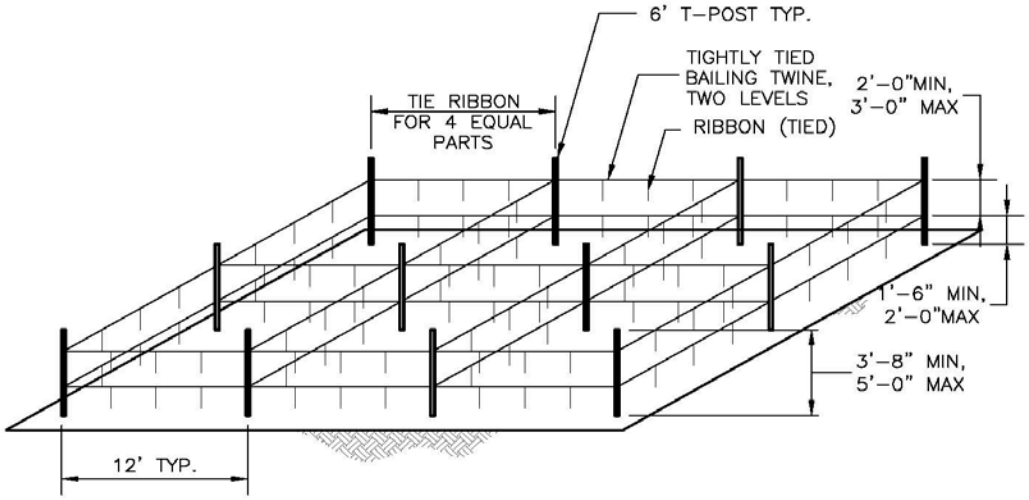


Figure 13-16. Waterfowl grazing control

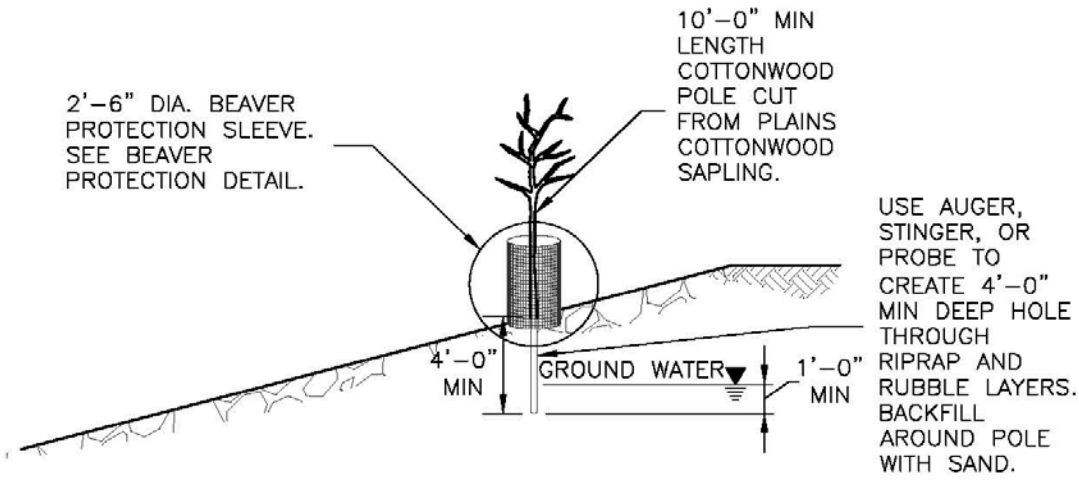


Figure 13-17. Cottonwood poling

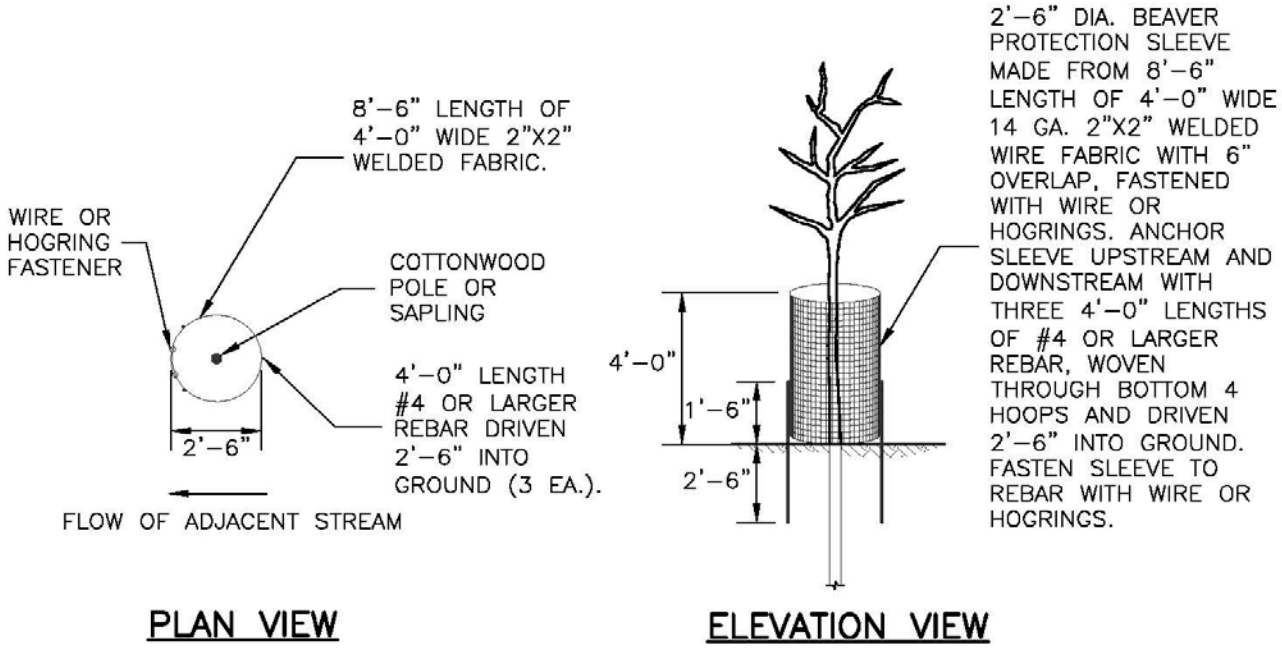


Figure 13-18. Beaver protection

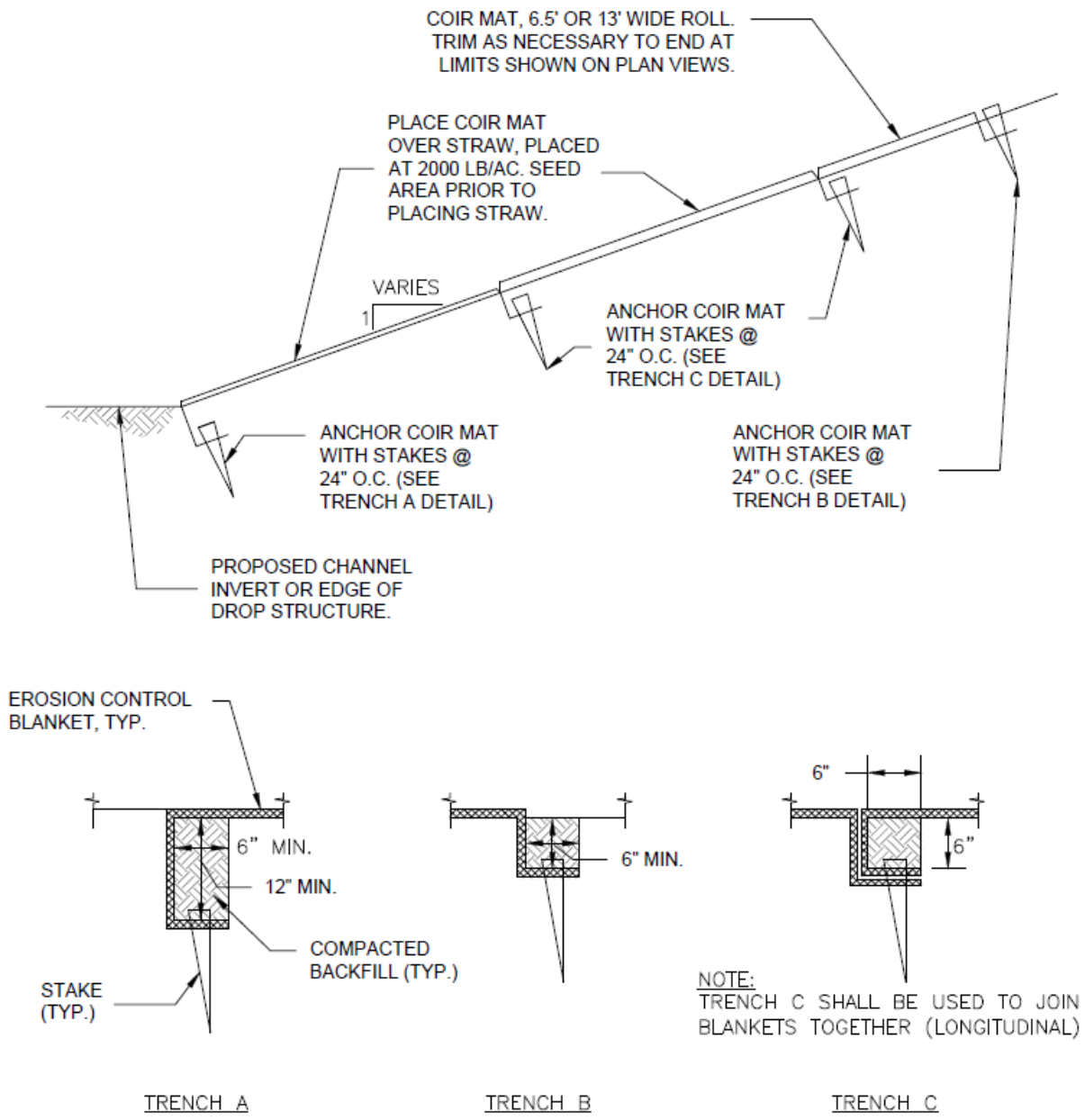


Figure 13-19. Coir mat placement and trenching detail

Appendix A. Seed Mix Tables

Upland Native Seed Mixes (drill seed rates)

Table A-1. Upland area seed mix – loamy to clay soils

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Grasses					
Blue grama	*Bouteloua gracilis*	Warm	Sod	25	1.8
Sand dropseed	*Sporobolus cryptandrus*	Warm	Bunch	20	0.2
Sideoats grama	*Bouteloua curtipendula*	Warm	Sod	20	6.3
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	15	8.2
Buffalograss	*Bouteloua dactyloides*	Warm	Sod	10	10.7
Inland saltgrass	*Distichlis spicata*	Warm	Sod	5	0.6
Herbaceous/Wildflowers					
Pasture sage	*Artemisia frigida*			1	0.01
Blanket flower	*Gaillardia aristata*			1	0.5
Prairie coneflower	*Ratibida columnifera*			1	0.1
Purple prairieclover	*Dalea (Petalostemum) purpurea*			1	0.3
Blue flax	*Linum lewisii*			1	0.4
TOTAL PLS POUNDS/ACRE				**100**	**29.11**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-2. Upland area seed mix – sandy soil

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Grasses					
Switchgrass	*Panicum virgatum*	Warm	Sod/Bunch	15	2.3
Prairie sandreed	*Calamovilfa longifolia*	Warm	Sod	10	2.2
Sideoats grama	*Bouteloua curtipendula*	Warm	Sod	10	3.1
Blue grama	*Bouteloua gracilis*	Warm	Sod	10	0.7
Indian ricegrass	*Oryzopsis hymenoides*	Cool	Bunch	10	4.3
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	5.5
Little bluestem	*Schizachyrium scoparium*	Warm	Bunch	10	2.3
Sand dropseed	*Sporobolus cryptandrus*	Warm	Bunch	10	0.1
Green needlegrass	*Stipa viridula*	Cool	Bunch	10	3.3
Herbaceous/Wildflowers					
Pasture sage	*Artemisia frigida*			1	0.1
Blanket flower	*Gaillardia aristata*			2	0.9
Tansy aster	*Maceranthera tanacetifolia*			2	0.2
TOTAL PLS POUNDS/ACRE				**100**	**25**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-3. Upland/transitional area seed mix – alkali soil

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Blue grama	*Bouteloua gracilis*	Warm	Sod	20	1.5
Sideoats grama	*Bouteloua curtipendula*	Warm	Sod	15	4.7
Slender wheatgrass	*Elymus trachycaulus*	Cool	Bunch	15	5.7
Alkali sacaton	*Sporobolus airoides*	Warm	Sod/Bunch	15	0.5
Inland saltgrass	*Distichlis spicata*	Warm	Sod	15	1.7
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	5.5
Sand dropseed	*Sporobolus cryptandrus*	Warm	Bunch	10	0.1
TOTAL PLS POUNDS/ACRE				**100**	**19.7**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Riparian Native Seed Mixes

Table A-4. Riparian seed mix – loamy to clay soils

(Recommended for middle to upper terraces and slopes above the 5-year flood elevations.)

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Grasses					
Blue grama	*Bouteloua gracilis*	Warm	Sod	20	1.5
Sand dropseed	*Sporobolus cryptandrus*	Warm	Bunch	20	0.2
Switchgrass	*Panicum virgatum*	Warm	Sod/Bunch	20	3.2
Sideoats grama	*Bouteloua curtipendula*	Warm	Sod	15	4.7
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	5.5
Green needlegrass	*Nasella viridula*	Cool	Bunch	10	3.3
Wildflowers					
Smooth aster	*Aster laevis*			1	0.1
Louisiana sage	*Artemisia ludovisciana*			1	0.1
Showy goldeneye	*Heliomeris multiflora (aka Viguiera)*			1	0.1
Blanket flower	*Gaillardia aristata*			1	0.5
Prairie coneflower	*Ratibida columnifera*			1	0.1
TOTAL POUNDS PLS/ACRE				**100**	**19.3**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-5. Riparian area seed mix – sandy soil

(Recommended for middle to upper terraces and slopes above 5-year flood elevations.)

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Sand dropseed	*Sporobolus*	Warm	Bunch	20	0.2
Switchgrass	*Panicum virgatum*	Warm	Sod/Bunch	20	3.1
Blue grama	*Bouteloua gracilis*	Warm	Sod	15	1.1
Canada wildrye	*Elymus canadensis*	Cool	Bunch	10	5.2
Sand bluestem	*Andropogon hallii*	Warm	Bunch	10	5.3
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	5.5
Yellow Indiangrass	*Sorghastrum nutans*	Warm	Sod	10	3.5
Wildflowers					
Blanket flower	*Gaillardia aristata*			1	0.5
Rocky Mountain	*Penstemon strictus*			1	0.1
Purple prairie clover	*Dalea purpurea*			1	0.3
Mexican hat	*Ratibida columnifera*			1	0.1
Western yarrow	*Achillea millefolium*			1	0.02
TOTAL PLS POUNDS/ACRE				**100**	**24.92**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-6. Riparian area seed mix – alkali soil

(Recommended for middle to upper terraces and slopes above the 5-year flood elevations.)

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Alkali sacaton	*Sporobolus airoides*	Warm	Bunch	25	0.9
Blue grama	*Bouteloua gracilis*	Warm	Sod	25	1.8
Inland saltgrass	*Distichlis spicata*	Warm	Sod	25	2.9
Streambank wheatgrass	*Elymus lanceolatus*	Cool	Sod	10	3.9
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	5.5
Buffalograss	*Bouteloua dactyloides*	Warm	Sod	5	5.4
TOTAL PLS POUNDS/ACRE				**100**	**20.4**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-7. Riparian/creek edge seed mix – moist to wet soils

(Recommended for riparian streambank/low terraces below the 5-year flood elevation.)

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Lb/ac (PLS[1])
Grasses					
Inland saltgrass	*Distichlis stricta*	Cool	Sod	15	1.7
Creeping spikerush	*Eleocharis palustris*	Cool	Sod	15	1.5
Baltic rush	*Juncus balticus*	Cool	Sod	15	0.1
Switchgrass	*Panicum virgatum*	Warm	Sod	12	1.9
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	8	4.4
Green needlegrass	*Nasella viridula*	Cool	Bunch	10	3.3
Prairie cordgrass	*Spartina pectinata*	Warm	Sod	10	3.1
Wooly sedge	*Carex lanuginosa*	Cool	Sod	5	1.0
Nebraska sedge	*Carex nebrascensis*	Cool	Sod	5	0.6
Wildflowers					
Wild Bergamot	*Monarda fistulosa*			1	0.1
Yarrow	*Achillea millefolium*			1	0.02
Blue vervain	*Verbena hastata*			2	0.1
Nuttall's sunflower	*Helianthus nuttallii*			1	0.2
TOTAL PLS POUNDS/ACRE					**18.02**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Wetland Native Seed Mixes

Table A-8. Wetland seed mix – loamy to sandy soils
(Recommended for detention ponds and less eroding wetland areas.)

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Wetland Indicator*	Lb/ac (PLS[1])
Grasses and Herbaceous Species						
American Sloughgrass	*Beckmannia syzigachne*	Cool	Sod	15	OBL	0.8
Prairie cordgrass	*Spartina pectinata*	Warm	Sod	15	FACW	4.6
Switchgrass	*Panicum virgatum*	Warm	Sod/Bunch	15	FAC	2.3
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	FACU	5.5
Fowl mannagrass	*Glyceria striata*	Cool	Sod	10	OBL	3.3
Hardstem bulrush	*Scirpus acutus*			10	OBL	1.6
Baltic rush	*Juncus balticus*			10	OBL	0.1
Creeping spikerush	*Eleocharis palustris*			10	OBL	1.0
Wildflowers						
Blue vervain	*Verbena hastata*			2.5	FACW	0.1
Nuttall's sunflower	*Helianthus nuttallii*			2.5	FAC	0.5
TOTAL PLS POUNDS/ACRE				**100**		**19.8**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-9. Wetland seed mix – clay and alkali soils
(Recommended for detention ponds and wetland areas.)

Common Name	Scientific Name	Growth Season	Growth Form	% Mix	Wetland Indicator*	Lb/ac (PLS[1]
Grasses and Herbaceous Species						
Alkali sacaton	*Sporobolus airoides*	Warm	Bunch	10	FAC	0.4
Inland saltgrass	*Distichlis spicata*	Warm	Sod	10	FACW	1.2
Nuttall's alkaligrass	*Puccinellia nuttalliana*	Cool	Bunch	10	OBL	0.2
Prairie cordgrass	*Spartina pectinata*	Warm	Sod	10	FACW	3.0
Slender wheatgrass	*Elymus trachycaulus spp.*	Cool	Bunch	10	FACU	3.8
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	10	FACU	5.5
Fowl mannagrass	*Glyceria striata*	Cool	Sod	10	OBL	3.3
Hardstem bulrush	*Scirpus acutus*			10	OBL	1.6
Baltic rush	*Juncus balticus*			10	OBL	0.1
Creeping spikerush	*Eleocharis palustris*			10	OBL	1.0
TOTAL PLS POUNDS/ACRE						**20.1**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Note: Wildflowers species not recommended for clay or alkali soils.

Wetland Indicator Key for Tables A-8 and A-9:

FAC = Facultative – Equally occurs in both wetlands and uplands.
FACU = Facultative Upland – Occurs mostly in uplands, but can occur in wetlands about 1/3 of the time.
FACW = Facultative Wetlands – Occurs mostly in wetlands, but can occur in uplands about 1/3 of the time.
OBL = Obligate Wetlands – Almost always occurs in wetlands.
UPL = Uplands – Almost always occurs in uplands.

Temporary Native Seed Mixes

Note: A sterile annual grass such as a wheat X wheatgrass hybrid may be used as temporary grass cover in areas that are likely to be disturbed again. A sterile annual cover crop is generally less expensive and quicker to establish than a temporary native grass seed mix. The native grass seed mixes as shown below offer an alternative to seeding with annual sterile grasses and can be used in areas where there may be limited future disturbance therefore warranting a temporary seed mix that can become permanent.

Table A-10. Upland area temporary seed mix – loamy to clay soils

Common Name	Scientific Name	Growth Season	Growth Form	% of Seed Mix	Lb/ac (PLS[1])
Slender wheatgrass	*Elymus trachycaulus spp.*	Cool	Bunch	20	5
Green needlegrass	*Nasella viridula*	Cool	Bunch	20	4.4
Western wheatgrass	*Pascopyrum smithii*	Cool	Sod	20	7.3
Arizona fescue	*Festuca arizonica*	Cool	Bunch	20	1.5
Sideoats grama	*Bouteloua curtipendula*	Warm	Bunch/Sod	20	4.2
TOTAL PLS POUNDS/ACRE				**100**	**22.4**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-11. Upland area temporary seed mix – sandy soil

Common Name	Scientific Name	Growth Season	Growth Form	% of Seed Mix	Lb/ac (PLS[1])
Sand lovegrass	*Eragrostis trichodes*	Warm	Bunch	20	0.5
Sand bluestem	*Andropogon hallii*	Warm	Sod	20	7.1
Prairie sandreed	*Calamovilfa longifolia*	Warm	Sod	15	2.2
Sand dropseed	*Sporobolus cryptandrus*	Warm	Bunch	15	0.1
Needle and Thread	*Hesperostipa comata spp. comata*	Cool	Bunch	15	5.2
Red three-awn	*Aristida purpurea var. longiseta*	Warm	Bunch	15	2
TOTAL PLS POUNDS/ACRE				**100**	**17.1**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-12. Upland area temporary seed mix –combination of soil types

Common Name	Scientific Name	Growth Season	Growth Form	% of Seed Mix	Lb/ac (PLS[1])
Slender wheatgrass	*Elymus trachycaulus spp.*	Cool	Bunch	25	6.3
Canada wildrye	*Elymus canadensis*	Cool	Bunch	15	5.2
Little bluestem	*Schizachyrium scoparium*	Warm	Bunch	15	2.3
Thickspike wheatgrass	*Elymus lanceolatus ssp. lanceolatus*	Cool	Sod	15	3.9
Sixweeks fescue	*Vulpia octoflora*	Cool	Annual/ Bunch	15	0.6
Bottlebrush squirreltail	*Elymus elymoides*	Cool	Bunch	15	3.1
TOTAL PLS POUNDS/ACRE				**100**	**21.4**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

Table A-13. Moist to wet area temporary seed mix – combination of soil types

Common Name	Scientific Name	Growth Season	Growth Form	% of Seed Mix	Lb/ac (PLS[1])
Streambank wheatgrass	*Elymus lanceolatus ssp. psammophilus*	Cool	Sod	20	5.1
Slender wheatgrass	*Elymus trachycaulus spp.*	Cool	Bunch	15	3.8
Switchgrass	*Panicum virgatum*	Warm	Sod/Bunch	15	1.5
American	*Beckmannia syzigachne*	Cool	Sod	15	0.5
Bluejoint reedgrass	*Calamagrostis canadensis*	Cool	Sod	15	0.3
Fowl mannagrass	*Glyceria striata*	Cool	Sod	10	2.2
Inland saltgrass	*Distichlis spicata*	Warm	Sod	10	0.8
TOTAL PLS POUNDS/ACRE				**100**	**14.2**

[1]PLS = Pure Live Seed – If broadcast seeding, double the rate

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3

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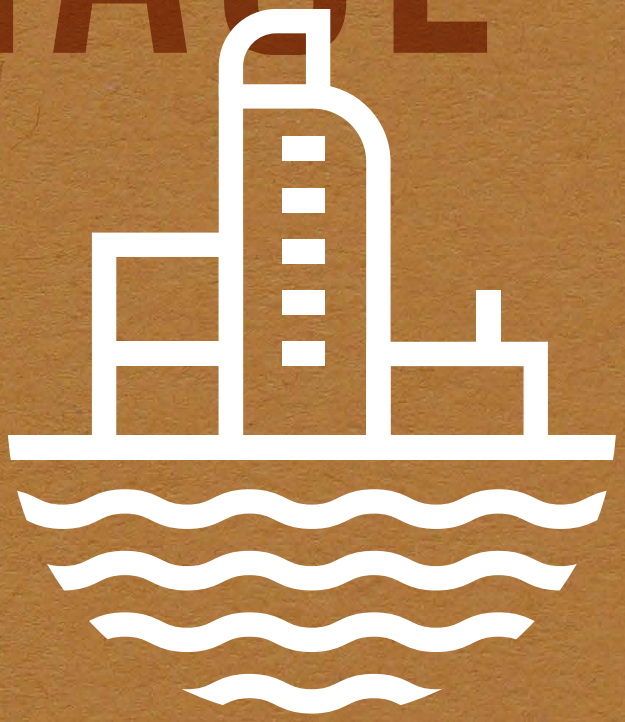

STORMWATER QUALITY

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Best Management Practices

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1.0 Acknowledgements

The Urban Storm Drainage Criteria Manual (USDCM), Volume 3, was first released in 1992 under the direction and leadership of Ben Urbonas, P.E., D.WRE. Although Mr. Urbonas retired from the Urban Drainage and Flood Control District (UDFCD) in 2008, he continued to serve as an advisor throughout the 2010 revision to Volume 3, for which we are grateful. This update builds upon the core philosophy, principles and practices developed by Mr. Urbonas and others in previous releases of Volume 3.

This revised and updated guidance manual is the product of an 18-month long process that included a large stakeholder committee, a technical advisory committee, and several core groups of experts in various aspects of stormwater management. These engineers, stormwater coordinators, planners and regulators represented government at every level during this process. Stormwater and land development professionals, as well as consulting engineers and landscape architects throughout Colorado also provided valuable input. UDFCD wishes to acknowledge and to thank all individuals and organizations that contributed to the development of this manual. The list of contributors is too long to acknowledge and thank everyone individually, for which we apologize.

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2.0 Purpose

Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM) is designed to provide guidance for engineers, planners, landscape architects, developers, and Municipal Separate Storm Sewer System (MS4) permit holders in selecting designing, maintaining, and carrying out best management practices (BMPs) to minimize water quality and quantity impacts from stormwater runoff. Whereas Volumes 1 and 2 of this manual focus primarily on stormwater quantity management for drainage and flood control purposes, Volume 3 focuses on smaller, more frequently occurring events that have the greatest overall impact on the quality of receiving waters.

3.0 Overview

This manual is organized according to these topics:

- **Chapter 1: Stormwater Management and Planning.** In order to effectively design stormwater quality BMPs, it is important to understand the impacts of urbanization on receiving waters, as well as to understand the federal and state regulatory requirements under the Clean Water Act. Chapter 1 provides basic information on these topics and introduces UDFCD's approach to reducing the impacts of urban runoff through implementation of a holistic Four Step Process (see inset below). UDFCD continues to emphasize the importance of implementing all four steps in this process. Chapter 1 provides expanded guidance on Step 1 (Runoff Reduction), which has historically been implemented only minimally, but will be increasingly important to comply with new federal regulations and state stormwater discharge permits.

The Four-Step Process for Stormwater Quality Management

Step 1 Employ Runoff Reduction Practices: To reduce runoff peaks, volumes, and pollutant loads from urbanizing areas, implement Low Impact Development (LID) strategies, including measures to "minimize directly connected impervious areas" (MDCIA). These practices reduce unnecessary impervious areas and route runoff from impervious surfaces over permeable areas to slow runoff (increase time of concentration) and promote onsite storage and infiltration.

Step 2 Implement BMPs that Provide a Water Quality Capture Volume (WQCV) with Slow Release: After runoff has been reduced, the remaining runoff must be treated through capture and slow release of the WQCV. WQCV facilities may provide both water quality and runoff reduction benefits, depending on the BMP selected. This manual provides design guidance for BMPs providing treatment of the WQCV.

Step 3 Stabilize Drainageways: During and following urban development, natural drainageways are often subject to bed and bank erosion due to increases in the frequency, rate, duration, and volume of runoff. Although Steps 1 and 2 help to minimize these effects, some degree of drainageway stabilization is required. Many drainageways within UDFCD boundaries are included in major drainageway or outfall systems plans, identifying recommended channel stabilization measures. If this can be done early, it is far more likely that natural drainageway functions can be maintained with the addition of grade control to accommodate future development. It is also less costly to stabilize a relatively stable drainageway rather than to repair an unraveled channel.

Step 4 Implement Site Specific and Other Source Control BMPs: Frequently, site-specific needs or operations require source control BMPs. This refers to implementation of both structural and procedural BMPs.

- **Chapter 2: BMP Selection.** Long-term effectiveness of BMPs depends not only on proper engineering design, but also on selecting the right combination of BMPs for the site conditions. In addition to physical factors, other factors such as life cycle costs and long-term maintenance requirements are also important considerations for BMP selection. This chapter provides information to aid in BMP selection and provides the foundation for the *UD-BMP* and *BMP-REALCOST* design aid tools that accompany this manual.

- **Chapter 3: Calculation the WQCV and Volume Reduction.** Chapter 3 provides the computational procedures necessary to calculate the WQCV, forming the basis for design of many treatment BMPs. This chapter also covers the Excess Urban Runoff Volume (EURV) and full spectrum detention, developed to best replicate predevelopment peak flows. Additionally, procedures for quantifying runoff reduction due to the implementation of practices that reduce the effective imperviousness of the site are also provided. These procedures provide incentive to implement MDCIA practices and LID strategies.

- **Chapter 4: Treatment BMPs.** Chapter 4 provides design criteria for a variety of BMPs, generally categorized as conveyance practices and storage practices that provide treatment of the WQCV or EURV. A BMP Fact Sheet is provided for each BMP, providing step-by-step design criteria, design details, an accompanying design worksheet, and selection guidance related to factors such as performance expectations, site conditions and maintenance requirements.

- **Chapter 5: Source Control BMPs.** It is generally more effective to prevent pollutants from coming into contact with precipitation and/or from being transported in urban runoff than it is to remove these pollutants downstream. For this reason, guidance is provided on a variety of source control BMPs, which can be particularly beneficial for municipal operations and at industrial and commercial sites. Source controls and good housekeeping practices are also required under MS4 permits.

- **Chapter 6: BMP Maintenance.** Long-term effectiveness and safety of BMPs is dependent on both routine maintenance and periodic rehabilitation. Maintenance recommendations are provided for each post-construction treatment BMP in this manual.

- **Chapter 7: Construction BMPs.** Many different types of BMPs are available for use during construction. This chapter provides design details and guidance for appropriate use of these temporary BMPs.

Volume 3 BMPs

Treatment BMPs

Grass Swale
Grass Buffer
Bioretention/Rain Garden*
Green Roof
Extended Detention Basin
Retention Pond
Sand Filter
Constructed Wetland Pond
Constructed Wetland Channel
Permeable Pavement Systems
Underground BMPs

Source Control BMPs

Covering Outdoor Storage & Handling Areas
Spill Prevention, Containment and Control
Disposal of Household Waste
Illicit Discharge Controls
Good Housekeeping
Preventative Maintenance
Vehicle Maintenance, Fueling & Storage
Use of Pesticides, Herbicides and Fertilizers
Landscape Maintenance
Snow and Ice Management
Street Sweeping and Cleaning
Storm Sewer System Cleaning

**Referred to as Porous Landscape Detention in Previous Releases of Volume 3*

- **Glossary:** A glossary is included to provide users of Volume 3 with a basic understanding of terms used in this manual.

- **Bibliography:** Many references have been used to develop this Manual. The Bibliography provides a listing of these references for more detailed information on key topics.

4.0 Revisions to USDCM Volume 3

Volume 3 of the USDCM has been updated and expanded several times since it was first published in 1992 as our understanding of urban hydrology and BMP performance expanded, and as the design of various BMPs has been refined. Updates will continue as the needs of communities and regulatory requirements change, and as UDFCD continues to build, use, and monitor BMPs. In 2010, this major revision to Volume 3 was completed, including the following:

- Increased emphasis on runoff reduction, which is Step 1 of the Four Step Process. Although UDFCD has previously included runoff reduction as the first step in stormwater management, this step has not been routinely implemented. A significant change to the manual includes quantifying stormwater management facility sizing credits using quantitative methods when MDCIA and LID practices are implemented.

- Substantial revision to design criteria for several BMPs already in this manual and inclusion of BMPs not previously in this manual. Green roofs and Underground BMPs were added. Although UDFCD continues to strongly recommend treatment of runoff above ground, we also recognize the need to provide guidance related to underground BMPs when surface treatment is not practicable.

- Revision and expansion of the Construction BMPs chapter.

- Addition of supplemental guidance to promote more effective implementation of BMPs. This information is typically provided in the form of "call-out" boxes. While this manual remains focused on engineering design criteria, UDFCD also recognizes that it is helpful for designers to be aware of why certain criteria have been developed, how various practices can best be implemented on a site, opportunities to consider, and common problems to avoid.

- New Excel® worksheets to assist in BMP selection based on site-specific conditions, BMP design including integration of the EURV for use with full spectrum detention, and BMP performance expectations and life cycle costs.

5.0 Acronyms and Abbreviations

>	Greater Than
<	Less Than
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BOD	Biochemical Oxygen Demand
BMPs	Best Management Practices
CDPHE	Colorado Department of Public Health and Environment
CDPS	Colorado Discharge Permit System
cfs	Cubic Feet Per Second
COD	Chemical Oxygen Demand
CRS	Colorado Revised Statutes
CSO	Combined Sewer Overflow
CUHP	Colorado Urban Hydrograph Procedure
CWC	Constructed Wetland Channel
CWCB	Colorado Water Conservation Board
CWQCC	Colorado Water Quality Control Commission
CWQCD	Colorado Water Quality Control Division
DCIA	Directly Connected Impervious Areas
DO	Dissolved Oxygen
DRCOG	Denver Regional Council of Governments
DRURP	Denver Regional Urban Runoff Program
EDB	Extended Detention Basin
EMC	Event Mean Concentration
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
EURV	Excess Urban Runoff Volume

fps	Feet per second
ft	Feet
FHWA	Federal Highway Administration
GB	Grass Buffer
GS	Grass Swale
H:V	Horizontal to Vertical Ratio of a Slope
HSG	Hydrologic Soil Group
i	Impervious Ratio of a Catchment (I_a/100)
I_a	Percent Imperviousness of Catchment
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
MCM	Minimum Control Measure
mg/L	Milligrams per Liter
µg/L	Micrograms per Liter
MDCIA	Minimize Directly Connected Impervious Areas
MS4	Municipal Separate Storm Sewer System
MSDS	Material Safety Data Sheets
MWCOG	Metropolitan Washington Council of Governments
N/A	Not applicable
NPDES	National Pollution Discharge Elimination System
NPV	Net Present Value
NRCS	Natural Resources Conservation Services
NTIS	National Technical Information Service
NTU	Nephelometric turbidity units
NURP	Nationwide Urban Runoff Program
NVDPC	Northern Virginia District Planning Commission
PA	Porous Asphalt

PC	Pervious Concrete
PICP	Permeable Interlocking Concrete Pavers
PLD	Porous Landscape Detention *(term replaced by Bioretention in 2010 update)*
PPS	Pervious Pavement System
ppm	Parts Per Million
RP	Retention Pond
RPA	Receiving Pervious Area
SCS	Soil Conservation Service (now the NRCS)
SEWRPC	Southeastern Wisconsin Regional Planning Commission
SF	Sand Filter Extended Detention
SPA	Separate Pervious Area
SWMM	Stormwater Management Model (EPA)
TOC	Total Organic Carbon
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
UDFCD	Urban Drainage and Flood Control District
UIA	Unconnected Impervious Area
USCC	United States Composting Council
USDCM	Urban Storm Drainage Criteria Manual
USGS	United States Geological Survey
WERF	Water Environment Research Foundation
WQCV	Water Quality Capture Volume

Chapter 1
Stormwater Management and Planning

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1.0 Introduction

The physical and chemical characteristics of stormwater runoff change as urbanization occurs, requiring comprehensive planning and management to reduce adverse effects on receiving waters. As stormwater flows across roads, rooftops, and other hard surfaces, pollutants are picked up and then discharged to streams and lakes. Additionally, the increased frequency, flow rate, duration, and volume of stormwater discharges due to urbanization can result in the scouring of rivers and streams, degrading the physical integrity of aquatic habitats, stream function, and overall water quality (EPA 2009). This chapter provides information fundamental to effective stormwater quality management and planning, including:

- An overview of the potential adverse impacts of urban stormwater runoff.
- A summary of key regulatory requirements for stormwater management in Colorado. These regulations set the minimum requirements for stormwater quality management. It is essential that those involved with stormwater management understand these requirements that shape stormwater management decisions at the construction and post-construction stages of development and redevelopment.
- UDFCD's Four Step Process to reduce the impacts of urban runoff.
- Discussion of on-site, sub-regional, and regional stormwater management alternatives at a planning level.

UDFCD highly recommends that engineers and planners begin the development process with a clear understanding of the seriousness of stormwater quality management from regulatory and environmental perspectives, and implement a holistic planning process that incorporates water quality upfront in the overall site development process. Chapters 2 and 3 provide BMP selection tools and detailed calculation procedures based on the concepts introduced in this chapter.

2.0 Urban Stormwater Characteristics

Numerous studies conducted since the late 1970s show stormwater runoff from urban and industrial areas can be a significant source of pollution (EPA 1983; Driscoll et al. 1990; Pitt et al. 2008). Stormwater impacts can occur during both the construction and post-construction phases of development. As a result, federal, state, and local regulations have been promulgated to address stormwater quality. Although historical focus of stormwater management was either flooding or chemical water quality, more recently, the hydrologic and hydraulic (physical) changes in watersheds associated with urbanization are recognized as significant contributors to receiving water degradation. Whereas only a few runoff events per year may occur prior to development, many runoff events per year may occur after urbanization (Urbonas et al. 1989). In the absence of controls, runoff peaks and volumes increase due to urbanization. This increased runoff is environmentally harmful, causing erosion in receiving streams and generating greater pollutant loading downstream. Figure 1-1 illustrates the many physical factors associated with stormwater runoff and the responses of receiving waters.

With regard to chemical water quality, Table 1-1 identifies a variety of pollutants and sources often found in urban settings such as solids, nutrients, pathogens, dissolved oxygen demands, metals, and oils. Several national data sources are available characterizing the chemical quality of urban runoff (e.g., EPA 1983; Pitt 2004). For purposes of this manual, Denver metro area data are the primary focus. In 1983, the Denver Regional Urban Runoff Program (DRURP) conducted by the Denver Regional Council of Governments (DRCOG), provided data for nine watersheds with various land uses for 15 constituents of

concern and for U.S. Environmental Protection Agency (EPA) "Priority Pollutants." In 1992, additional urban stormwater monitoring was completed by UDFCD in support of the Stormwater National Pollutant Discharge Elimination System (NPDES) Part 2 Permit Application Joint Appendix (City of Aurora et al. 1992) for the Denver area communities affected by the Phase I stormwater regulation. Table 1-2 contains a summary of the results of these monitoring efforts, followed by a discussion of key findings from the DRURP study and other research since that time.

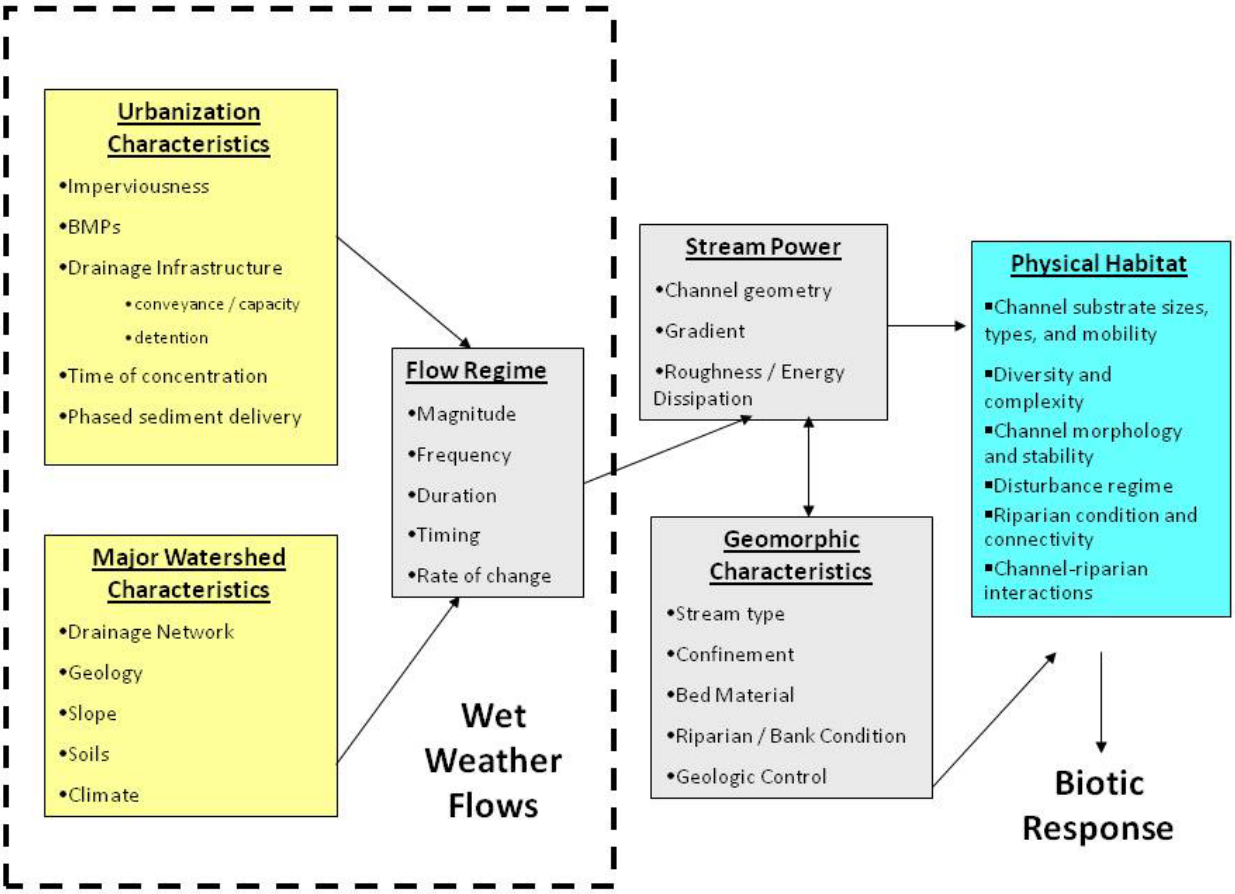

Figure 1-1. Physical effects of urbanization on streams and habitat

(Source: Roesner, L. A. and B. P. Bledsoe. 2003. *Physical Effects of Wet Weather Flows on Aquatic Habitats*. Water Environment Research Foundation: Alexandria, VA. Co-published by IA Publishing: United Kingdom.)

Table 1-1. Common urban runoff pollutant sources

(Adapted form: Horner, R.R., J.J. Skupien, E.H. Livingston and H.E. Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Intuitional Issues*. Washington, DC: Terrene Institute and EPA.)

Pollutant Category Source	Solids	Nutrients	Pathogens	Dissolved Oxygen Demands	Metals	Oils	Synthetic Organics
Soil erosion	X	X		X	X		
Cleared vegetation	X	X		X			
Fertilizers		X	X	X			
Human waste	X	X	X	X			
Animal waste	X	X	X	X			
Vehicle fuels and fluids	X			X	X	X	X
Fuel combustion						X	
Vehicle wear	X			X	X		
Industrial and household chemicals	X	X		X	X	X	X
Industrial processes	X	X		X	X	X	X
Paints and preservatives					X	X	X
Pesticides				X	X	X	X
Stormwater facilities w/o proper maintenance[1]	X	X	X	X	X	X	X

Table 1-2. Event mean concentrations of constituents in Denver metropolitan area runoff
(based on Denver metropolitan area data collected as part of the Colorado Regulation 85 Nutrient Data Gap Analysis Report, 2013)

	Commercial			Residential			Industrial			Natural Grassland		
Analyte	**n**	**Mean (95% CIs)**	**Median (95% CIs)**	**n**	**Mean (95% CIs)**	**Median (95% CIs)**	**n**	**Mean (95% CIs)**	**Median (95% CIs)**	**n**	**Mean (95% CIs)**	**Median (95% CIs)**
Total Nitrogen (mg/L)	246	3.70 (3.33-4.06)	2.92 (2.75-3.20)	204	4.74 (4.34-5.13)	3.86 (3.59-4.40)	9	4.35 (2.58-6.12)	3.60 (1.20-5.70)	7	3.40 (1.90-4.90)	3.76 (1.49-4.11)
Total Kjeldahl Nitrogen (mg/L)	250	2.80 (2.50-3.09)	2.20 (2.03-2.40)	192	3.33 (3.00-3.66)	2.70 (2.47-3.00)	20	3.12 (2.29-3.95)	2.97 (2.01-4.2)	7	2.88 (1.56-4.21)	3.10 (1.30-3.26)
Nitrate Plus Nitrite (mg/L)	253	0.89 (0.79-0.99)	0.72 (0.63-0.78)	238	1.02 (0.91-1.12)	0.81 (0.76-0.94)	9	1.23 (0.78-1.68)	1.00 (0.30-1.60)	7	0.52 (0.23-0.80)	0.56 (0.09-0.66)
Phosphorus as P, Total (mg/L)	273	0.35 (0.29-0.42)	0.19 (0.17-0.24)	254	0.52 (0.48-0.57)	0.42 (0.38-0.46)	21	0.42 (0.27-0.58)	0.30 (0.17-0.41)	7	0.41 (0.25-0.58)	0.41 (0.21-0.53)
Phosphorus as P, Dissolved (mg/L)	192	0.13 (0.10-0.15)	0.07 (0.05-0.08)	233	0.24 (0.22-0.27)	0.19 (0.17-0.20)	9	0.34 (0.13-0.54)	0.18 (0.10-0.52)	7	0.13 (0.08-0.18)	0.15 (0.07-0.17)
Phosphorus, Ortho-P (mg/L)	136	0.15 (0.10-0.20)	0.06 (0.06-0.08)	97	0.22 (0.16-0.27)	0.15 (0.13-0.18)		NA	NA	7	0.13 (0.08-0.18)	0.12 (0.07-0.13)
TSS (mg/L)	280	219 (173-265)	85 (63-125)	270	221 (185-256)	122 (103-143)	9	502 (240-764)	370 (126-540)	7	397 (166-627)	257 (194-464)
TDS (mg/L)	9	149 (81-217)	117 (33-214)	7	146 (46-245)	95 (60-126)	9	84 (52-117)	75 (30-102)		NA	NA
COD (mg/L)	156	187 (159-215)	139 (114-162)	140	120 (105-136)	93 (80-108)		NA	NA	7	72 (51-94)	71 (42-71)
DOC (mg/L)	51	35 (24-45)	22 (17-34)	55	17 (13-21)	12 (10-14)		NA	NA	7	16 (6-27)	12 (9-12)
TOC (mg/L)	156	36 (28-44)	21 (18-27)	80	27 (23-31)	21 (18-25)	9	66 (48-84)	57 (24-82)	7	26 (11-42)	23 (13-23)
Cadmium, Total (ug/L)	147	NP	NP	119	NP	NP	9	NP	NP		NA	NA
Copper, Total (ug/L)	249	27 (20-34)	13 (12-16)	182	22 (19-25)	15 (11-20)	9	86 (31-141)	46 (39-86)	7	37 (-0.1-74)	20 (10-60)
Lead, Total (ug/L)	209	13 (10-16)	5 (5-6)	126	14 (11-17)	8 (5-10)	9	205 (3-408)	120 (63-160)		NA	NA
Zinc, Total (ug/L)	251	156 (120-192)	64 (55-80)	181	115 (99-131)	80 (68-110)	9	760 (280-1240)	520 (340-620)	7	101 (56-147)	90 (40-120)

Monitoring locations limited to Denver Metro area. 1980's lead data excluded from summary due to the phase-out of leaded gasoline.
CI = 95% confidence interval provided for mean and median values. n = number of samples. NP = Not provided due to large percentage of non-detects.

Selected findings of DRURP include:

- Urban runoff was identified as a significant source of stormwater pollutants including sediment, fecal indicator bacteria, nutrients, organic matter, and heavy metals (e.g., lead, zinc, cadmium). Sediment loading occurred regardless of the existence of major land disturbances causing erosion. In addition, nutrients from urban runoff were identified as a concern for lakes and reservoirs.

- Very few EPA Priority Pollutants were detected in runoff samples. Organic pollutants found were particularly sparse; the most commonly occurring was a pesticide. The most significant non-priority pollutant found was 2,4-D, which is an herbicide.

- Pollutant loading was not closely related to basin imperviousness or land use. Vague relationships between event mean concentrations and imperviousness were noted, but proved statistically insignificant. Concentrations of pollutants did not vary in a predictable or anticipated pattern.

- Non-storm urban runoff (e.g., dry weather discharges such as irrigation runoff) was also identified as a source of pollutants. This was not expected and was determined indirectly in the study analysis.

In addition to these pollutants, Urbonas and Doerfer (2003) have reported that atmospheric fallout is a significant contributor to urban runoff pollution in the Denver area. Snow and ice management activities also affect the quality of urban runoff since snow and ice may be contaminated by hydrocarbons, pet waste, deicing chemicals and sand.

Although Table 1-2 indicates that constituent concentrations in urban runoff in the metro Denver area are not necessarily greater than that for natural grasslands (background) for some constituents (e.g., TSS, TDS, TKN), it is important to recognize that the table does not provide data on pollutant loads, which are the product of runoff volume and pollutant concentrations. Runoff volume from urbanized areas is much greater than that from a natural grassland; therefore, resultant differences in pollutant loads are generally greater than the difference in concentrations.

Stormwater runoff issues can be discussed in general terms for both streams and lakes; however, there are some unique effects with regard to lakes. Some of these include:

- Lakes respond to cumulative pollutant loading over time in terms of days, weeks, and longer time frames, unlike streams, which typically show effects within hours or days.

- Floating trash and shore damage are notable visible impacts of stormwater on lakes.

- Nutrient enrichment from stormwater runoff can have a significant water quality impact on lakes. This can result in the undesirable growth of algae and aquatic plants, increasing BOD and depleting dissolved oxygen.

- Lakes do not flush contaminants as quickly as streams and act as sinks for nutrients, metals, and sediments. This means that lakes take longer to recover once contaminated.

With regard to construction-phase stormwater runoff, EPA reports sediment runoff rates from construction sites can be much greater than those from agricultural lands and forestlands, contributing large quantities of sediment over a short period of time, causing physical and biological harm to receiving waters (EPA 2005). Fortunately, a variety of construction-phase and post-construction BMPs are available to help minimize the impacts of urbanization. Proper selection, design, construction and maintenance of these practices are the focus of the remainder of this manual.

Additional Resources Regarding Urban Stormwater Issues and Management

American Society of Civil Engineers and Water Environment Federation. *1992. Design and Construction of Urban Stormwater Management Systems. ASCE Manual and Reports of Engineering Practice No. 77 and WEF Manual of Practice FD-20.* Alexandria, VA: WEF.

Burton and Pitt. 2001. *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers*. Lewis Publishers.
http://www.epa.gov/ednnrmrl/publications/books/handbook/index.htm

Center for Watershed Protection Website: http://www.cwp.org

Debo, T. and A. Reese. 2002. *Municipal Stormwater Management*. 2nd Edition. Boca Raton, FL: Lewis Publishers.

EPA Stormwater Program Website: http://cfpub.epa.gov/npdes/home.cfm?program_id=6

International Stormwater Best Management Practices Database: www.bmpdatabase.org

Low Impact Development (LID) Center Website: http://www.lid-stormwater.net/

National Research Council. 2008. *Urban Stormwater Management in the United States.* National Academies Press. http://www.epa.gov/npdes/pubs/nrc_stormwaterreport.pdf

Oregon State University et al. 2006. *Evaluation of Best Management Practices for Highway Runoff Control.* Transportation Research Board. NCHRP-565.
http://www.trb.org/news/blurb_detail.asp?id=7184

Pitt, R., Maestre, A., and R. Morquecho. 2004. The National Stormwater Quality Database (NSQD). Version 1.1. http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html

Shaver et al. 2007. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues*, Second Edition. EPA and North American Lake Management Society.
http://www.nalms.org/Resources/PDF/Fundamentals/Fundamentals_full_manual.pdf

Water Environment Federation and American Society of Civil Engineers. 1998. *Urban Runoff Quality Management. WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87.* Alexandria, VA: Water Environment Federation.

Watershed Management Institute. 1997. *Operation, Maintenance and Management of Stormwater Management Systems.* Ingleside, MD: Watershed Management Institute.

3.0 Stormwater Management Requirements under the Clean Water Act

3.1 Clean Water Act Basics

The Federal Water Pollution Control Act of 1972, as amended (33 U.S.C. 1251 et seq.) is commonly known as the Clean Water Act and establishes minimum stormwater management requirements for urbanized areas in the United States. At the federal level, the EPA is responsible for administering and enforcing the requirements of the Clean Water Act. Section 402(p) of the Clean Water Act requires urban and industrial stormwater be controlled through the NPDES permit program. Requirements affect both construction and post-construction phases of development. As a result, urban areas must meet requirements of Municipal Separate Storm Sewer System (MS4) permits, and many industries and institutions such as state departments of transportation must also meet NPDES stormwater permit requirements. MS4 permittees are required to develop a Stormwater Management Program that includes measurable goals and to implement needed stormwater management controls (i.e., BMPs). MS4 permittees are also required to assess controls and the effectiveness of their stormwater programs and to reduce the discharge of pollutants to the "maximum extent practicable." Although it is not the case for every state, the EPA has delegated Clean Water Act authority to the State of Colorado. The State must meet the minimum requirements of the federal program.

3.2 Colorado's Stormwater Permitting Program

The Colorado Water Quality Control Act (25-8-101 et seq., CRS 1973, as amended) established the Colorado Water Quality Control Commission (CWQCC) within the Colorado Department of Public Health and Environment (CDPHE) to develop water quality regulations and standards, classifications of state waters for designated uses, and water quality control regulations. The Act also established the Colorado Water Quality Control Division (CWQCD) to administer and enforce the Act and administer the discharge permit system, among other responsibilities. Violations of the Act are subject to significant monetary penalties, as well as criminal prosecution in some cases.

Colorado's stormwater management regulations have been implemented in two phases and are included in *Regulation No. 61 Colorado Discharge Permit System (CDPS) Regulations* (CWQCC 2009). After the 1990 EPA "Phase I" stormwater regulation became effective, Colorado was required to develop a stormwater program that covered specific types of industries and storm sewer systems for municipalities with populations of more than 100,000. Phase I affected Denver, Aurora, Lakewood, Colorado Springs, and the Colorado Department of Transportation (CDOT). Phase 1 requirements included inventory of stormwater outfalls, monitoring and development of municipal stormwater management requirements, as well as other requirements. Construction activities disturbing five or more acres of land were required to obtain construction stormwater discharge permits.

Phase II of Colorado's stormwater program was finalized in March 2001, establishing additional stormwater permitting requirements. Two major changes included regulation of small municipalities ($\geq$ 10,000 and <100,000 population) in urbanized areas and requiring construction permits for sites disturbing one acre or more. The Phase II regulation resulted in a large number of new permit holders including MS4 permits for almost all of the metro Denver area communities. MS4 permit holders are required to develop, implement, and enforce a CDPS Stormwater Management Program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable, to protect water quality, and to satisfy the appropriate water quality requirements of the Colorado Water Quality Control Act (25-8-101 et seq., C.R.S.) and the Colorado Discharge Permit Regulations (Regulation 61).

The CWQCD administers and enforces the requirements of the CDPS stormwater program, generally including these general permit categories:

- **Municipal**: CDPS General Permit for Stormwater Discharges Associated with Municipal Separate Storm Sewer Systems (MS4s) (Permit No. COR-090000). The CWQCD has issued three municipal general permits:

  1. A permit for MS4s within the Cherry Creek Reservoir Basin,

  2. A permit for other MS4s statewide, and

  3. A permit specifically for non-standard MS4s. (Non-standard MS4s are publicly owned systems for facilities that are similar to a municipality, such as military bases and large education, hospital or prison complexes.)

- **Construction**: CDPS General Permit for Stormwater Discharges Associated with Construction Activity (Permit No. COR-030000).

- **Industrial**: CDPS General Permits are available for light industry, heavy industry, metal mining, sand and gravel, coal mining and the recycling industries.

The Phase II municipal MS4 permits require implementation of six minimum control measures (MCM):

1. Public education and outreach on stormwater impacts
2. Public involvement/participation
3. Illicit connections and discharge detection and elimination
4. Construction site stormwater management
5. Post-construction stormwater management in new development and redevelopment
6. Pollution prevention/good housekeeping for municipal operations

This manual provides guidance to address some of the requirements for measures 4, 5, and 6.

Resources for More Information on Colorado's Stormwater Regulations

CDPHE Stormwater Permitting Website: www.colorado.gov/pacific/cdphe/wqcd

See the CDPHE Regulation No. 61 Colorado Discharge Permit System Regulations and Colorado's Stormwater Program Fact Sheet both located on this website.

Common Stormwater Management Terms

Best Management Practice (BMP): A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters. (Some entities use the terms "Stormwater Control Measure," "Stormwater Control," or "Management Practice.")

Low Impact Development (LID): LID is a comprehensive land planning and engineering design approach to managing stormwater runoff with the goal of mimicking the pre-development hydrologic regime. LID emphasizes conservation of natural features and use of engineered, on-site, small-scale hydrologic controls that infiltrate, filter, store, evaporate, and detain runoff close to its source. The terms Green Infrastructure and Better Site Design are sometimes used interchangeably with LID.

LID Practice: LID practices are the individual techniques implemented as part of overall LID development or integrated into traditional development, including practices such as bioretention, green roofs, permeable pavements and other infiltration-oriented practices.

Minimizing Directly Connected Impervious Area (MDCIA): MDCIA includes a variety of runoff reduction strategies based on reducing impervious areas and routing runoff from impervious surfaces over grassy areas to slow runoff and promote infiltration. The concept of MDCIA has been recommended by UDFCD as a key technique for reducing runoff peaks and volumes following urbanization. MDCIA is a key component of LID.

Maximum Extent Practicable (MEP): MS4 permit holders are required to implement stormwater programs to reduce pollutant loading to the maximum extent practicable. This narrative standard does not currently include numeric effluent limits.

Municipal Separate Storm Sewer System (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) owned or operated by an MS4 permittee and designed or used for collecting or conveying stormwater.

Nonpoint Source: Any source of pollution that is not considered a "point source." This includes anthropogenic and natural background sources.

Point Source: Any discernible, confined and discrete conveyance from which pollutants are or may be discharged. Representative sources of pollution subject to regulation under the NPDES program include wastewater treatment facilities, most municipal stormwater discharges, industrial dischargers, and concentrated animal feeding operations. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture.

Water Quality Capture Volume (WQCV): This volume represents runoff from frequent storm events such as the 80th percentile storm. The volume varies depending on local rainfall data. Within the UDFCD boundary, the WQCV is based on runoff from 0.6 inches of precipitation.

Excess Urban Runoff Volume (EURV): EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff from pervious land surfaces (generally greater than the 2-year event). The EURV is relatively constant for a given imperviousness over a wide range of storm events.

Full Spectrum Detention: This practice utilizes capture and slow release of the EURV. UDFCD found this method to better replicate historic peak discharges for the full range of storm events compared to multi-stage detention practices.

3.2.1 Construction Site Stormwater Runoff Control

Under the Construction Program, permittees are required to develop, implement, and enforce a pollutant control program to reduce pollutants in stormwater runoff to their MS4 from construction activities that result in land disturbance of one or more acres. MS4 permittees frequently extend this requirement to smaller areas of disturbance if the total site acreage is one acre or larger or if it drains to an environmentally sensitive area. See Chapter 7 for detailed information on construction BMPs.

3.2.2 Post-construction Stormwater Management

Under the post-construction stormwater management in new development and redevelopment provisions, the MS4 General Permit (CWQCD 2008) requires the permittee to develop, implement, and enforce a program to address stormwater runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into the MS4. The program must ensure controls are in place that would prevent or minimize water quality impacts. See Chapter 4, Treatment BMPs and Chapter 5, Source Control BMPs, for detailed information on post-construction BMPs.

Redevelopment

The EPA Stormwater Phase 2 Final Rule Fact Sheet 2.7 states that redevelopment projects alter the footprint of an existing site or building in such a way that that there is a disturbance of equal to or greater than one acre of land.

This means that a "roadway rehabilitation" project, for example, where pavement is removed and replaced with essentially the same footprint would not be considered "redevelopment", whereas a "roadway widening project", where additional pavement (or other alterations to the footprint, pervious or impervious) equal to or in excess of one acre would be considered "redevelopment".

Although MS4 general permits have historically focused on water quality, it is noteworthy that there has been increased emphasis on reducing stormwater runoff volumes through use of Low Impact Development (LID) techniques. For example, MS4 permit language for some Phase I municipalities has also included the following:

> Implement and document strategies which include the use of structural and/or non-structural BMPs appropriate for the community, that address the discharge of pollutants from new development and redevelopment projects, or that follow principles of low-impact development to mimic natural (i.e., pre-development) hydrologic conditions at sites to minimize the discharge of pollutants and prevent or minimize adverse in-channel impacts associated with increased imperviousness (City and County of Denver 2008 MS4 permit).

Similarly, at the national level, the Energy Independence and Security Act of 2007 (Pub.L. 110-140) includes Section 438, Storm Water Runoff Requirements for Federal Development Projects. This section requires:

> …any sponsor of any development or redevelopment project involving a federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

Finally, in October 2009, EPA issued a notice in the Federal Register (Federal Register Vol. 74, No. 209, 56191-56193) expressing its intent to implement new comprehensive stormwater regulations for new developments and redevelopments by 2012. EPA intends to propose requirements, including design or performance standards, for stormwater discharges from, at a minimum, newly developed and redeveloped sites. In the notice, EPA cites the National Research Council (2008) recommendations that "EPA address stormwater discharges from impervious land cover and promote practices that harvest, infiltrate and evapotranspirate stormwater to reduce or prevent it from being discharged, which is critical to reducing the volume and pollutant loading to our nation's waters."

Although it is important to be aware of increased regulatory emphasis on volume control, it is also noteworthy that UDFCD guidance has recommended volume reduction as the first step in urban stormwater quality management since the initial release of the USDCM Volume 3, in 1992. Chapter 2 of this manual provides the designer with additional tools to encourage site designs that better incorporate volume reduction, based on site-specific conditions.

3.2.3 Pollution Prevention/Good Housekeeping

Under the Pollution Prevention/Good Housekeeping requirements, permittees are required to develop and implement an operation and maintenance/training program with the ultimate goal of preventing or reducing pollutant runoff from municipal operations. Chapter 5 provides information on source controls and non-structural BMPs that can be used in support of some of these requirements. Stormwater managers must also be aware that non-stormwater discharges to MS4s are not allowed, with the exception of certain conditions specified in the MS4 permit.

3.3 Total Maximum Daily Loads and Stormwater Management

Section 303(d) of the Clean Water Act requires states to develop a list of water bodies that are not attaining water quality standards for their designated uses, and to identify relative priorities for addressing the impaired water bodies. States must then develop Total Maximum Daily Loads (TMDLs) to assign allowable pollutant loads to various sources to enable the water body to meet the designated uses established for that water body. (For more information about the TMDL program, see http://www.epa.gov/owow/tmdl.) Implementation plans to achieve the loads specified under TMDLs commonly rely on BMPs to reduce pollutant loads associated with stormwater sources.

In the context of this manual, it is important for designers, planners and other stormwater professionals to understand TMDLs because TMDL provisions can directly affect stormwater permit requirements and BMP selection and design. EPA provides this basic description of TMDLs:

> A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. Pollutant sources are characterized as either regulated stormwater, sometimes called "point sources" that receive a waste load allocation (WLA), or nonpoint sources that receive a load allocation (LA). Point sources include all sources subject to regulation under the NPDES program (e.g., wastewater treatment facilities, most municipal stormwater discharges and concentrated animal feeding operations). Nonpoint sources include all remaining sources of the pollutant, as well as anthropogenic and natural background sources. TMDLs must also account for seasonal variations in water quality, and include a margin of safety (MOS) to account for uncertainty in predicting how well pollutant reductions will result in meeting water quality standards.

The TMDL calculation is:

$$TMDL = \Sigma WLA + \Sigma LA + MOS \quad \text{Equation 1-1}$$

Where:

ΣWLA = the sum of waste load allocations (point sources),

ΣLA = the sum of load allocations (nonpoint sources and background)

MOS = the margin of safety.

Although states are primarily responsible for developing TMDLs, EPA is required to review and approve or disapprove TMDLs. EPA has developed a basic "TMDL Review Checklist" with the minimum recommended elements that should be present in a TMDL document.

Once EPA approves a TMDL, there are varying degrees of impact to communities involved in the process, generally differentiated among whether point sources or non-point sources of pollution are identified in the TMDL. Permitted stormwater discharges are considered point sources. Essentially, this means that wastewater or stormwater permit requirements consistent with waste load allocations must be implemented and are enforceable under the Clean Water Act through NPDES permits.

If the MS4 permittee discharges into a waterbody with an approved TMDL that includes a pollutant-specific waste load allocation under the TMDL, then the CWQCD can amend the permit to include specific requirements related to that TMDL. For example, the permit may be amended to require specific BMPs, and compliance schedules to implement the BMPs may be required. Numeric effluent limits may also be incorporated under these provisions. TMDLs can have substantive effects on MS4 permit requirements. As an example, the City and County of Denver's MS4 permit has additional requirements to control *E. coli* related to the *E. coli* TMDL approved for the South Platte River (Segment 14). Information on 303(d) listings and priorities for TMDL development can be obtained from the EPA and CWQCC websites (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm and www.colorado.gov/pacific/cdphe/impaired-waters).

EPA's Recommended TMDL Checklist
(http://www.epa.gov/owow/tmdl/overviewoftmdl.html)

- Identification of Waterbody, Pollutant of Concern, Pollutant Sources, and Priority Ranking
- Applicable Water Quality Standard & Numeric Water Quality Target[1]
- Loading Capacity[1]
- Load Allocations and Waste Load Allocations[1]
- Margin of Safety[1]
- Consideration of Seasonal Variation[1]
- Reasonable Assurance for Point Sources/Non-point Sources
- Monitoring Plan to Track TMDL Effectiveness
- Implementation Plan
- Public Participation

[1] Legally required components under 40 C.F.R. Part 130

4.0 Four Step Process to Minimize Adverse Impacts of Urbanization

UDFCD has long recommended a Four Step Process for receiving water protection that focuses on reducing runoff volumes, treating the water quality capture volume (WQCV), stabilizing streams, and implementing long-term source controls. The Four Step Process pertains to management of smaller, frequently occurring events, as opposed to larger storms for which drainage and flood control infrastructure are sized. Implementation of these four steps helps to achieve stormwater permit requirements described in Section 3. Added benefits of implementing the complete process can include improved site aesthetics through functional landscaping features that also provide water quality benefits. Additionally, runoff reduction can decrease required storage volumes, thus increasing developable land. An overview of the Four Step Process follows, with Chapters 2 and 3 providing BMP selection tools and quantitative procedures for completing these steps.

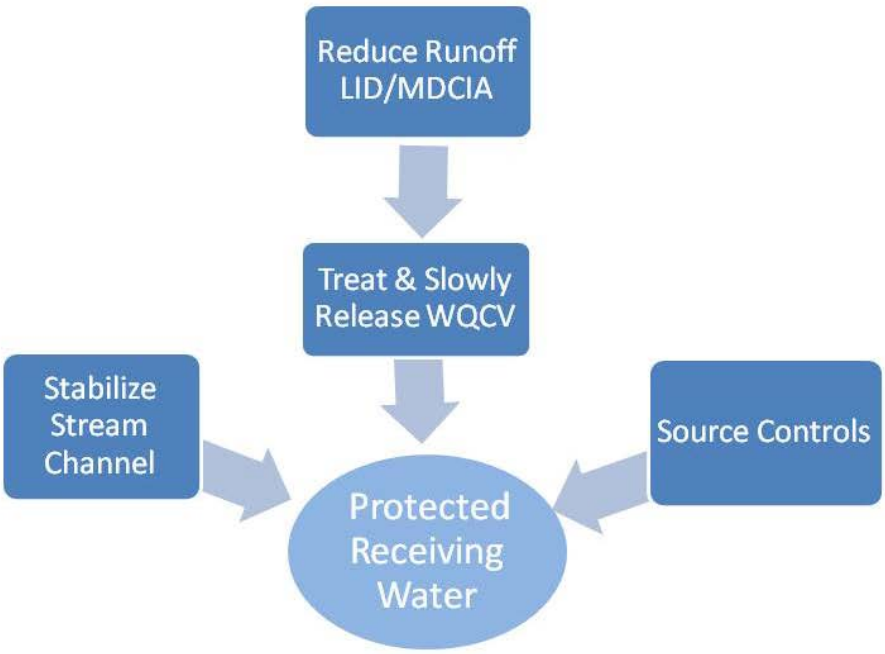

Figure 1-2. The four step process for stormwater quality management

4.1 Step 1. Employ Runoff Reduction Practices

To reduce runoff peaks, volumes, and pollutant loads from urbanizing areas, implement LID strategies, including MDCIA. For every site, look for opportunities to route runoff through vegetated areas, where possible by sheet flow. LID practices reduce unnecessary impervious areas and route runoff from impervious surfaces over permeable areas to slow runoff (increase time of concentration) and promote infiltration. When LID/MDCIA techniques are implemented throughout a development, the effective imperviousness is reduced, thereby potentially reducing sizing requirements for downstream facilities.

Differences between LID and Conventional Stormwater Quality Management

Low Impact Development (LID) is a comprehensive land planning and engineering design approach to managing stormwater runoff with a goal of replicating the pre-development hydrologic regime of urban and developing watersheds. Given the increased regulatory emphasis on LID, volume reduction and mimicking pre-development hydrology, questions may arise related to the differences between conventional stormwater management and LID. For example, Volume 3 has always emphasized MDCIA as the first step in stormwater quality planning and has provided guidance on LID techniques such as grass swales, grass buffers, permeable pavement systems, bioretention, and pollution prevention (pollutant source controls). Although these practices are all key components of LID, LID is not limited to a set of practices targeted at promoting infiltration. Key components of LID, in addition to individual BMPs, include practices such as:

- An overall site planning approach that promotes conservation design at both the watershed and site levels. This approach to development seeks to "fit" a proposed development to the site, integrating the development with natural features and protecting the site's natural resources. This includes practices such as preservation of natural areas including open space, wetlands, soils with high infiltration potential, and stream buffers. Minimizing unnecessary site disturbances (e.g., grading, compaction) is also emphasized.
- A site design philosophy that emphasizes multiple controls distributed throughout a development, as opposed to a central treatment facility.
- The use of swales and open vegetated conveyances, as opposed to curb and gutter systems.
- Volume reduction as a key hydrologic objective, as opposed to peak flow reduction being the primary hydrologic objective. Volume reduction is emphasized not only to reduce pollutant loading and peak flows, but also to move toward hydrologic regimes with flow durations and frequencies closer to the natural hydrologic regime.

Even with LID practices in place, most sites will also require centralized flood control facilities. In some cases, site constraints may limit the extent to which LID techniques can be implemented, whereas in other cases, developers and engineers may have significant opportunities to integrate LID techniques that may be overlooked due to the routine nature and familiarity of conventional approaches. This manual provides design criteria and guidance for both LID and conventional stormwater quality management, and provides additional facility sizing credits for implementing Step 1, Volume Reduction, in a more robust manner.

Key LID techniques include:

- **Conserve Existing Amenities**: During the planning phase of development, identify portions of the site that add value and should be protected or improved. Such areas may include mature trees, stream corridors, wetlands, and Type A/B soils with higher infiltration rates. In order for this step to provide meaningful benefits over the long-term, natural areas must be protected from compaction during the construction phase. Consider temporary construction fence for this purpose. In areas where disturbance cannot practically be avoided, rototilling and soil amendments should be integrated to restore the infiltration capacity of areas that will be restored with vegetation.
- **Minimize Impacts**: Consider how the site lends itself to the desired development. In some cases, creative site layout can reduce the extent of paved areas, thereby saving on initial capital cost of pavement and then saving on pavement maintenance, repair, and replacement over time. Minimize

imperviousness, including constructing streets, driveways, sidewalks and parking lot aisles to the minimum widths necessary, while still providing for parking, snow management, public safety and fire access. When soils vary over the site, concentrate new impervious areas over Type C and D soils, while preserving Type A and B soils for landscape areas and other permeable surfaces. Maintaining natural drainage patterns, implementing sheet flow (as opposed to concentrated flow), and increasing the number and lengths of flow paths will all reduce the impact of the development.

Permeable pavement techniques and green roofs are common LID practices that may reduce the effects of paved areas and roofs:

- **Permeable Pavement**: The use of various permeable pavement techniques as alternatives to paved areas can significantly reduce site imperviousness.

- **Green Roofs**: Green roofs can be used to decrease imperviousness associated with buildings and structures. Benefits of green roofs vary based on design of the roof. Research is underway to assess the effectiveness of green roofs in Colorado's semi-arid climate.

- **Minimize Directly Connected Impervious Areas (MDCIA)**: Impervious areas should drain to pervious areas. Use non-hardened drainage conveyances where appropriate. Route downspouts across pervious areas, and incorporate vegetation in areas that generate and convey runoff. Three key BMPs include:

  - **Grass Buffers**: Sheet flow over a grass buffer slows runoff and encourages infiltration, reducing effects of the impervious area.

  - **Grass Swales**: Like grass buffers, use of grass swales instead of storm sewers slows runoff and promotes infiltration, also reducing the effects of imperviousness.

  - **Bioretention (rain gardens)**: The use of distributed on-site vegetated features such as rain gardens can help maintain natural drainage patterns by allowing more infiltration onsite. Bioretention can also treat the WQCV, as described in the Four Step Process.

Photograph 1-1. **Permeable Pavement**. Permeable pavement consists of a permeable pavement layer underlain by gravel and sand layers in most cases. Uses include parking lots and low traffic areas, to accommodate vehicles while facilitating stormwater infiltration near its source. Photo coustesey of Bill Wenk.

Photograph 1-2. Grass Buffer. This roadway provides sheet flow to a grass buffer. The grass buffer provides filtration, infiltration, and settling to reduce runoff pollutants.

Photograph 1-3. Grass Swale. This densely vegetated grass swale is designed with channel geometry that forces the flow to be slow and shallow, facilitating sedimentation while limiting erosion.

Historically, this critical volume reduction step has often been overlooked by planners and engineers, instead going straight to WQCV requirements, despite WQCV reductions allowed based on MDCIA. Chapter 3 extends reductions to larger events and provides a broader range of reductions to WQCV sizing requirements than were previously recommended by UDFCD, depending on the extent to which Step 1 has been implemented. Developers should anticipate more stringent requirements from local governments to implement runoff reduction/MDCIA/LID measures (in addition to WQCV capture), given changes in state and federal stormwater regulations. In addition to benefiting the environment through reduced hydrologic and water quality impacts, volume reduction measures can also have the added economic benefit to the developer of increasing the area of developable land by reducing required detention volumes and potentially reducing both capital and maintenance costs.

Practical Tips for Volume Reduction and Better Integration of Water Quality Facilities
(Adapted from: Denver Water Quality Management Plan, WWE et al. 2004)

- **Consider stormwater quality needs early in the development process.** When left to the end of the site development process, stormwater quality facilities will often be shoe-horned into the site, resulting in few options. When included in the initial planning for a project, opportunities to integrate stormwater quality facilities into a site can be fully realized. Dealing with stormwater quality after major site plan decisions have been made is too late and often makes implementation of LID designs impractical.

- **Take advantage of the entire site when planning for stormwater quality treatment.** Stormwater quality and flood detention is often dealt with only at the low corner of the site, and ignored on the remainder of the site. The focus is on draining runoff quickly through inlets and storm sewers to the detention facility. In this "end-of-pipe" approach, all the runoff volume is concentrated at one point and designers often find it difficult to fit the required detention into the space provided. This can lead to use of underground BMPs that can be difficult to maintain or deep, walled-in basins that detract from a site and are also difficult to maintain. Treating runoff over a larger portion of the site reduces the need for big corner basins and allows implementation of LID principles.

- **Place stormwater in contact with the landscape and soil**. Avoid routing storm runoff from pavement to inlets to storm sewers to offsite pipes or concrete channels. The recommended approach places runoff in contact with landscape areas to slow down the stormwater and promote infiltration. Permeable pavement areas also serve to reduce runoff and encourage infiltration.

- **Minimize unnecessary imperviousness, while maintaining functionality and safety.** Smaller street sections or permeable pavement in fire access lanes, parking lanes, overflow parking, and driveways will reduce the total site imperviousness.

- **Select treatment areas that promote greater infiltration.** Bioretention, permeable pavements, and sand filters promote greater volume reduction than extended detention basins, since runoff tends to be absorbed into the filter media or infiltrate into underlying soils. As such, they are more efficient at reducing runoff volume and can be sized for smaller treatment volumes than extended detention basins.

4.2 Step 2. Implement BMPs That Provide a Water Quality Capture Volume with Slow Release

After runoff has been minimized, the remaining runoff should be treated through capture and slow release of the WQCV. WQCV facilities may provide both water quality and volume reduction benefits, depending on the BMP selected. This manual provides design guidance for BMPs providing treatment of the WQCV, including permeable pavement systems with subsurface storage, bioretention, extended detention basins, sand filters, constructed wetland ponds, and retention ponds. Green roofs and some underground BMPs may also provide the WQCV, depending on the design characteristics. Chapter 3 provides background information on the development of the WQCV for the Denver metropolitan area as well as a step-by-step procedure to calculate the WQCV.

4.3 Step 3. Stabilize Streams

During and following development, natural streams are often subject to bed and bank erosion due to increases in frequency, duration, rate, and volume of runoff. Although Steps 1 and 2 help to minimize these effects, some degree of stream stabilization is required. Many streams within UDFCD boundaries are included in major drainageway or outfall systems plans, identifying needed channel stabilization measures. These measures not only protect infrastructure such as utilities, roads and trails, but are also important to control sediment loading from erosion of the channel itself, which can be a significant source of sediment and associated constituents, such as phosphorus, metals and other naturally occurring constituents. If stream stabilization is implemented early in the development process, it is far more likely that natural stream characteristics can be maintained with the addition of grade control to accommodate future development. Targeted fortification of a relatively stable stream is typically much less costly than repairing an unraveled channel. The *Open Channels* chapter in Volume 1 of this manual provides guidance on stream stabilization.

4.4 Step 4. Implement Site Specific and Other Source Control BMPs

Site specific needs such as material storage or other site operations require consideration of targeted source control BMPs. This is often the case for new development or significant redevelopment of an industrial or commercial site. Chapter 5 includes information on source control practices such as covering storage/handling areas and spill containment and control.

5.0 Onsite, Subregional and Regional Stormwater Management

Stormwater quality BMPs should be implemented as close to the source as practicable. This results in smaller BMPs (in parallel or in series) that are distributed throughout a site rather than the "end of pipe" alternative. Whereas flood control is best handled on a regional basis, stormwater quality is best managed when stormwater is viewed as a resource and distributed throughout the site. When the watershed of a BMP is so big that a base flow is present, this both limits the type of BMP appropriate for use and complicates the design. The treatment provided by a regional BMP will also vary when base flows differ from that assumed during design.

Although not preferred, WQCV facilities may be implemented regionally (serving a major drainageway with a drainage area between 130 acres and one square mile) or subregionally (serving two or more development parcels with a total drainage area less than 130 acres). Drainage master plans should be consulted to determine if regional or subregional facilities are already planned or in place for new developments or redevelopments. Life-cycle costs of onsite, subregional, and regional facilities, including long-term maintenance responsibilities, should be part of the decision-making process when selecting the combinations of facilities and channel improvements needed to serve a development or redevelopment. Potential benefits of regional/subregional facilities include consolidated maintenance efforts, economies of scale for larger facilities as opposed to multiple onsite WQCV facilities, simplified long-term adequate assurances for operation and maintenance for public facilities, and potential integration with flood control facilities. Additionally, regional storage-based facilities may be beneficial in areas where onsite BMPs are not feasible due to geotechnical or land use constraints or when retrofitting an existing flood control facility in a fully developed watershed.

One of the most common challenges regarding regional facilities relates to the timing of funding for construction of the facilities. Often, regional facilities are funded by revenues collected from new development activities. New developments (and revenues) are required to fund construction of the water quality facility, but the water quality facility is needed upfront to provide protection for new development. This timing problem can be solved by constructing onsite water quality facilities for new development that occur before a regional facility is in place. These onsite BMPs are temporary in that they can be converted to developable land once the regional facility is constructed. Another option is to build a smaller interim regional facility that can be expanded with future development.

When regional water quality facilities are selected, BMPs are still required onsite to address water quality and channel stability for the reach of the drainageway upstream of the regional facility. In accordance with MS4 permits and regulations, BMPs must be implemented prior to discharges to a State Water from areas of "New Development and Significant Redevelopment." Therefore, if a regional BMP is utilized downstream of a discharge from a development into a State Water, additional BMPs are required to protect the State Water between the development site and the regional facility. However, these BMPs may not have to be as extensive as would normally be required, as long as they are adequate to protect the State Water upstream of the regional BMP. Although the CWQCD does not require onsite WQCV per se, MS4 permits contain conditions that require BMPs be implemented to the Maximum Extent Practicable to prevent "pollution of the receiving waters in excess of the pollution permitted by an applicable water quality standard or applicable antidegradation requirement." Additional requirements may also apply in the case of streams with TMDLs. As a result, MS4 permit holders must have a program in place that

requires developers to provide adequate onsite measures so that the MS4 permit holder remains in compliance with their permit and meets the conditions of current regulations.

State Waters

State Waters are any and all surface and subsurface waters which are contained in or flow in or through this State, but does not include waters in sewage systems, waters in treatment works of disposal systems, waters in potable water distribution systems, and all water withdrawn for use until use and treatment have been completed (from Regulation 61, Colorado Discharge Permit System Regulations).

When a regional or subregional facility is selected to treat the WQCV for a development, the remaining three steps in the Four Step Process should still be implemented. For example, minimizing runoff volumes on the developed property by disconnecting impervious area and infiltrating runoff onsite (Step 1) can potentially reduce regional WQCV requirements, conveyance system costs, and costs of the regional/subregional facility. Stream stabilization requirements (Step 3) must still be evaluated and implemented, particularly if identified in a master drainage plan. Finally, specific source controls (Step 4 BMPs) such as materials coverage should be implemented onsite, even if a regional/subregional facility is provided downstream. Although UDFCD does not specify minimum onsite treatment requirements when regional/subregional facilities are used, some local governments (e.g., Arapahoe County) have specific requirements related to the minimum measures that must be implemented to minimize directly connected impervious area.

Chapter 2 provides a BMP selection tool to help planners and engineers determine whether onsite, subregional or regional strategies are best suited to the given watershed conditions.

6.0 Conclusion

Urban stormwater runoff can have a variety of chemical, biological, and physical effects on receiving waters. As a result, local governments must comply with federal, state and local requirements to minimize adverse impacts both during and following construction. UDFCD criteria are based on a Four Step Process focused on reducing runoff volumes, treating the remaining WQCV, stabilizing receiving drainageways and providing targeted source controls for post-construction operations at a site. Stormwater management requirements and objectives should be considered early in the site development process, taking into account a variety of factors, including the effectiveness of the BMP, long-term maintenance requirements, cost and a variety of site-specific conditions. The remainder of this manual provides guidance for selecting, designing, constructing and maintaining stormwater BMPs.

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Chapter 2
BMP Selection

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1.0 BMP Selection

This chapter provides guidance on factors that should be considered when selecting BMPs for new development or redevelopment projects. This guidance is particularly useful in the planning phase of a project. BMP selection involves many factors such as physical site characteristics, treatment objectives, aesthetics, safety, maintenance requirements, and cost. Typically, there is not a single answer to the question of which BMP (or BMPs) should be selected for a site; there are usually multiple solutions ranging from stand alone BMPs to treatment trains that combine multiple BMPs to achieve the water quality objectives. Factors that should be considered when selecting BMPs are the focus of this chapter.

1.1 Physical Site Characteristics

The first step in BMP selection is identification of physical characteristics of a site including topography, soils, contributing drainage area, groundwater, baseflows, wetlands, existing drainageways, and development conditions in the tributary watershed (e.g., construction activity). A fundamental concept of Low Impact Development (LID) is preservation and protection of site features including wetlands, drainageways, soils that are conducive to infiltration, tree canopy, etc., that provide water quality and other benefits. LID stormwater treatment systems are also designed to take advantage of these natural resources. For example, if a portion of a site is known to have soils with high permeability, this area may be well-suited for rain gardens or permeable pavement. Areas of existing wetlands, which would be difficult to develop from a Section 404 permitting perspective, could be considered for polishing of runoff following BMP treatment, providing additional water quality treatment for the site, while at the same time enhancing the existing wetlands with additional water supply in the form of treated runoff.

Some physical site characteristics that provide opportunities for BMPs or constrain BMP selection include:

- **Soils:** Soils with good permeability, most typically associated with Hydrologic Soil Groups (HSGs) A and B provide opportunities for infiltration of runoff and are well-suited for infiltration-based BMPs such as rain gardens, permeable pavement systems, sand filter, grass swales, and buffers, often without the need for an underdrain system. Even when soil permeability is low, these types of BMPs may be feasible if soils are amended to increase permeability or if an underdrain system is used. In some cases, however, soils restrict the use of infiltration based BMPs. When soils with moderate to high swell potential are present, infiltration should be avoided to minimize damage to adjacent structures due to water-induced swelling. In some cases, infiltration based designs can still be used if an impermeable liner and underdrain system are included in the design; however, when the risk of damage to adjacent infrastructure is high, infiltration based BMPs may not be appropriate. In all cases, consult with a geotechnical engineer when designing infiltration BMPs near structures. Consultation with a geotechnical engineer is necessary for evaluating the suitability of soils for different BMP types and establishing minimum distances between infiltration BMPs and structures.

- **Watershed Size**: The contributing drainage area is an important consideration both on the site level and at the regional level. On the site level, there is a practical minimum size for certain BMPs, largely related to the ability to drain the WQCV over the required drain time. For example, it is technically possible to size the WQCV for an extended detention basin for a half-acre site; however, designing a functional outlet to release the WQCV over a 40-hour drain time is practically impossible due to the very small orifices that would be required. For this size watershed, a filtering BMP, such as a rain garden, would be more appropriate. At the other end of the spectrum, there must be a limit on the maximum drainage area for a regional facility to assure adequate treatment of rainfall events that may produce runoff from only a portion of the area draining to the BMP. If the overall drainage

area is too large, events that produce runoff from only a portion of the contributing area will pass through the BMP outlet (sized for the full drainage area) without adequate residence time in the BMP. As a practical limit, the maximum drainage area contributing to a water quality facility should be no larger than one square mile.

- **Groundwater**: Shallow groundwater on a site presents challenges for BMPs that rely on infiltration and for BMPs that are intended to be dry between storm events. Shallow groundwater may limit the ability to infiltrate runoff or result in unwanted groundwater storage in areas intended for storage of the WQCV (e.g., porous sub-base of a permeable pavement system or in the bottom of an otherwise dry facility such as an extended detention basin). Conversely, for some types of BMPs such as wetland channels or constructed wetland basins, groundwater can be beneficial by providing saturation of the root zone and/or a source of baseflow. Groundwater quality protection is an issue that should be considered for infiltration-based BMPs. Infiltration BMPs may not be appropriate for land uses that involve storage or use of materials that have the potential to contaminate groundwater underlying a site (i.e., "hot spot" runoff from fueling stations, materials storage areas, etc.). If groundwater or soil contamination exists on a site and it will not be remediated or removed as a part of construction, it may be necessary to avoid infiltration-based BMPs or use a durable liner to prevent infiltration into contaminated areas.

- **Base Flows**: Base flows are necessary for the success of some BMPs such as constructed wetland ponds, retention ponds and wetland channels. Without baseflows, these BMPs will become dry and unable to support wetland vegetation. For these BMPs, a hydrologic budget should be evaluated. Water rights are also required for these types of BMPs in Colorado.

- **Watershed Development Activities (or otherwise erosive conditions)**: When development in the watershed is phased or when erosive conditions such as steep slopes, sparse vegetation, and sandy soils exist in the watershed, a treatment train approach may be appropriate. BMPs that utilize filtration should follow other measures to collect sediment loads (e.g., a forebay). For phased developments, these measures must be in place until the watershed is completely stabilized. When naturally erosive conditions exist in the watershed, these measures should be permanent. The designer should consider existing, interim and future conditions to select the most appropriate BMPs.

1.2 Space Constraints

Space constraints are frequently cited as feasibility issues for BMPs, especially for high-density, lot-line-to-lot-line development and redevelopment sites. In some cases, constraints due to space limitations arise because adequate spaces for BMPs are not considered early enough in the planning process. This is most common when a site plan for roads, structures, etc., is developed and BMPs are squeezed into the remaining spaces. The most effective and integrated BMP designs begin by determining areas of a site that are best suited for BMPs (e.g., natural low areas, areas with well-drained soils) and then designing the layout of roads, buildings, and other site features around the existing drainage and water quality resources of the site. Allocating a small amount of land to water quality infrastructure during early planning stages will result in better integration of water quality facilities with other site features.

1.3 Targeted Pollutants and BMP Processes

BMPs have the ability to remove pollutants from runoff through a variety of physical, chemical and biological processes. The processes associated with a BMP dictate which pollutants the BMP will be effective at controlling. Primary processes include peak attenuation, sedimentation, filtration, straining, adsorption/absorption, biological uptake and hydrologic processes including infiltration and evapotranspiration. Table 2-1 lists processes that are associated with BMPs in this manual. For many

sites, a primary goal of BMPs is to remove gross solids, suspended sediment and associated particulate fractions of pollutants from runoff. Processes including straining, sedimentation, and infiltration/filtration are effective for addressing these pollutants. When dissolved pollutants are targeted, other processes including adsorption/absorption and biological uptake are necessary. These processes are generally sensitive to media composition and contact time, oxidation/reduction potential, pH and other factors. In addition to pollutant removal capabilities, many BMPs offer channel stability benefits in the form of reduced runoff volume and/or reduced peak flow rates for frequently occurring events. Brief descriptions of several key processes, generally categorized according to hydrologic and pollutant removal functions are listed below:

Hydrologic Processes

1. **Flow Attenuation**: BMPs that capture and slowly release the WQCV help to reduce peak discharges. In addition to slowing runoff, volume reduction may also be provided to varying extents in BMPs providing the WQCV.

2. **Infiltration:** BMPs that infiltrate runoff reduce both runoff peaks and surface runoff volumes. The extent to which runoff volumes are reduced depends on a variety of factors such as whether the BMP is equipped with an underdrain and the characteristics and long-term condition of the infiltrating media. Examples of infiltrating BMPs include (unlined) sand filters, bioretention and permeable pavements. Water quality treatment processes associated with infiltration can include filtration and sorption.

3. **Evapotranspiration**: Runoff volumes can be reduced through the combined effects of evaporation and transpiration in vegetated BMPs. Plants extract water from soils in the root zone and transpire it to the atmosphere. Evapotranspiration is the hydrologic process provided by vegetated BMPs, whereas biological uptake may help to reduce pollutants in runoff.

Pollutant Removal/Treatment Processes

1. **Sedimentation:** Gravitational separation of particulates from urban runoff, or sedimentation, is a key treatment process by BMPs that capture and slowly release runoff. Settling velocities are a function of characteristics such as particle size, shape, density, fluid density, and viscosity. Smaller particles under 60 microns in size (fine silts and clays) (Stahre and Urbonas, 1990) can account for approximately 80% of the metals in stormwater attached or adsorbed along with other contaminants and can require long periods of time to settle out of suspension. Extended detention allows smaller particles to agglomerate into larger ones (Randall et al, 1982), and for some of the dissolved and liquid state pollutants to adsorb to suspended particles, thus removing a larger proportion of them through sedimentation. Sedimentation is the primary pollutant removal mechanism for many treatment BMPs including extended detention basins, retention ponds, and constructed wetland basins.

2. **Straining**: Straining is physical removal or retention of particulates from runoff as it passes through a BMP. For example, grass swales and grass buffers provide straining of sediment and coarse solids in runoff. Straining can be characterized as coarse filtration.

3. **Filtration**: Filtration removes particles as water flows through media (often sand or engineered soils). A wide variety of physical and chemical mechanisms may occur along with filtration, depending on the filter media. Metcalf and Eddy (2003) describe processes associated with filtration as including straining, sedimentation, impaction, interception, adhesion, flocculation, chemical adsorption, physical adsorption, and biological growth. Filtration is a primary treatment process

provided by infiltration BMPs. Particulates are removed at the ground surface and upper soil horizon by filtration, while soluble constituents can be absorbed into the soil, at least in part, as the runoff infiltrates into the ground. Site-specific soil characteristics, such as permeability, cation exchange potential, and depth to groundwater or bedrock are important characteristics to consider for filtration (and infiltration) BMPs. Examples of filtering BMPs include sand filters, bioretention, and permeable pavements with a sand filter layer.

4. **Adsorption/Absorption**: In the context of BMPs, sorption processes describe the interaction of waterborne constituents with surrounding materials (e.g., soil, water). Absorption is the incorporation of a substance in one state into another of a different state (e.g., liquids being absorbed by a solid). Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another molecule. Many factors such as pH, temperature and ionic state affect the chemical equilibrium in BMPs and the extent to which these processes provide pollutant removal. Sorption processes often play primary roles in BMPs such as constructed wetland basins, retention ponds, and bioretention systems. Opportunities may exist to optimize performance of BMPs through the use of engineered media or chemical addition to enhance sorption processes.

5. **Biological Uptake:** Biological uptake and storage processes include the assimilation of organic and inorganic constituents by plants and microbes. Plants and microbes require soluble and dissolved constituents such as nutrients and minerals for growth. These constituents are ingested or taken up from the water column or growing medium (soil) and concentrated through bacterial action, phytoplankton growth, and other biochemical processes. In some instances, plants can be harvested to remove the constituents permanently. In addition, certain biological activities can reduce toxicity of some pollutants and/or possible adverse effects on higher aquatic species. Unfortunately, not much is understood yet about how biological uptake or activity interacts with stormwater during the relatively brief periods it is in contact with the biological media in most BMPs, with the possible exception of retention ponds between storm events (Hartigan, 1989). Bioretention, constructed wetlands, and retention ponds are all examples of BMPs that provide biological uptake.

When selecting BMPs, it is important to have realistic expectations of effluent pollutant concentrations. The International Stormwater BMP Database (www.bmpdatabase.org) provides BMP performance information that is updated periodically and summarized in Table 2-2. BMPs also provide varying degrees of volume reduction benefits. Both pollutant concentration reduction and volume reduction are key components in the whole life cycle cost tool *BMP-REALCOST.xls* (Roesner and Olson 2009) discussed later in this chapter.

It is critical to recognize that for BMPs to function effectively, meet performance expectations, and provide for public safety, BMPs must:

1. Be designed according to UDFCD criteria, taking into account site-specific conditions (e.g., high groundwater, expansive clays and long-term availability of water).

2. Be constructed as designed. This is important for all BMPs, but appears to be particularly critical for permeable pavements, rain gardens and infiltration-oriented facilities.

3. Be properly maintained to function as designed. Although all BMPs require maintenance, infiltration-oriented facilities are particularly susceptible to clogging without proper maintenance. Underground facilities can be vulnerable to maintenance neglect because maintenance needs are not evident from the surface without special tools and procedures for access. Maintenance is not only essential for proper functioning, but also for aesthetic and safety reasons. Inspection of facilities is an important step to identify and plan for needed maintenance.

Table 2-1. Primary, Secondary and Incidental Treatment Process Provided by BMPs

	Hydrologic Processes			Treatment Processes				
	Peak	Volume		Physical			Chemical	Biological
UDFCD BMP	Flow Attenuation	Infiltration	Evapo-transpiration	Sedimentation	Filtration	Straining	Adsorption/ Absorption	Biological Uptake
Grass Swale	I	S	I	S	S	P	S	S
Grass Buffer	I	S	I	S	S	P	S	S
Constructed Wetland Channel	I	N/A	P	P	S	P	S	P
Green Roof	P	S	P	N/A	P	N/A	I	P
Permeable Pavement Systems	P	P	N/A	S	P	N/A	N/A	N/A
Bioretention	P	P	S	P	P	S	S[1]	P
Extended Detention Basin	P	I	I	P	N/A	S	S	I
Sand Filter	P	P	I	P	P	N/A	S[1]	N/A
Constructed Wetland Pond	P	I	P	P	S	S	P	P
Retention Pond	P	I	P	P	N/A	N/A	P	S
Underground BMPs	Variable	N/A	N/A	Variable	Variable	Variable	Variable	N/A

Notes:

P = Primary; S = Secondary, I = Incidental; N/A = Not Applicable

[1] Depending on media

Table 2-2. BMP Effluent EMCs (Source: International Stormwater BMP Database, August

Solids and Nutrients (milligrams/liter)										
BMP Category	Sample Type	Total Suspended Solids	Total Dissolved Solids	Nitrogen, Total	Total Kjeldahl Nitrogen (TKN)	Nitrogen, Ammonia as N	Nitrogen, Nitrate (NO3) as N*	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N*	Phosphorus as P, Total	Phosphorus, Orthophosphate as P
Bioretention (w/Underdrain)	Inflow	44.6 (41.8-53.3, n= 6)	NC	1.46 (1.24-1.63, n= 7)	1.22 (1.00-1.33, n= 8)	0.19 (0.16-0.23, n= 8)	NC	0.30 (0.25-0.38, n= 10)	0.13 (0.12-0.17, n= 12)	0.04 (0.01-0.10, n= 7)
	Outflow	12.9 (6.8-17.3, n= 6)	NC	1.15 (0.92-2.98, n= 7)	0.94 (0.60-2.09, n= 8)	0.06 (0.05-0.38, n= 8)	NC	0.21 (0.14-0.29, n= 10)	0.13 (0.08-0.19, n= 12)	0.06 (0.03-0.33, n= 7)
Grass Buffer	Inflow	52.3 (50.0-63.3, n= 14)	57.5 (32.0-89.3, n= 12)	NC	1.40 (1.15-2.10, n= 13)	0.38 (0.23-0.64, n= 10)	0.44 (0.42-0.92, n= 13)	NC	0.18 (0.09-0.25, n= 14)	0.04 (0.03-0.06, n= 10)
	Outflow	22.3 (15.0-28.3, n= 14)	88.0 (73.3-110.0, n= 12)	NC	1.20 (0.95-1.50, n= 13)	0.25 (0.13-0.36, n= 9)	0.33 (0.23-0.78, n= 13)	NC	0.30 (0.11-0.56, n= 14)	0.10 (0.05-0.29, n= 10)
Grass Swale	Inflow	54.5 (30.5-76.5, n= 15)	79.5 (64.2-100.1, n= 12)	NC	1.83 (1.40-2.11, n= 12)	0.06 (0.02-0.09, n= 4)	0.41 (0.23-0.78, n= 12)	0.25 (0.19-0.37, n= 4)	0.22 (0.13-0.29, n= 15)	0.04 (0.03-0.04, n= 3)
	Outflow	18.0 (8.9-39.5, n= 19)	71.0 (34.9-85.0, n= 10)	0.60 (0.55-1.34, n= 6)	1.23 (0.41-1.48, n= 16)	0.05 (0.03-0.06, n= 8)	0.29 (0.21-0.66, n= 15)	0.22 (0.18-0.31, n= 8)	0.23 (0.19-0.31, n= 19)	0.10 (0.08-0.12, n= 7)
Detention Basin (aboveground extended det.)	Inflow	59.5 (17.8-83.8, n= 18)	88.5 (85.0-98.8, n= 6)	1.05 (1.04-1.25, n= 3)	1.32 (0.77-1.70, n= 10)	0.08 (0.04-0.10, n= 5)	0.45 (0.30-0.90, n= 8)	0.23 (0.17-0.50, n= 5)	0.20 (0.18-0.30, n= 17)	NC
	Outflow	22.0 (11.6-28.5, n= 20)	85.0 (54.3-113.5, n= 6)	2.54 (1.7-2.69, n= 3)	1.66 (0.86-1.95, n= 10)	0.09 (0.07-0.10, n= 5)	0.40 (0.27-0.85, n= 8)	0.17 (0.08-0.43, n= 6)	0.20 (0.13-0.26, n= 18)	NC
Media Filters (various types)	Inflow	44.0 (32.0-75.0, n= 21)	42.0 (28.4-59.0, n= 13)	1.51 (0.73-1.80, n= 5)	1.53 (0.87-2.00, n= 17)	0.34 (0.08-1.12, n= 11)	0.38 (0.23-0.57, n= 16)	0.33 (0.23-0.51, n= 6)	0.20 (0.13-0.33, n= 21)	0.02 (0.02-0.06, n= 7)
	Outflow	8.0 (5.0-17.0, n= 21)	55.0 (46.0-62.0, n= 13)	0.63 (0.43-1.41, n= 4)	0.80 (0.50-1.22, n= 17)	0.11 (0.04-0.15, n= 10)	0.66 (0.39-0.73, n= 16)	0.43 (0.05-1.00, n= 5)	0.11 (0.06-0.15, n= 21)	0.02 (0.02-0.06, n= 7)
Retention Pond (aboveground wet pond)	Inflow	44.5 (24.0-88.3, n= 40)	89.0 (59.3-127.5, n= 9)	1.71 (1.07-2.36, n= 19)	1.18 (0.77-1.42, n= 28)	0.09 (0.04-0.15, n= 23)	0.43 (0.32-0.69, n= 15)	0.27 (0.11-0.55, n= 24)	0.23 (0.14-0.39, n= 38)	0.09 (0.07-0.21, n= 26)
	Outflow	12.1 (7.9-19.7, n= 40)	151.3 (70.8-182.0, n= 9)	1.31 (1.01-1.54, n= 19)	0.99 (0.76-1.29, n= 30)	0.07 (0.04-0.17, n= 24)	0.19 (0.13-0.26, n= 15)	0.05 (0.02-0.20, n= 24)	0.11 (0.07-0.19, n= 40)	0.05 (0.02-0.08, n= 27)
Wetland Basin	Inflow	39.6 (24.0-56.8, n= 14)	NA	1.54 (1.07-2.16, n= 6)	1.10 (0.77-1.30, n= 4)	0.10 (0.04-0.13, n= 8)	0.32 (0.32-0.44, n= 5)	0.46 (0.11-0.63, n= 7)	0.12 (0.14-0.27, n= 11)	0.04 (0.07-0.13, n= 5)
	Outflow	12.0 (8.5-17.5, n= 16)	NC	1.16 (0.98-1.39, n= 6)	1.00 (0.90-1.14, n= 8)	0.06 (0.04-0.10, n= 8)	0.12 (0.10-0.16, n= 7)	0.17 (0.05-0.34, n= 7)	0.08 (0.05-0.14, n= 13)	0.06 (0.02-0.25, n= 7)
Permeable Pavement**	Inflow	23.5 (16.0-45.3, n = 5)	NA	NC	2.40 (1.80-3.30, n = 3)	NC	NC	0.59 (0.27-0.80, n = 5)	0.12 (0.10-0.13, n = 5)	NC
	Outflow	29.1 (16.3-34.0, n = 7)	NA	NC	1.05 (0.90-1.33, n = 7)	NC	NC	1.24 (1.21-1.39, n = 4)	0.13 (0.10-0.19, n = 5)	NC

*Some BMP studies include analyses for both NO2/NO3 and NO3; therefore, these analytes are reported separately, even though results are expected to be comparable in stormwater runoff.

Table Notes provided below part 2 of this table.

Metals (micrograms/liter)															
BMP Category	Sample Type	Arsenic, Diss.	Arsenic, Total	Cadmium, Diss.	Cadmium, Total	Chromium, Diss.	Chromium, Total	Copper, Diss.	Copper, Total	Lead, Diss.	Lead, Total	Nickel, Diss.	Nickel, Total	Zinc, Diss.	Zinc, Total
Bioretention (w/Underdrain)	Inflow	NA	NC	NC	NC	NC	NC	NC	19.5 (15.3-35.8, n= 3)	NC	NC	NC	NC	NC	68.0 (51-68.5, n= 5)
	Outflow	NA	NC	NC	NC	NC	NC	NC	10.0 (7.3-16.8, n= 3)	NC	NC	NC	NC	NC	8.5 (5.0-35.0, n= 5)
Grass Buffer	Inflow	0.8 (0.5-1.2, n= 12)	1.1 (0.9-2.3, n= 12)	0.2 (0.1-0.2, n= 12)	0.4 (0.3-0.8, n= 12)	2.4 (1.1-4.5, n= 12)	4.9 (2.9-7.4, n= 13)	12.9 (6.8-17.3, n= 12)	21.2 (15.0-41.0, n= 13)	0.9 (0.5-2.0, n= 12)	11.0 (6-35, n= 13)	2.9 (1.1-3.2, n= 12)	4.8 (3.4-8.4, n= 12)	37.8 (12.8-70, n= 12)	100.5 (53.0-245.0, n= 13)
	Outflow	1.2 (0.5-2.4, n= 12)	2.0 (0.7-3.0, n= 12)	0.1 (0.1-0.2, n= 12)	0.2 (0.1-0.2, n= 12)	2.3 (1.0-3.8, n= 12)	2.9 (2.0-5.5, n= 13)	7.1 (4.8-11.6, n= 12)	8.3 (6.4-12.5, n= 13)	0.5 (0.5-1.3, n= 12)	3.2 (1.8-6.0, n= 13)	2.1 (2.0-2.3, n= 12)	2.6 (2.2-3.2, n= 12)	19.8 (10.7-24.3, n= 12)	25.5 (15.0-57.9, n= 13)
Grass Swale	Inflow	0.6 (0.5-2.2, n= 9)	1.7 (1.6-2.7, n= 9)	0.3 (0.1-0.4, n= 13)	0.5 (0.4-0.9, n= 14)	2.2 (1.1-3.3, n= 7)	6.1 (3.6-8.3, n= 7)	10.6 (8.1-15.0, n= 13)	33.0 (26-34, n= 13)	1.4 (0.6-6.7, n= 13)	21.6 (12.5-46.4, n= 14)	5.1 (4.5-6.6, n= 6)	8.7 (7-12.5, n= 6)	40.3 (35.3-109.0, n= 13)	149.5 (43.8-244.3, n= 15)
	Outflow	0.6 (0.6-1.2, n= 8)	1.2 (0.9-1.7, n= 8)	0.2 (0.1-0.2, n= 12)	0.3 (0.2-0.4, n= 13)	1.1 (1.0-3.0, n= 6)	3.5 (1.7-5.0, n= 6)	8.6 (5.5-9.7, n= 13)	14.0 (6.7-18.5, n= 17)	1.0 (0.5-4.1, n= 13)	10.5 (1.7-12.0, n= 18)	2.0 (2.0-2.3, n= 5)	4.0 (3.1-4.5, n= 5)	22.6 (20.1-33.2, n= 13)	55.0 (20.6-65.4, n= 19)
Detention Basin (aboveground extended det.)	Inflow	1.1 (0.9-1.2, n= 5)	2.1 (1.3-2.6, n= 6)	0.3 (0.2-0.4, n= 8)	0.6 (0.3-1.2, n= 11)	2.6 (2.0-3.2, n= 3)	5.6 (5.0-6.5, n= 6)	5.8 (2.6-11.8, n= 8)	10.0 (4.8-33.5, n= 11)	1.0 (0.5-1.4, n= 8)	10.0 (1.5-41.0, n= 11)	2.9 (1.9-3.9, n= 4)	6.3 (5-9.4, n= 5)	16.4 (6.1-53.5, n= 8)	125.0 (21.5-225.3, n= 11)
	Outflow	1.2 (0.9-1.2, n= 5)	1.7 (1.1-1.9, n= 6)	0.3 (0.2-0.4, n= 9)	0.4 (0.2-0.6, n= 12)	1.9 (1.7-3.0, n= 4)	2.9 (1.9-3.8, n= 6)	9.0 (3.0-13.0, n= 9)	11.0 (6.2-20.1, n= 12)	1.0 (0.5-1.3, n= 9)	9.5 (1.3-18.6, n= 12)	3.1 (2.0-3.2, n= 5)	4.3 (3.2-5.4, n= 6)	19.0 (7.8-54.0, n= 9)	48.5 (19.1-94.0, n= 13)
Media Filters (various types)	Inflow	0.7 (0.5-1.1, n= 12)	1.1 (0.6-1.6, n= 12)	0.2 (0.2-0.2, n= 14)	0.4 (0.2-1.0, n= 17)	1.0 (1.0-1.0, n= 13)	2.1 (1.4-4.0, n= 13)	6.2 (5.4-7.4, n= 13)	13.5 (8.8-16.4, n= 18)	1.1 (1.0-2.0, n= 14)	9.0 (5.3-22.0, n= 17)	2.0 (2.0-2.7, n= 13)	3.9 (3.3-4.8, n= 13)	42.7 (28.5-79.2, n= 14)	86.0 (51.8-106.0, n= 19)
	Outflow	0.7 (0.6-1.1, n= 12)	1.1 (0.7-1.6, n= 12)	0.2 (0.2-0.2, n= 13)	0.2 (0.1-0.7, n= 17)	1.0 (1.0-1.0, n= 13)	1.0 (1.0-1.9, n= 13)	5.8 (3.1-8.3, n= 13)	7.3 (4.3-9.6, n= 18)	1.0 (1.0-1.0, n= 13)	1.6 (1.0-4.4, n= 17)	2.0 (2.0-2.6, n= 13)	2.9 (2.0-3.9, n= 13)	12.5 (6.7-49.0, n= 13)	20.0 (8.6-35.0, n= 19)
Retention Pond (aboveground wet pond)	Inflow	NC	1.0 (1.0-1.4, n= 3)	0.2 (0.2-0.4, n= 3)	1.0 (0.3-2.6, n= 20)	5.9 (1.6-10.0, n= 4)	5.0 (3.0-7.4, n= 12)	7.0 (6.0-9.5, n= 7)	6.3 (4.3-10.6, n= 26)	2.0 (1.0-5.1.0, n= 11)	9.7 (4-28, n= 33)	10.0 (6.2-10.0, n= 3)	6.5 (3.6-9, n= 8)	30.0 (15.5-42.6, n= 8)	51.8 (43.9-78.1, n= 32)
	Outflow	NC	1.0 (0.8-1.0, n= 3)	0.2 (0.2-0.4, n= 3)	0.4 (0.2-2.5, n= 20)	5.5 (1.0-10.0, n= 4)	2.2 (1.4-5.3, n= 12)	5.0 (4.7-5.8, n= 7)	5.4 (3.0-6.2, n= 26)	1.2 (1.0-4.9, n= 12)	4.7 (1.6-10.0, n= 33)	10.0 (7.2-10.0, n= 3)	2.5 (2.0-5.5, n= 9)	12.5 (9.4-28.6, n= 8)	26.0 (12.0-37.0, n= 33)
Wetland Basin	Inflow	NA	NA	NC	0.3 (0.3-0.4, n= 3)	NA	NA	NC	10.5 (4.3-15.9, n= 4)	NC	16.0 (4.0-23.8, n= 4)	NA	NA	NC	51.0 (43.9-120.8, n= 7)
	Outflow	NA	NA	0.5 (0.3-0.5, n= 3)	0.3 (0.1-0.5, n= 5)	NA	NA	5.0 (5.0-5.7, n= 3)	4.5 (3.3-5.0, n= 6)	1.0 (0.8-1.0, n= 3)	1.0 (1.0-2.5, n= 6)	NA	NA	11.0 (11.0-13.1, n= 3)	15.0 (5.0-28.9, n= 9)
Permeable Pavement**	Inflow	NA	NC	NC	NA	NC	NC	5.0 (2.5-6.4, n =3)	7.0 (4.5-19.4, n = 3)	0.1 (0.03-0.3, n = 3)	2.5 (1.3-15.1, n = 3)	NC	NC	25.0 (19.0-27.5, n = 3)	50.0 (45.0-51.0, n = 5)
	Outflow	NA	NC	NC	0.3 (0.3-0.4, n =3)	NC	NC	6.2 (4.5-6.4, n =4)	9.0 (3.0-14.7, n = 5)	0.3 (0.04-0.5, n = 4)	2.5 (1.3-9.5, n = 7)	NC	NC	14.6 (13.5-16.0, n = 4)	22.0 (20.0-31.6, n = 7)

Table Key

Sample Type	Analyte	Description
Inflow	52.3	= Median inflow value
	(50-63.3, n= 14)	= Interquartile range, sample size
Outflow	22.3	= Median outflow value
	(15-28.3, n= 14)	= Interquartile range, sample size

NA = Not available; studies containing 3 or more storms not available.
NC = Not calculated because fewer than 3 BMP studies for this category.
Interquartile Range = 25th percentile to 75th percentile values, calculated in Excel, which uses linear interpolation to calculate percentiles. For small sample sizes (particularly n<5), interquartile values may vary depending on statistical package used.

Table Notes:

**Permeable pavement data should be used with caution due to limited numbers of BMP studies and small numbers of storm events typically monitored at these sites. "Inflow" values are typically outflows monitored at a reference conventional paving site.

Descriptive statistics calculated by weighting each BMP study equally. Each BMP study is represented by the median analyte value reported for all storms monitored at each BMP (i.e., "n" = number of BMP studies, as opposed to number of storm events). Depending on the analysis objectives, researchers may also choose to use a storm-weighted analysis approach, a unit treatment process-based grouping of studies, or other screening based on design parameters and site-specific characteristics.
Analysis based on August 2010 BMP Database, which contains substantial changes relative to the 2008 BMP Database. Multiple BMPs have been recategorized into new BMP categories; therefore, the 2008 and 2010 data analysis are not directly comparable for several BMP types.

This table contains descriptive statistics only. Values presented in this table should not be used to draw conclusions related to statistically significant differences in performance for BMP categories. (Hypothesis testing for BMP Categories is provided separately in other BMP Database summaries available at www.bmpdatabase.org.)

These descriptive statistics are based on different statistical measures than those used in the 2008 BMP Database tabular summary. Be aware that results will vary depending on whether a "BMP Weighted" (one median or average value represents each BMP) or "Storm Weighted" (all storms for all BMPs included in statistical calculations) approach is used, as well as whether the median or another measure of central tendency is used. Several BMP Database publications in 2010 have focused on the storm-weighted approach, which may result in some differences between this table and other published summaries.

Values below detection limits replaced with 1/2 of detection limit.

1.4 Storage-Based Versus Conveyance-Based

BMPs in this manual generally fall into two categories: 1) storage-based and 2) conveyance-based. Storage-based BMPs provide the WQCV and include bioretention/rain gardens, extended detention basins, sand filters, constructed wetland ponds, retention ponds, and permeable pavement systems. Conveyance-based BMPs include grass swales, grass buffers, constructed wetlands channels and other BMPs that improve quality and reduce volume but only provide incidental storage. Conveyance-based BMPs can be implemented to help achieve objectives in Step 1 of the Four Step Process. Although conveyance BMPs do not satisfy Step 2 (providing the WQCV), they can reduce the volume requirements of Step 2. Storage-based BMPs are critical for Step 2 of the Four Step Process. Site plans that use a combination of conveyance-based and storage-based BMPs can be used to better mimic pre-development hydrology.

1.5 Volume Reduction

BMPs that promote infiltration or that incorporate evapotranspiration have the potential to reduce the volume of runoff generated. Volume reduction is a fundamental objective of LID. Volume reduction has many benefits, both in terms of hydrology and pollution control. While stormwater regulations have traditionally focused on runoff peak flow rates, emerging stormwater regulations require BMPs to mimic the pre-development hydrologic budget to minimize effects of hydromodification. From a pollution perspective, decreased runoff volume translates to decreased pollutant loads. Volume reduction has economic benefits, including potential reductions in storage requirements for minor and major events, reduced extent and sizing of conveyance infrastructure, and cost reductions associated with addressing channel stability issues. UDFCD has developed a computational method for quantifying volume reduction. This is discussed in detail in Chapter 3.

Hydromodification

The term hydromodification refers to altered hydrology due to increased imperviousness combined with constructed of conveyance systems (e.g., pipes) that convey stormwater efficiently to receiving waters. Hydromodification produces increased peaks, volume, frequency, and duration of flows, all of which can result in stream degradation, including stream bed down cutting, bank erosion, enlarged channels, and disconnection of streams from the floodplain. These factors lead to loss of stream and riparian habitat, reduced aquatic diversity, and can adversely impact the beneficial uses of our waterways.

Infiltration-based BMPs can be designed with or without underdrains, depending on soil permeability and other site conditions. The most substantial volume reductions are generally associated with BMPs that have permeable sub-soils and allow infiltration to deeper soil strata and eventually groundwater. For BMPs that have underdrains, there is still potential for volume reduction although to a lesser degree. As runoff infiltrates through BMP soils to the underdrain, moisture is retained by soils. The moisture eventually evaporates, or is taken up by vegetation, resulting in volume reduction. Runoff that drains from these soils via gravity to the underdrain system behaves like interflow from a hydrologic perspective with a delayed response that reduces peak rates. Although the runoff collected in the underdrain system is ultimately discharged to the surface, on the time scale of a storm event, there are volume reduction benefits.

Although effects of evapotranspiration are inconsequential on the time scale of a storm event, on an annual basis, volume reduction due to evapotranspiration for vegetated BMPs such as retention and constructed wetland ponds can be an important component of the hydrologic budget. Between events, evapotranspiration lowers soil moisture content and permanent pool storage, providing additional storage capacity for subsequent events.

Other surface BMPs also provide volume reduction through a combination of infiltration, use by the vegetation and evaporation. Volume reduction provided by a particular BMP type will be influenced by site-specific conditions and BMP design features. National research is ongoing with regard to estimating volume reduction provided by various BMP types. Based on analysis of BMP studies contained in the International Stormwater BMP Database, Geosyntec and WWE (2010) reported that normally-dry vegetated BMPs (filter strips, vegetated swales, bioretention, and grass lined detention basins) appear to have substantial potential for volume reduction on a long-term basis, on the order of 30 percent for filter strips and grass-lined detention basins, 40 percent for grass swales, and greater than 50 percent for bioretention with underdrains. Bioretention facilities without underdrains would be expected to provide greater volume reduction.

1.6 Pretreatment

Design criteria in this manual recommend forebays for extended detention basins, constructed wetland basins, and retention ponds. The purpose of forebays is to settle out coarse sediment prior to reaching the main body of the facility. During construction, source control including good housekeeping can be more effective than pre-treatment. It is extremely important that high sediment loading be controlled for BMPs that rely on infiltration, including permeable pavement systems, rain gardens, and sand filter extended detention basins. These facilities should not be brought on-line until the end of the construction phase when the tributary drainage area has been stabilized with permanent surfaces and landscaping.

1.7 Treatment Train

The term "treatment train" refers to multiple BMPs in series (e.g., a disconnected roof downspout draining to a grass swale draining to a constructed wetland basin.) Engineering research over the past decade has demonstrated that treatment trains are one of the most effective methods for management of stormwater quality (WERF 2004). Advantages of treatment trains include:

- **Multiple processes for pollutant removal**: There is no "silver bullet" for a BMP that will address all pollutants of concern as a stand-alone practice. Treatment trains that link together complementary processes expand the range of pollutants that can be treated with a water quality system and increase the overall efficiency of the system for pollutant removal.

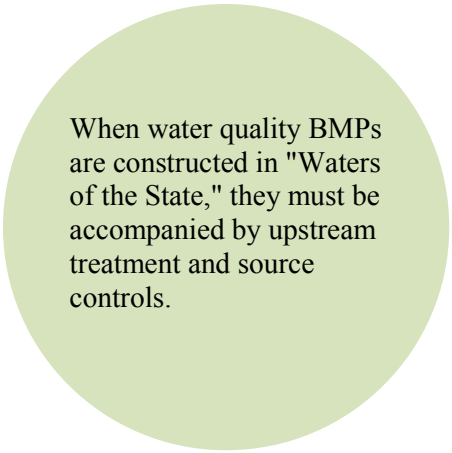
- **Redundancy**: Given the natural variability of the volume, rate and quality of stormwater runoff and the variability in BMP performance, using multiple practices in a treatment train can provide more consistent treatment of runoff than a single practice and provide redundancy in the event that one component of a treatment train is not functioning as intended.

- **Maintenance**: BMPs that remove trash, debris, coarse sediments and other gross solids are a common first stage of a treatment train. From a maintenance perspective, this is advantageous since this first stage creates a well-defined, relatively small area that can be cleaned out routinely. Downgradient components of the treatment train can be maintained less frequently and will benefit from reduced potential for clogging and accumulation of trash and debris.

1.8 Online Versus Offline Facility Locations

The location of WQCV facilities within a development site and watershed requires thought and planning. Ideally this decision-making occurs during a master planning process. Outfall system plans and other reports may depict a recommended approach for implementing WQCV on a watershed basis. Such reports may call for a few large regional WQCV facilities, smaller sub-regional facilities, or an onsite approach. Early in the development process, it is important to determine if a master planning study has been completed that addresses water quality and to attempt to follow the plan's recommendations.

When a master plan identifying the type and location of water quality facilities has not been completed, a key decision involves whether to locate a BMP online or offline. Online refers to locating a BMP such that all of the runoff from the upstream watershed is intercepted and treated by the BMP. A single online BMP should be designed to treat both site runoff and upstream (offsite) runoff. Locating BMPs offline requires that all onsite catchment areas flow though a BMP prior to combining with flows from the upstream (offsite) watershed. Be aware, when water quality BMPs are constructed in "Waters of the State" they must be accompanied by upstream treatment controls and source controls.



Online WQCV facilities are only recommended if the offsite watershed has less impervious area than that of the onsite watershed. Nevertheless, online WQCV facilities must be sized to serve the entire upstream watershed based on future development conditions. This recommendation is true even if upstream developments have installed their own onsite WQCV facilities. The only exception to this criterion is when multiple online regional or sub-regional BMPs are constructed in series and a detailed hydrologic model is prepared to show appropriate sizing of each BMP. The maximum watershed recommended for a water quality facility is approximately one square mile. Larger watersheds can be associated with decreased water quality.

1.9 Integration with Flood Control

In addition to water quality, most projects will require detention for flood control, whether on-site, or in a sub-regional or regional facility. In many cases, it is efficient to combine facilities since the land requirements for a combined facility are lower than for two separate facilities. Wherever possible, it is recommended WQCV facilities be incorporated into flood control detention facilities.

Local jurisdictions in the Denver area use different approaches for sizing volumes within a combined water quality and quantity detention facility. This varies from requiring no more than the 100-year detention volume, even though the WQCV is incorporated within it, to requiring the 100-year detention volume plus the full WQCV. This manual does not stipulate or recommend which policy should be used. When a local policy has not been established, UDFCD suggests the following approach:

- **Water Quality**: The full WQCV is to be provided according to the design procedures documented in this manual.
- **Minor Storm (not EURV)**: The full WQCV, plus the full minor storm detention volume, is to be provided.

- **100-Year Storm**: One-half the WQCV plus the full 100-year storm event volume should be provided for volumes obtained using the empirical equations or the FAA Method. When the analysis is done using hydrograph routing methods, each level of controls needs to be accounted for and the resultant 100-year control volume used in final design.

- **100-Year Storm using Full Spectrum Detention**: The full 100-year storm event volume should be provided according to the design protocol provided in the *Storage* chapter of Volume 2.

The *Storage* chapter in Volume 2 provides design criteria for full spectrum detention, which shows more promise in controlling the peak flow rates in receiving waterways than the multi-stage designs described above. Full spectrum detention not only addresses the WQCV for controlling water quality and runoff from frequently occurring runoff events, but also extends that control for all return periods through the 100-year event and closely matches historic peak flows downstream.

Finally, designers should also be aware that water quality BMPs, especially those that promote infiltration, could result in volume reductions for flood storage. These volume reductions are most pronounced for frequently occurring events, but even in the major event, some reduction in detention storage volume can be achieved if volume-reduction BMPs are widely used on a site. Additional discussion on volume reduction benefits, including a methodology for quantifying effects on detention storage volumes, is provided in Chapter 3.

1.9.1 Sedimentation BMPs

Combination outlets are relatively straightforward for most BMPs in this manual. For BMPs that utilize sedimentation (e.g. EDBs, constructed wetland ponds, and retention ponds) see BMP Fact Sheet T-12. This Fact Sheet shows examples and details for combined quality/quantity outlet structures.

1.9.2 Infiltration/Filtration BMPs

For other types of BMPs (e.g. rain gardens, sand filters, permeable pavement systems, and other BMPs utilizing processes other than sedimentation), design of a combination outlet structure generally consists of multiple orifices to provide controlled release of WQCV as well as the minor and major storm event. Incorporation of full spectrum detention into these structures requires reservoir routing. The *UD-Detention* worksheet available at www.udfcd.org can be used for this design. When incorporating flood control into permeable pavement systems, the design can be simplified when a near 0% slope on the pavement surface can be achieved. The flatter the pavement the fewer structures required. This includes lateral barriers as well as outlet controls since each pavement cell typically requires its own outlet structure. When incorporating flood control into a rain garden, the flood control volume can be placed on top of or downstream of the rain garden. Locating the flood control volume downstream can reduce the total depth of the rain garden, which will result in a more attractive BMP, and also benefit the vegetation in the flood control area because inundation and associated sedimentation will be less frequent, limited to events exceeding the WQCV.

1.10 Land Use, Compatibility with Surroundings, and Safety

Stormwater quality areas can add interest and diversity to a site, serving multiple purposes in addition to providing water quality functions. Gardens, plazas, rooftops, and even parking lots can become amenities and provide visual interest while performing stormwater quality functions and reinforcing urban design goals for the neighborhood and community. The integration of BMPs and associated landforms, walls, landscape, and materials can reflect the standards and patterns of a neighborhood and help to create lively, safe, and pedestrian-oriented districts. The quality and appearance of stormwater quality facilities should

reflect the surrounding land use type, the immediate context, and the proximity of the site to important civic spaces. Aesthetics will be a more critical factor in highly visible urban commercial and office areas than at a heavy industrial site. The standard of design and construction should maintain and enhance property values without compromising function (WWE et al. 2004).

Public access to BMPs should be considered from a safety perspective. The highest priority of engineers and public officials is to protect public health, safety, and welfare. Stormwater quality facilities must be designed and maintained in a manner that does not pose health or safety hazards to the public. As an example, steeply sloped and/or walled ponds should be avoided. Where this is not possible, emergency egress, lighting and other safety considerations should be incorporated. Facilities should be designed to reduce the likelihood and extent of shallow standing water that can result in mosquito breeding, which can be a nuisance and a public health concern (e.g., West Nile virus). The potential for nuisances, odors and prolonged soggy conditions should be evaluated for BMPs, especially in areas with high pedestrian traffic or visibility.

1.11 Maintenance and Sustainability

Maintenance should be considered early in the planning and design phase. Even when BMPs are thoughtfully designed and properly installed, they can become eyesores, breed mosquitoes, and cease to function if not properly maintained. BMPs can be more effectively maintained when they are designed to allow easy access for inspection and maintenance and to take into consideration factors such as property ownership, easements, visibility from easily accessible points, slope, vehicle access, and other factors. For example, fully consider how and with what equipment BMPs will be maintained in the future. Clear, legally-binding written agreements assigning maintenance responsibilities and committing adequate funds for maintenance are also critical (WWE et al. 2004). The MS4 permit holder may also require right of access to perform emergency repairs/maintenance should it become necessary.

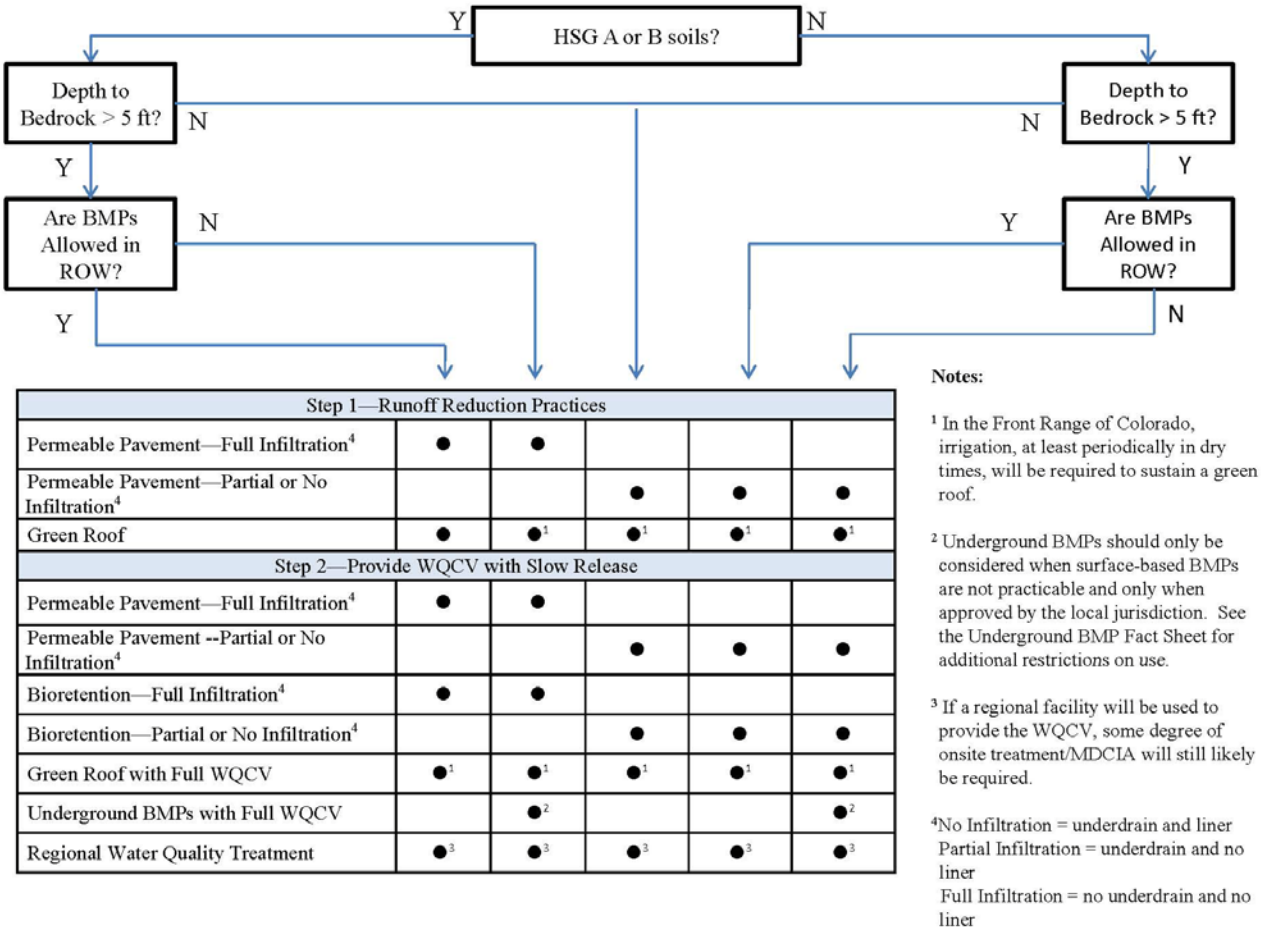
Sustainability of BMPs is based on a variety of considerations related to how the BMP will perform over time. For example, vegetation choices for BMPs determine the extent of supplemental irrigation required. Choosing native or drought-tolerant plants and seed mixes (as recommended in the *Revegetation* chapter of Volume 2) helps to minimize irrigation requirements following plant establishment. Other sustainability considerations include watershed conditions. For example, in watersheds with ongoing development, clogging of infiltration BMPs is a concern. In such cases, a decision must be made regarding either how to protect and maintain infiltration BMPs, or whether to allow use of infiltration practices under these conditions.

1.12 Costs

Costs are a fundamental consideration for BMP selection, but often the evaluation of costs during planning and design phases of a project focuses narrowly on up-front, capital costs. A more holistic evaluation of life-cycle costs including operation, maintenance and rehabilitation is prudent and is discussed in greater detail in Section 4 of this chapter. From a municipal perspective, cost considerations are even broader, involving costs associated with off-site infrastructure, channel stabilization and/or rehabilitation, and protection of community resources from effects of runoff from urban areas.

2.0 BMP Selection Tool

To aid in selection of BMPs, UDFCD has developed a BMP selection tool (*UD-BMP*) to guide users of this manual through many of the considerations identified above and to determine what types of BMPs are most appropriate for a site. This tool helps to screen BMPs at the planning stages of development and can be used in conjunction with the *BMP-REALCOST* tool described in Section 4. Simplified schematics of the factors considered in the *UD-BMP* tool are provided in Figures 2-1, 2-2, and 2-3, which correspond to highly urbanized settings, conventional developments, and linear construction in urbanized areas. Separate figures are provided because each setting or type of development presents unique constraints. Highly urbanized sites are often lot-line to lot-line developments or redevelopments with greater than 90 percent imperviousness with little room for BMPs. Linear construction typically refers to road and rail construction.



Step 1—Runoff Reduction Practices					
Permeable Pavement—Full Infiltration[4]	●	●			
Permeable Pavement—Partial or No Infiltration[4]			●	●	●
Green Roof	●	●[1]	●[1]	●[1]	●[1]
Step 2—Provide WQCV with Slow Release					
Permeable Pavement—Full Infiltration[4]	●	●			
Permeable Pavement --Partial or No Infiltration[4]			●	●	●
Bioretention—Full Infiltration[4]	●	●			
Bioretention—Partial or No Infiltration[4]			●	●	●
Green Roof with Full WQCV	●[1]	●[1]	●[1]	●[1]	●[1]
Underground BMPs with Full WQCV		●[2]			●[2]
Regional Water Quality Treatment	●[3]	●[3]	●[3]	●[3]	●[3]

Notes:

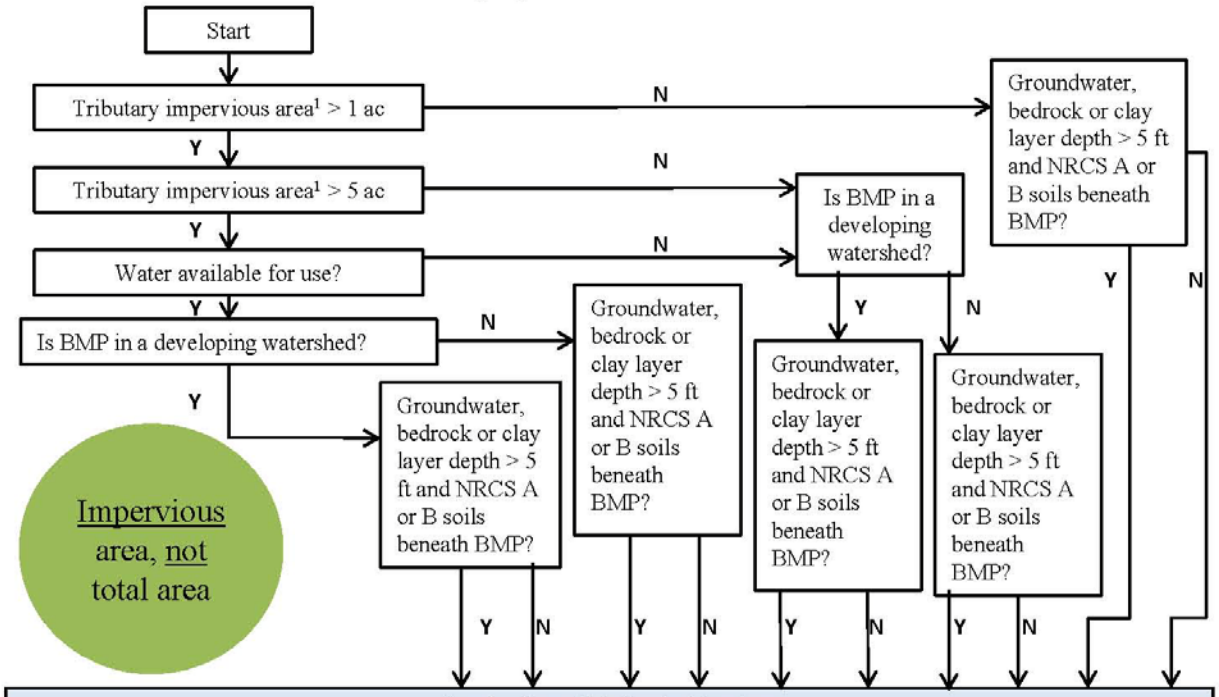
[1] In the Front Range of Colorado, irrigation, at least periodically in dry times, will be required to sustain a green roof.

[2] Underground BMPs should only be considered when surface-based BMPs are not practicable and only when approved by the local jurisdiction. See the Underground BMP Fact Sheet for additional restrictions on use.

[3] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.

[4] No Infiltration = underdrain and liner
Partial Infiltration = underdrain and no liner
Full Infiltration = no underdrain and no liner

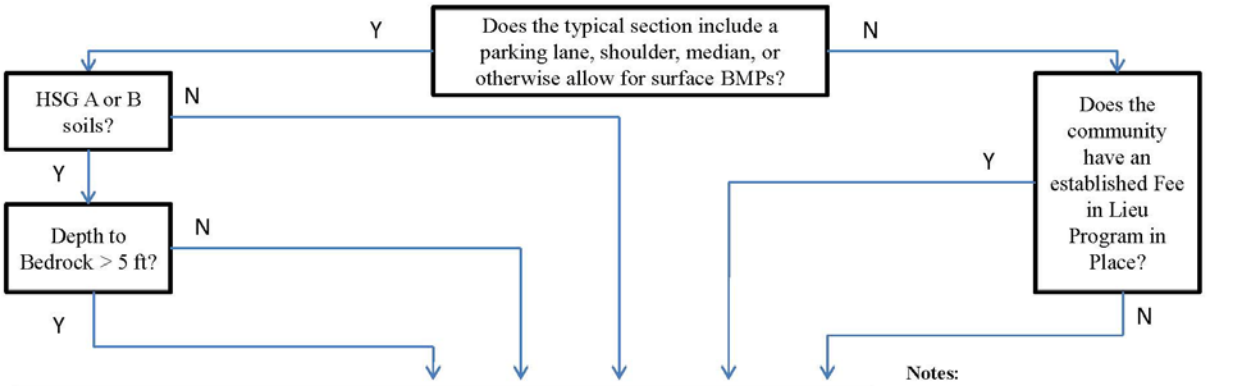
Figure 2-1. BMP Decision Tree for Highly Urbanized Sites



Step 1—Runoff Reduction Practices										
Grass Swale	●	●	●	●	●	●	●	●	●	●
Grass Buffer	●	●	●	●	●	●	●	●	●	●
Constructed Wetland Channel[2]	●[2]	●[2]	●[2]	●[2]						
Permeable Pavement—Full Infiltration[5]			●[6]				●[6]		●	
Permeable Pavement—No or Partial Infiltration[5]				●[6]				●[6]		●
Green Roof	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3]	●[3]
Step 2—Provide WQCV with Slow Release										
Permeable Pavement — Full Infiltration[5]			●[6]				●[6]		●	
Permeable Pavement – No or Partial Infiltration[5]				●[6]				●[6]		●
Bioretention—Full Infiltration[5]			●[6]				●[6]		●	
Bioretention—No or Partial Infiltration[5]				●[6]				●[6]		●
Extended Dry Detention Basin	●		●		●		●			
Constructed Wetland Basin[2]	●	●	●	●						
Retention Pond	●	●	●	●						
Sand Filter Extended Detention--Full Infiltration[5]			●				●		●	
Sand Filter Extended Detention--No or Partial Infiltration[5]				●				●		●
Green Roof	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3]	●[3]
Regional Water Quality Treatment	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]

Notes: [1] "Tributary impervious area" refers to the impervious area draining to the BMP, **not** the total area of the project site.
[2] For a successful wetland channel or basin, a water source (groundwater or baseflow) will be required.
[3] In the Front Range of Colorado, irrigation, at least periodically in dry times, will be required to sustain a green roof.
[4] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.
[5] No Infiltration = underdrain and liner, Partial Infiltration = underdrain and no liner, Full Infiltration = no underdrain and no liner.
[6] Consider this BMP for a portion of your site. It's best suited for impervious tributary areas of approximately one acre or less.

Figure 2-2. BMP Decision Tree for Conventional Development Sites



Step 1—Runoff Reduction Practices					
Permeable Pavement—Full Infiltration[3]	●				
Permeable Pavement—Partial or No Infiltration[3]		●	●		
Biofiltration Tree Planter	●	●	●	●	●
Step 2—Provide WQCV with Slow Release					
Permeable Pavement—Full Infiltration[3]	●				
Permeable Pavement –Partial or No Infiltration[3]		●	●		
Bioretention—Full Infiltration[3]	●				
Bioretention—Partial or No Infiltration[4]		●	●		
Fee in Lieu/Offsite Mitigation				●[4]	
Underground BMPs with Full WQCV				●[1]	●[1]
Regional Water Quality Treatment	●[2]	●[2]	●[2]	●[2]	●[2]

Notes:

[1] Underground BMPs should only be considered when surface-based BMPs are not practicable and only when approved by the local jusisdiction. See the Underground BMP Fact Sheet for additional restrictions on use.

[2] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.

[3] No Infiltration = underdrain and liner
Partial Infiltration = underdrain and no liner
Full Infiltration = no underdrain and no liner

[4] Only recommended when the community has an established program for "Fee in Lieu"

Figure 2-3. BMP Decision Tree for Linear Construction in Urbanized Areas

3.0 Life Cycle Cost and BMP Performance Tool

The importance of cost effective BMP planning and selection is gaining recognition as agencies responsible for stormwater management programs continue to face stricter regulations and leaner budgets. The goal of the *BMP-REALCOST* tool is to help select BMPs that meet the project objectives at the lowest unit cost, where the project objectives are quantifiable measures such as reducing pollutant loads or runoff volumes to a receiving water. To do so, UDFCD has developed an approach that provides estimates for both the whole life costs and performance of BMPs. The approach was developed to be most effective at the large-scale, planning phase; however, it can also be applied to smaller scales during the design phase, perhaps with minor loss of accuracy. The *BMP-REALCOST* spreadsheet tool incorporates this approach and requires minimal user inputs in order to enhance its applicability to planning level evaluations. An overview of the general concepts providing the underlying basis of the tool follows.

3.1 BMP Whole Life Costs

Whole life costs (also known as life cycle costs) refer to all costs that occur during the economic life of a project. This method of cost estimating has gained popularity in the construction and engineering fields over the past few decades and the American Society of Civil Engineers (ASCE) encourages its use for all civil engineering projects. Generally, the components of the whole life cost for a constructed facility include construction, engineering and permitting, contingency, land acquisition, routine operation and maintenance, and major rehabilitation costs minus salvage value. In addition, UDFCD recommends the cost of administering a stormwater management program also be included as a long-term cost for BMPs. Reporting whole life costs in terms of net present value (NPV) is an effective method for comparing mutually exclusive alternatives (Newnan 1996).

To understand the value of using whole life cost estimating, one must first realize how the various costs of projects are generally divided amongst several stakeholders. For example, a developer is typically responsible for paying for the "up front" costs of construction, design, and land acquisition; while a homeowners' association or stormwater management agency becomes responsible for all costs that occur after construction. Many times, the ratios of these costs are skewed one way or another, with BMPs that are less expensive to design and construct having greater long-term costs, and vice versa. This promotes a bias, depending on who is evaluating the BMP cost effectiveness. Whole life cost estimating removes this bias; however, successful implementation of the concept requires a cost-sharing approach where the whole life costs are equitably divided amongst all stakeholders.

The methods incorporated into the *BMP-REALCOST* tool for estimating whole life costs are briefly described below. All cost estimates are considered "order-of-magnitude" approximations, hence UDFCD's recommendation of using this concept primarily at the planning level.

- **Construction Costs:** Construction costs are estimated using a parametric equation that relates costs to a physical parameter of a BMP; total storage volume (for storage-based BMPs), peak flow capacity (for flow-based or conveyance BMPs) or surface area (for permeable pavements).

- **Contingency/Engineering/Administration Costs:** The additional costs of designing and permitting a new BMP are estimated as a percentage of the total construction costs. For Denver-area projects, a value of 40% is recommended if no other information is available.

- **Land Costs:** The cost of purchasing land for a BMP is estimated using a derived equation that incorporates the number of impervious acres draining to the BMP and the land use designation in which the BMP will be constructed.

- **Maintenance Costs:** Maintenance costs are estimated using a derived equation that relates average annual costs to a physical parameter of the BMP.

- **Administration Costs:** The costs of administering a stormwater management program are estimated as percentage of the average annual maintenance costs of a BMP. For Denver-area projects, a value of 12% is recommended if no other information is available.

- **Rehabilitation/Replacement Costs:** After some period of time in operation, a BMP will require "major" rehabilitation. The costs of these activities (including any salvage costs or value) are estimated as a percentage of the original construction costs and applied near the end of the facility's design life. The percentages and design lives vary according to BMP.

3.2 BMP Performance

The performance of structural BMPs can be measured as the reduction in stormwater pollutant loading, runoff volume and runoff peak flows to the receiving water. It is generally acknowledged that estimating BMP performance on a storm-by-storm basis is unreliable, given the inherent variability of stormwater hydrologic and pollutant build-up/wash off processes. Even if the methods to predict event-based BMP performance were available, the data and computing requirements to do so would likely not be feasible at the planning level. Instead, UDFCD recommends an approach that is expected to predict long-term (i.e. average annual) BMP pollutant removal and runoff volume reduction with reasonable accuracy, using BMP performance data reported in the International Stormwater BMP Database (as discussed in Section 1.3).

3.3 Cost Effectiveness

The primary outputs of the *BMP-REALCOST* tool include net present value (NPV) of the whole life costs of the BMP(s) implemented, the average annual mass of pollutant removed (P_R, lbs/year) and the average annual volume of surface runoff reduced (R_R, ft^3/year). These reported values can then be used to compute a unit cost per lb of pollutant (C_P) or cubic feet of runoff (C_R) removed over the economic life (n, years) of the BMP using Equations 2-1 and 2-2, respectively.

$$C_P = \frac{NPV}{nP_R} \qquad \text{Equation 2-1}$$

$$C_R = \frac{NPV}{nR_R} \qquad \text{Equation 2-2}$$

4.0 Conclusion

A variety of factors should be considered when selecting stormwater management approaches for developments. When these factors are considered early in the design process, significant opportunities exist to tailor stormwater management approaches to site conditions. Two worksheets are available at www.udfcd.org for the purpose of aiding in the owner or engineer in the proper selection of treatment BMPs. The *UD-BMP* tool provides a list of BMPs for consideration based on site-specific conditions. *BMP-REALCOST* provides a comparison of whole life cycle costs associated with various BMPs based on land use, watershed size, imperviousness, and other factors.

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Chapter 3
Calculating the WQCV and Volume Reduction

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1.0 Introduction

This chapter presents the hydrologic basis and calculations for the Water Quality Capture Volume (WQCV) and discusses the benefits of attenuating this volume or that of the Excess Urban Runoff Volume (EURV). This chapter also describes various methods for quantifying volume reduction when using Low Impact Development (LID) practices. Use of these methods should begin during the planning phase for preliminary sizing and development of the site layout. The calculations and procedures in this chapter allow the engineer to calculate the WQCV and more accurately quantify potential volume reduction benefits of stormwater control measures (BMPs).

2.0 Hydrologic Basis of the WQCV

2.1 Development of the WQCV

The purpose of designing control measures based on the WQCV is both to improve water quality and reduce hydromodification and the associated impacts on receiving waters. (These impacts are described in Chapter 1.) Although flow-based BMPs can remove pollutants, in order to offset the hydrologic impacts of urbanization including increases to flow, volume, duration, and frequency, BMPs must be designed to reduce (infiltrate) a significant portion of the WQCV or to treat and slowly release the WQCV. This section provides a brief background on the development of the WQCV.

The WQCV is based on an analysis of rainfall and runoff characteristics for 36 years of record at the Denver Stapleton Rain Gage (1948-1984) conducted by Urbonas, Guo, and Tucker (1989) and documented in *Sizing a Capture Volume for Stormwater Quality Enhancement* (available at www.MHFD.org). In 2019, Mile High Flood District (MHFD) repeated this analysis for an extended period of record, including data from 1985 - 2013, using the Water Quality Capture Optimization and Statistical Model (WQ-COSM), Version 2.0 (Urban Watersheds Research Institute [UWRI] 2012). Results of the updated WQ-COSM analysis were essentially unchanged from the earlier analysis by Urbonas et al. for the mean storm depth, the 80th percentile runoff-producing event and the overall percentile distribution of rainfall depths.

Table 3-1 summarizes the relationship between total storm depth and the annual number of storms based on the updated WQ-COSM analysis. Development of the WQCV disregards storm events with no anticipated runoff, events 0.1 inches and smaller. As the table shows, these small storms that do not produce significant runoff represent 45 of the 74 storm events that occur on an average annual basis, or 61% of rainfall events. Urbonas et al. (1989) identified the runoff produced from a precipitation event of 0.6 inches as the optimal target for the WQCV, where treating larger volumes has a diminishing return of investment in terms of the number of storms captured and treated. The 0.6-inch precipitation depth corresponds to the 80th percentile of runoff-producing storms. The WQCV for a given watershed will vary depending on the imperviousness and the drain time of the BMP, but assuming 0.1 inches of depression storage for impervious areas, the maximum capture volume required is approximately 0.5 inches over the area of the watershed. Urbonas et al. (1989) concluded treating and detaining the volume of runoff produced from impervious areas during these storms can significantly improve water quality.

Using WQCV and Flood Control Hydrology

Channels are typically designed for an event that is large and infrequent, such as the 100-year event. A common misconception is that these large events are also responsible for most of the erosion within the stream. Instead, the *effective discharge*, by definition, is the discharge that transports the most sediment on an annual basis and this is a good estimate of the *channel-forming flow* or the discharge that shapes the stream through sediment transport and erosion. The effective discharge does not correlate with a specific return period, but often is characterized as a magnitude between the annual (1-year) event and the 5-year peak flow, depending on watershed-specific characteristics.

The typical flood control facility design may include peak reduction of the 5- or 10-year storm event as well as the 100-year event. Widespread use of minor and major event detention reduces flooding of streets and streams. However, this practice does little to limit the frequency of channel-forming flows. MHFD recommends *Full Spectrum Detention*, a concept developed to replicate historic peak flows for a broad spectrum of storm events. This method is described in more detail in the *Storage* chapter of Volume 2 of the USDCM.

Widespread use of full spectrum detention would, in theory, improve channel stability and reduce erosion; however, full spectrum detention does not necessarily reduce volume, duration, and frequency, which also contribute to instability.

Therefore, this manual provides a variety of BMPs that provide the WQCV and address hydrologic effects of urbanization through storage, infiltration, and/or evapotranspiration.

Table 3-1. Number of Rainfall Events in the Denver Area.

(Adapted from Urbonas et al. 1989, updated with additional data [1985 – 2013] by MHFD 2019)

Total Rainfall Depth (inches)	Average Annual Number of Storm Events	Percent of Total Storm Events	Percentile of Runoff-producing Storms
0.0 to 0.1	45	60.9%	0.0%
0.1 to 0.5	22	29.4%	75.2%
≤ 0.6	**68**	**92.2%**	**80%**
0.5 to 1.0	4.6	6.3%	91.1%
1.0 to 1.5	1.5	2.1%	96.6%
1.5 to 2.0	0.6	0.8%	98.6%
2.0 to 3.0	0.2	0.3%	99.4%
3.0 to 4.0	0.15	0.2%	99.9%
4.0 to 5.0	0.015	<0.1%	100%
> 5.0	0	<0.1%	100%
TOTAL:	**74**	**100%**	**100%**

2.2 Optimizing the Capture Volume

Optimizing the capture volume is critical. If the capture volume is too small, the effectiveness of the BMP will be reduced due to the frequency of storms exceeding the capacity of the facility and allowing some volume of runoff to bypass treatment. On the other hand, if the capture volume for a BMP that provides treatment through sedimentation is too large, the smaller runoff events may pass too quickly through the facility, without the residence time needed to provide treatment.

Small, frequently occurring storms account for the predominant number of events that result in stormwater runoff from urban catchments. Consequently, these frequent storms also account for a significant portion of the annual pollutant loads. Capture and treatment of the stormwater from these small and frequently occurring storms is the recommended design approach for water quality enhancement, as opposed to flood control facility designs that focus on less frequent, larger events.

The analysis of precipitation data at the Denver Stapleton Rain Gage revealed a relationship between the percent imperviousness of a watershed and the capture volume needed to significantly reduce stormwater pollutants (Urbonas, Guo, and Tucker, 1990). Subsequent studies (Guo and Urbonas, 1996 and Urbonas, Roesner, and Guo, 1996) of precipitation resulted in a recommendation by the Water Environment Federation and American Society of Civil Engineers (1998) that stormwater quality treatment facilities (i.e., post-construction BMPs) be based on the capture and treatment of runoff from storms ranging in size from "mean" to "maximized[1]" storms. The "mean" and "maximized" storm events represent the 70th and 90th percentile storms, respectively. Based on these studies, water quality facilities for the Colorado Front Range should capture and treat the 80th percentile runoff-producing event. Capturing and properly treating this volume should remove between 80 and 90% of the annual total suspended solids (TSS) load, while doubling the capture volume was estimated to increase the removal rate by only 1 to 2%.

2.3 Attenuation of the WQCV (BMP Drain Time)

The WQCV must be released over an extended period to provide effective pollutant removal for post-construction BMPs that use sedimentation (i.e., extended detention basin, retention ponds and constructed wetland ponds). A field study of basins with extended detention in the Washington, D.C. area identified an average drain time of 24 hours to be effective for extended detention basins. This generally equates to a 40-hour drain time for the brim-full basin. Retention ponds and constructed wetland basins have reduced drain times (12 hours and 24 hours, respectively) because the hydraulic residence time of the effluent is essentially increased due to the mixing of the inflow with the permanent pool.

When pollutant removal is achieved primarily through filtration such as in a sand filter or rain garden BMP, MHFD still recommends an extended drain time to promote stability of the receiving stream. In addition to counteracting hydromodification, attenuation in filtering BMPs can also improve pollutant removal by increasing contact time, which aids adsorption/absorption processes. The minimum recommended drain time for a post-construction BMP is 12 hours; however, this minimum value should only be used for BMPs where filtration is the primary treatment process, sometimes referred to as “filtration BMPs.”

2.4 Excess Urban Runoff Volume (EURV) and Full Spectrum Detention

The EURV represents the difference in stormwater runoff volume between the developed and pre-developed runoff volume for the range of storms that produce runoff from pervious land surfaces. The EURV is relatively constant volume for a given imperviousness regardless of recurrence interval. Consistent with the concept of treating and slowly releasing the WQCV, the EURV is a greater volume than the WQCV and is detained over a longer time. It typically accommodates the recommended drain

time of the WQCV and is used to better replicate peak discharge in receiving waters for runoff events exceeding the WQCV. The EURV is associated with full spectrum detention which refers to a design method that includes slow release of the EURV as well as flood control detention. Designing a detention basin to capture the EURV and release it very slowly results in reduced flow rates for frequent storm events and thus reduced erosion. This method, however, does not address volume and duration which also contribute to stream and stability. This is why volume reduction practices are also necessary.

For additional information on the EURV and full spectrum detention, including calculation procedures, please refer to the *Storage* chapter of Volume 2.

[1] The term "maximized storm" refers to the optimization of the storage volume of a BMP. The WQCV for the "maximized" storm represents the point of diminishing returns in terms of the number of storm events and volume of runoff fully treated versus the storage volume provided.

3.0 Calculation of the WQCV

The WQCV is calculated as a function of imperviousness and BMP type using Equation 3-1 and Table 3-2, and as shown in Figure 3-1:

$$WQCV = a\left(0.91I^3 - 1.19I^2 + 0.78I\right) \quad \textbf{Equation 3-1}$$

Where:

WQCV = Water Quality Capture Volume (watershed-inches)

a = Coefficient corresponding to BMP type and based on WQCV design drain time (Table 3-2)

I = Imperviousness (percent expressed as a decimal) Note: At a planning level, the watershed imperviousness can be estimated based on the zoned density. When finalizing design, calculate imperviousness based on the site plan.

Table 3-2. Drain Time Coefficients for WQCV Calculations

Drain Time (hours)	Coefficient, a
12 hours (filtration BMPs and retention ponds)	0.8
24 hours (constructed wetland ponds)	0.9
40 hours (extended detention)	1.0
No attenuation (e.g., grass buffer or swale)	1.0

Figure 3-2, which illustrates the relationship between imperviousness and WQCV for various drain times, is appropriate for use in Colorado's high plains near the foothills. For areas beyond this region, use WQ-COSM (UWRI 2013) and local rainfall data to determine precipitation depth for WQCV event.

After calculating WQCV in watershed-inches, convert this to a volume using Equation 3-2. Note that the area in this equation is the entirety of the area tributary to the control measure. This is regardless of the volume treated upstream.

$$V = \frac{WQCV}{12} A \quad \textbf{Equation 3-2}$$

Where:

V = required storage volume (acre-feet)

A = watershed tributary area upstream (acres)

WQCV = Water Quality Capture Volume (watershed-inches)

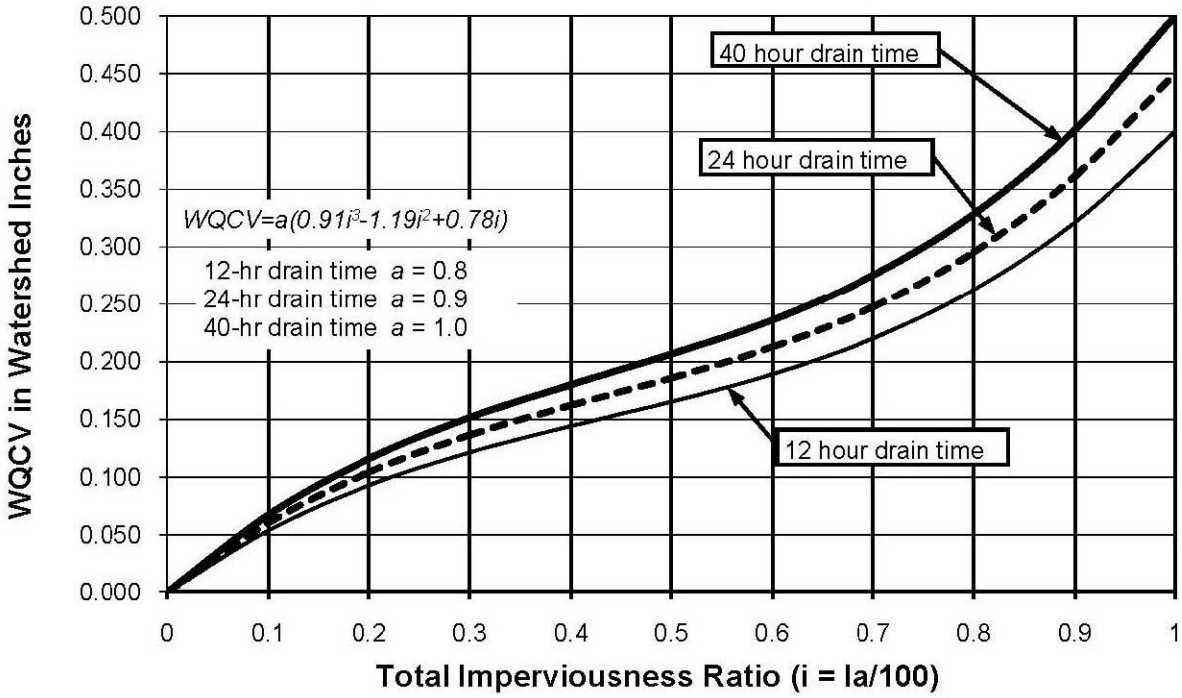

Figure 3-1. Water Quality Capture Volume (WQCV) Based on BMP Drain Time

4.0 Quantifying Volume Reduction

Runoff volume reduction is an important part of the Four Step Process for stormwater management as discussed in Chapter 1 and is fundamental to effectively manage stormwater runoff. Quantifying volume reduction associated with LID practices and other BMPs is important for watershed master planning as well as conceptual and final site design. It is also important in a regulatory context with the Runoff Reduction Standard that is included in the 2016 General MS4 Permit. A variety of approaches have been developed in the past to quantify volume reduction including "Level 1" and "Level 2" MDCIA curves for watershed-level models, Effective Imperviousness curves developed from modeling for site-level design, and others. The hydrologic response of watersheds and sites utilizing MDCIA and other volume reduction practices is an area of ongoing monitoring and research in the field of urban hydrology. Methods of quantifying runoff reduction are evolving and improving. The approaches recommended in this section are backed by physically-based modeling of rainfall-runoff, using input parameters that can be easily measured or estimated. These methods have been compared with field data from infiltration tests on receiving pervious areas including swales and provide good agreement with field data.

The approach recommended in this section is based on the Four-Component Land Use Model that is used by the Colorado Urban Hydrograph Procedure (CUHP) and the EPA Stormwater Management Model (SWMM). This conceptual model, illustrated in Figure 3-3, represents a drainage area by four components:

- Directly Connected Impervious Area (DCIA) – DCIA is impervious area that drains to the storm drain system or stream without flowing over surfaces that would allow for infiltration.

- Unconnected Impervious Area (UIA) – UIA is impervious area that drains to a receiving pervious area, where there is an opportunity for infiltration.
- Receiving Pervious Area (RPA) – RPA is pervious area that receives runoff from UIA and allows for infiltration.
- Separate Pervious Area (SPA) – SPA is pervious area that does not receive runoff from impervious surfaces.

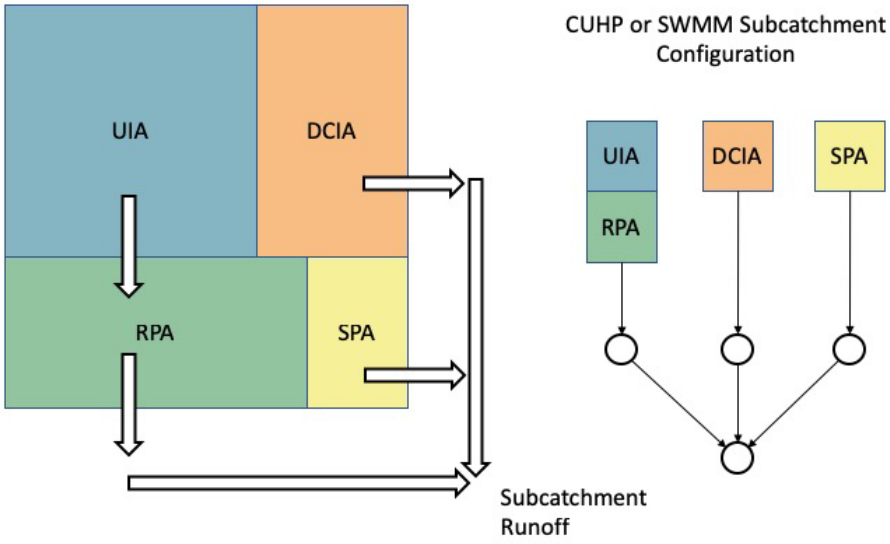

Figure 3-2. Four Component Land Use Model

Photograph 3-1. Separate Pervious Area (SPA) is permeable but does not receive runoff from impervious areas, such as the tree lawn in this photo. The drive and street are examples of DCIA.

Photograph 3-2. Directly Connected Impervious Area (DCIA) drains directly to a storm drain inlet with no opportunities for infiltration.

Photograph 3-3. Unconnected impervious area (UIA) draining to receiving pervious area (RPA). Vegetated buffer strips and/or raingardens are common ways to disconnect impervious area in parking lots.

Three approaches for quantifying runoff volume reduction are discussed in this section:

- Level 1 and 2 MDCIA: MHFD has developed curves for approximating LID effects at early planning stages. Level 1 and 2 MDCIA curves allow users to evaluate runoff reduction for two conceptual levels of LID implementation, described below. Only use these curves at early planning stages. Once the four land use fractions can be quantified, apply a more detailed method (CUHP-SWMM or the UD-BMP Runoff Reduction spreadsheet).

- CUHP and EPA SWMM: Use this approach to explicitly model directly connected and unconnected impervious areas, vegetated conveyances and BMPs, including LID practices. This method is appropriate at scales ranging from several acres (block or neighborhood scale) to several square miles (watershed scale, with appropriate sub-basin discretization).

- UD-BMP Runoff Reduction spreadsheet: This spreadsheet was developed by MHFD based on thousands of SWMM scenarios with variations of total area, ratio of UIA to RPA, hydrologic soil group, slope, roughness, depression storage, and length-to-width ratio. This approach is best-suited for small watersheds, where UIA-RPA pairs total less than 1 acre and sheet flow conditions prevail.

Infiltration Parameters for Runoff Reduction Analysis

Infiltration parameters used to evaluate runoff reduction from frequently occurring storms may vary from infiltration parameters for modeling larger flood events. A degree of conservatism is appropriate for flood modeling to account for unknowns including antecedent moisture conditions, heterogeneity of subsurface conditions, compaction of pervious areas, and others. When evaluating infiltration associated with frequent events, rates somewhat higher than those in the *Runoff* chapter that are based on Hydrologic Soil Groups (HSGs) are appropriate.

As an example, a Fondis Silt Loam soil is classified as HSG C, which corresponds to a final infiltration rate of 0.5 inches per hour in Table 6-7 of the *Runoff* chapter of Volume 1. Based on the NRCS Web Soil Survey, the saturated hydraulic conductivity (final infiltration rate) is 1.3 inches per hour. The value from Table 6-7 of the *Runoff* chapter (0.5 inches per hour) is appropriate for evaluating flood events, where it is appropriate to be more conservative, while the saturated hydraulic conductivity from the Web Soil Survey (1.3 inches per hour) may be appropriate for evaluating water quality events.

To determine appropriate infiltration rates for evaluating volume reduction from small storm events, use information on saturated hydraulic conductivity from the NRCS Web Soil Survey or data from a geotechnical report. Field measurements of infiltration rates using an infiltrometer also provide useful site-specific data for quantifying volume reduction.

4.1 Watershed/Master Planning-level Volume Reduction Method

For watershed-level assessments and master planning, CUHP provides options for users to model effects of LID through the "D" and "R" curves that are embedded in the model. The "D" curve relates the ratio of DCIA to total impervious area ($D = A_{DCIA}/A_{Imp}$). The "R" curve relates the ratio of RPA to total pervious area ($R = A_{RPA}/A_{Perv}$). Since site-level details (i.e., specific percentages of DCIA, UIA, RPA and SPA for a parcel or site-level drainage basin) are not generally known at the master planning level, MHFD has developed default values for D and R in CUHP based on SWMM modeling and analysis of typical developments in the Denver metropolitan area. For any given value of total imperviousness, the

CUHP model assigns values of D and R based on overall imperviousness and typical development patterns for two levels of LID implementation, MDCIA Level 1 and MDCIA Level 2:

> **MDCIA Level 1.** The primary intent is to direct the runoff from impervious surfaces to flow over grass-covered areas and/or permeable pavement, and to provide sufficient travel time to facilitate the removal of suspended solids before runoff leaves the site, enters a curb and gutter system, or enters another stormwater collection system. Thus, at Level 1, to the extent practical, impervious surfaces are designed to drain over grass buffer strips or other pervious surfaces before reaching a stormwater conveyance system.
>
> **MDCIA Level 2.** As an enhancement to Level 1, Level 2 replaces solid street curb and gutter systems with no curb or slotted curbing, low-velocity grass-lined swales and pervious street shoulders, including pervious rock-lined swales. Conveyance systems and storm drain inlets are still needed to collect runoff at downstream intersections and crossings where stormwater flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways. The primary difference between Levels 1 and 2 is that for Level 2, a pervious conveyance system (i.e., swales) is provided rather than continuous pipes. Disconnection of roof drains and other lot-level impervious areas is essentially the same for both Levels 1 and 2.

Figure 3-3 and Figure 3-4 provide effective imperviousness values for Level 1 and Level 2. Because rainfall intensity varies with return interval, the effective imperviousness also varies, as demonstrated by the separate curves for the 2-, 10- and 100-year return intervals. Effective impervious values from these figures are appropriate only as an estimate of the WQCV. These figures should not be used for final design. Figure 3-3 and Figure 3-4 are intended for use at the planning level before the specific D and R relationships in CUHP are known.

Note that the reductions in effective imperviousness shown in Figure 3-3 and Figure 3-4 are relatively modest, ranging from little to no benefit for large events up to a reduction of approximately 12% (from 50% to 38%) for Level 2 MDCIA during the 2-year event. At a more advanced stage of design and when site-specific disconnected areas, receiving pervious areas, flow paths, and other design details are available, the site-level methods in Sections 4.2 and 4.3 will better quantify volume reduction. Results will typically show greater reductions in effective imperviousness for aggressive LID implementation than reflected in the default D and R relationships used to create Figure 3-3 and Figure 3-4. Even so, it is unlikely that conveyance-based BMPs alone will provide adequate pollutant removal and volume reduction for most project sites, and a storage-based BMP will also be required.

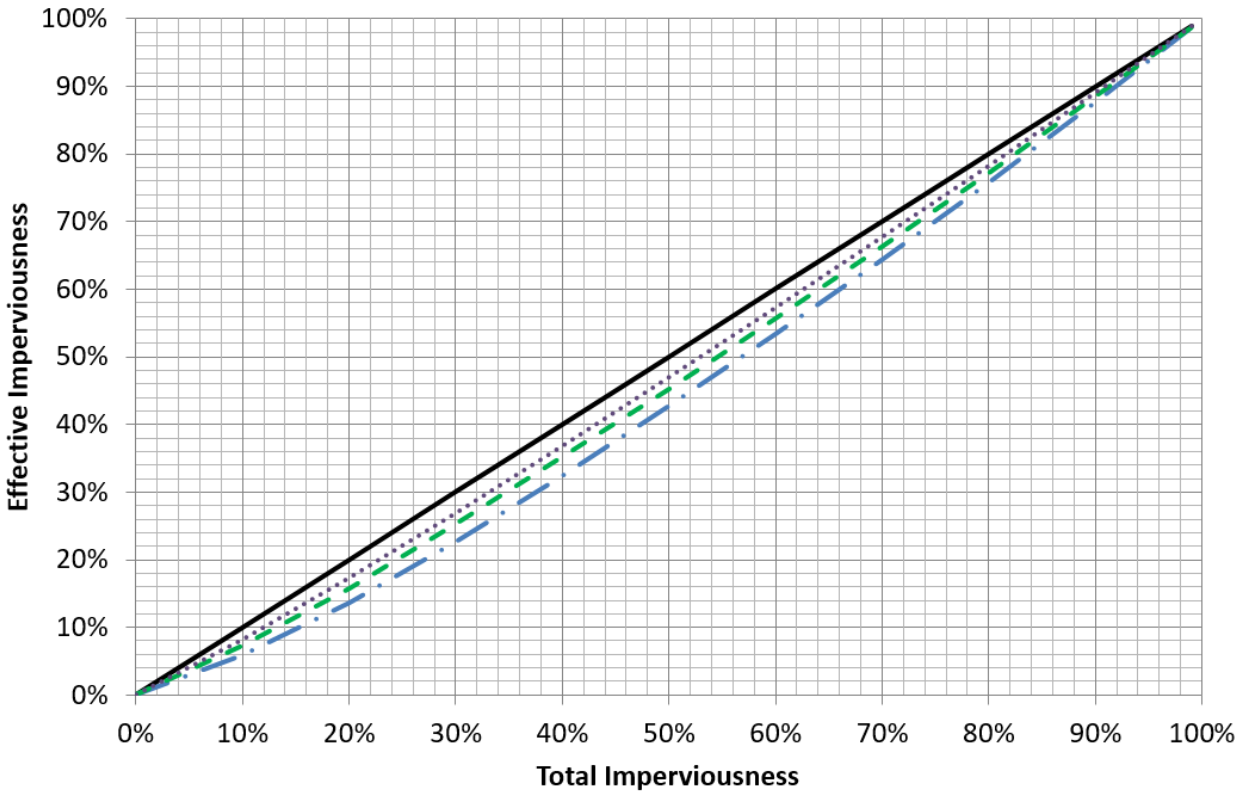

Figure 3-3. Effective Imperviousness Adjustments for Level 1 MDCIA

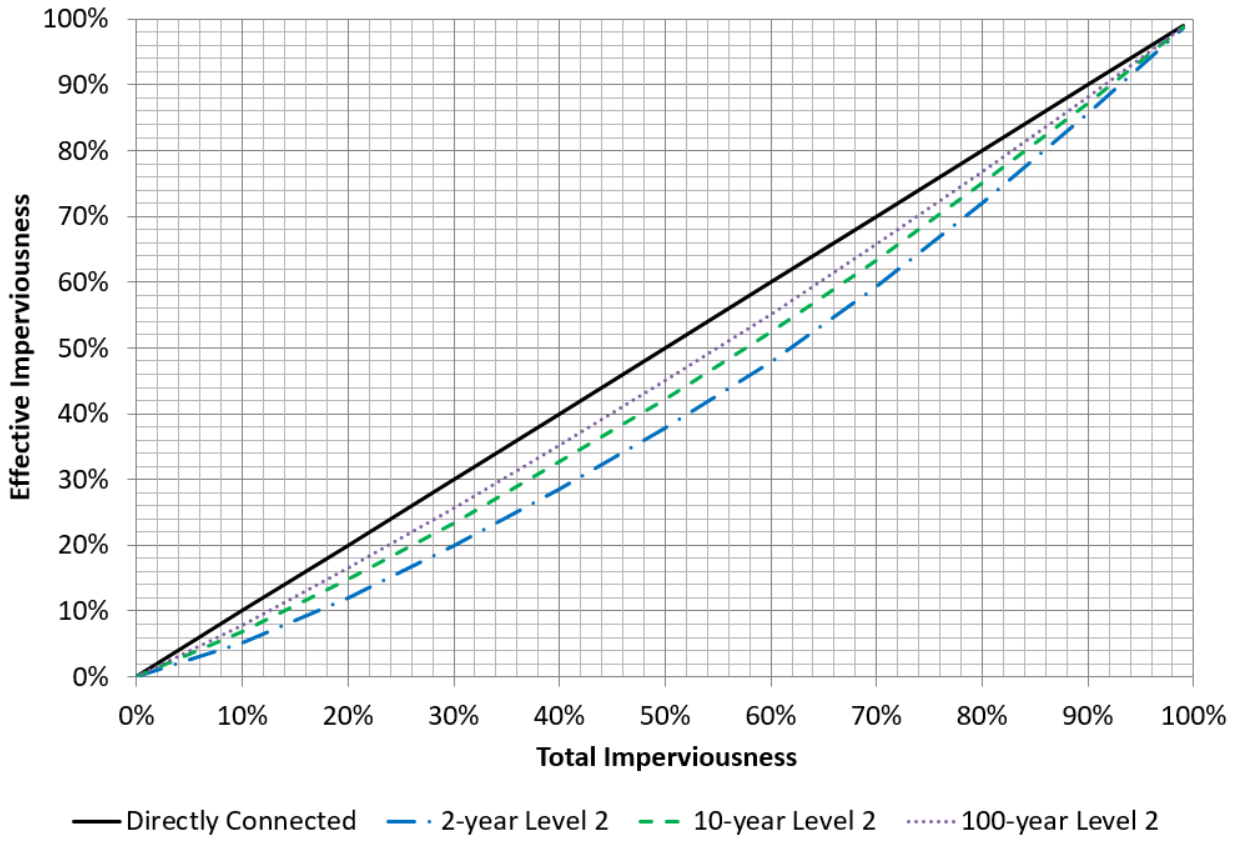

Figure 3-4. Effective Imperviousness Adjustments for Level 2 MDCIA

4.2 CUHP-SWMM Modeling of Volume Reduction

CUHP-SWMM is used for MHFD master plans at the watershed scale and for planning and design of infrastructure at the master development and filing scales. CUHP-SWMM can be applied at a lot or block scale as well, but simplified modeling methods, including UD-BMP, UD-Rational and/or UD-Detention (all of which are available at MHFD.org, are more common at the finer scales. The CUHP-SWMM approach uses CUHP to perform hydrologic calculations and SWMM to route hydrographs and represent detention and water quality features. The following sections provide methods to account for runoff reduction using CUHP-SWMM.

4.2.1 CUHP Imperviousness Parameters

Using standard settings, CUHP performs calculations that make implicit assumptions about connected and unconnected fractions of impervious area for typical development in the metropolitan area. The default assumptions in CUHP are for "incidental" disconnection of impervious area, typical of a development that is not intentionally designed with LID features. For watersheds or developments with deliberate implementation of LID to reduce runoff rates and volumes, the Subcatchment Override Parameters provide a way to specify the fractions of DCIA and RPA represented in Figure 3-2:

- The Directly Connected Impervious Fraction (DCIF) is a decimal fraction (e.g. 0.5 = 50%). The DCIF is equal to the percent of the impervious area that is directly connected to the drainage system. Based on the conceptual model in Figure 3-2, DCIF = DCIA/(UIA+DCIA).
- The Receiving Pervious Fraction (RPF) is the decimal fraction of receiving pervious area to total

pervious area. Based on the conceptual model in Figure 3-3, RPF = RPA/(SPA+RPA).

Peak runoff rates and volumes can vary significantly depending on these fractions, so the engineer should avoid overestimating the amount of RPA in a watershed. A common error in defining RPA is assuming that the entirety of drainage corridors, water quality features, and detention features act as RPA. Consider only the portion wetted by the design event. For example, the RPA associated with a drainage swale receiving runoff from an impervious area (UIA) would be the wetted perimeter of the swale for the design event multiplied by the length of the swale. This means a trapezoidal swale typically will be more efficient at reducing volume than a triangular swale. Upper portions of the swale side slopes that are not wetted by the design event are SPA, not RPA.

Along with accurately representing the extents and locations of RPAs to account for infiltration losses due to disconnected area, selection of soil infiltration parameters for pervious areas also may have significant effects on peak runoff rates and volumes. The values for infiltration parameters presented in Table 6-7 of the *Runoff* chapter of the USDCM for Hydrologic Soil Groups A, B and C/D are appropriate for flood modeling. For water quality events and channel forming events, infiltration rates for pervious areas may be adjusted based on site-specific data or soil permeability data from the NRCS Web Soil Survey to more accurately represent infiltration capabilities of pervious areas.

4.2.2 Conveyance Losses

EPA SWMM provides several options for evaluating conveyance losses that occur with permeable conveyances including vegetated swales and buffers. The option that is most compatible with the CUHP-SWMM modeling approach recommended by MHFD is the constant loss rate approach, which specifies constant infiltration rates for conveyance elements based on soil characteristics. To use this approach, the constant infiltration rate for the conveyance element (link) should be set to the saturated hydraulic conductivity for the type of soil underlying the swale or buffer area. Determine this value based on field measurements. In areas where the NRCS Web Soil Survey provides reliable data (e.g., undeveloped land), the Soil Survey may also be used for this purpose. In reality, infiltration will begin at an initial rate and decay to the final rate (saturated hydraulic conductivity); however, sensitivity analysis using typical decay coefficients from the *Runoff* chapter shows that the decay to the final rate is fairly rapid and that over a multi-hour runoff event, the saturated hydraulic conductivity is a reasonable and slightly conservative estimate of infiltration potential.

4.2.3 Detention and Water Quality Features

SWMM provides a seepage option for storage nodes to account for infiltration that occurs while runoff is stored in a water quality or detention facility. When using this option, the infiltration rate should be set to the saturated hydraulic conductivity based on field testing of the underlying soils. If evaluating long-term performance, consider further reducing the rate to account for clogging of pores due to sedimentation that will occur over time. Only use seepage losses in detention and water quality features when evaluating water quality events (not flood events) and when supporting infiltration data are available to justify parameter selection. Additionally, where underdrains are used, do not equate flow discharged from underdrain with infiltration.

4.3 UD-BMP Runoff Reduction Spreadsheet

Another approach for quantifying site-scale volume reduction is a simplified approach that is based on SWMM modeling of thousands of variations of UIA and RPA combinations with varying slopes, geometry, infiltration characteristics, roughness and depression storage. Based on this modeling analysis, MHFD developed a multi-variable regression equation that calculates volume reduction for the WQCV

based on input parameters including UIA, RPA, DCIA, and SPA, Hydrologic Soil Groups, the average RPA slope and the UIA:RPA interface width (Piza and Rapp 2018). The regression equation is incorporated into the UD-BMP workbook on the Runoff Reduction tab. The spreadsheet provides a simple tool that can be used to demonstrate compliance with the Runoff Reduction Standard in the MS4 General Permit. This spreadsheet is intended for application at the site scale rather than the watershed scale. Additional information on this spreadsheet, including a design example, are located in Fact Sheet T-0, *Quantifying Runoff Reduction* which is in Chapter 4 of this manual.

4.4 Other Types of Credits for Volume Reduction BMPs/LID

In addition to facility sizing reduction credits following the quantitative procedures in Section 4.0, communities can also consider other incentives to encourage volume reduction practices. Such incentives will depend on the policies and objectives of local governments. Representative examples include:

- Stormwater utility fee credits.
- Lower stormwater system development fees with certain minimum criteria.
- Density bonuses that allow greater residential densities with the implementation of LID techniques.
- Variances for requirements such as number of required parking spaces or road widths.
- Flexibility in bulk, dimensional and height restrictions, allowing greater building heights and floor area ratios, reduced setbacks and others.
- Fast-tracking the review process to provide priority status to LID projects with decreased time between receipt and review. If LID projects typically result in a longer review process, ensure equal status.
- Publicity, such as providing recognition on websites, at Council meetings and in utility mailers.
- Opportunities for grant funding for large public projects serving as demonstration projects.
- Sustainable SITES Initiative or LEED credits.
- Flexibility with landscaping requirements (i.e. allowing vegetated BMPs to count toward landscape requirements or allowing BMPs in the right-of-way).

5.0 Example Calculation of WQCV

Calculate the WQCV for a 1.0-acre sub-watershed with a total area-weighted imperviousness of 50% that drains to a rain garden:

1. Determine the appropriate drain time for the type of BMP. For a rain garden, the required drain time is 12 hours. The corresponding coefficient, *a*, from Table 3-2 is 0.8.

2. Either calculate or use Figure 3-2 to find the WQCV based on the drain time of 12 hours (*a* = 0.8) and total imperviousness = 50% (*I* = 0.50 in Equation 3-1):

   $$\text{WQCV} = 0.8(0.91(0.50)^3 - 1.19(0.50)^2 + 0.78(0.50))$$

   $$\text{WQCV} = 0.17 \text{ watershed-inches}$$

Calculate the WQCV in cubic feet using the total area of the sub-watershed and appropriate unit conversions:

$$WQCV = 0.17\ w.s.in. \cdot 1\ ac \cdot \frac{1\ ft}{12\ in} \cdot \frac{43560\ ft^2}{1\ ac} \approx 600\ ft^3$$

6.0 Conclusion

This chapter provides the computational procedures necessary to calculate the WQCV and adjust imperviousness values used in these calculations due to implementation of LID/MDCIA in the tributary watershed. The resulting WQCV can then be combined with BMP-specific design criteria in Chapter 4 to complete the BMP design(s).

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Chapter 4
Treatment BMPs

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Tables

Table 4.1. General Overview of Treatment BMP's Included in Volume 3..... 3

1.0 Overview

Treatment BMPs in Volume 3

- Grass Swale
- Grass Buffer
- Bioretention (Rain Garden)[1]
- Green Roof
- Extended Detention Basin
- Retention Pond
- Sand Filter Basin
- Constructed Wetland Pond
- Constructed Wetland Channel
- Permeable Pavement Systems
- Underground Practices

[1]Also known as Porous Landscape Detention

UDFCD has established design criteria, procedures, and details for a number of BMPs providing treatment of post-construction urban runoff. Additionally, general guidance has been developed and included for green roofs and underground BMPs. As discussed in Chapter 2, BMPs provide treatment through a variety of hydrologic, physical, biological, and chemical processes. The functions provided by BMPs may include volume reduction, treatment and slow release of the water quality capture volume (WQCV), and combined water quality/flood detention. Ideally, site designs will include a variety of source control and treatment BMPs combined in a "treatment train" that controls pollutants at their sources, reduces runoff volumes, and treats pollutants in runoff. Sites that are well designed for treatment of urban runoff will include all of the steps in the Four Step Process discussed in Chapter 1.

Building upon concepts and procedures introduced in Chapters 1 through 3, this chapter provides design procedures for treatment BMPs. Table 4-1 provides a qualitative overview of key aspects of the post-construction treatment BMPs included in this chapter. The table includes the degree to which the BMP is able to provide various functions, general effectiveness for treating targeted pollutants and other considerations such as life cycle costs. The table indicates which BMPs provide a conveyance function or a WQCV function. This distinction is important because not all treatment BMPs provide the WQCV. Wherever practical, combinations of BMPs in a treatment train approach are recommended. For example, BMPs that provide sedimentation functions can potentially improve the lifespan and reduce the maintenance frequency of filtration-oriented BMPs when the two BMPs are paired in series. Table 4-1 is based on best professional judgment from experiences in the Denver area along with data from the International Stormwater BMP Database (www.bmpdatabase.org) and is intended for general guidance only. Specific BMP designs and site-specific conditions may result in performance that differs from the general information provided in the table. In the case of underground and proprietary BMPs, wide variations in unit treatment processes make it difficult to provide generalized characterizations. Additionally, with regard to pollutant removal, in some cases, BMPs may be able to reduce pollutant concentrations, but this does not necessarily mean that the BMPs are able to treat runoff to numeric stream standards. For example, various studies have indicated that bioretention and retention pond BMPs may be able to reduce fecal indicator bacteria in urban runoff, but not necessarily meet instream primary contact recreational standards (WWE and Geosyntec 2010).

After reviewing physical site constraints, treatment objectives, master plans, and other factors, the designer can select the BMPs for implementation at the site and complete the engineering calculations and specifications for the selected BMPs. This chapter provides Fact Sheets for treatment BMPs that can be used in conjunction with the WQCV and volume reduction calculations in Chapter 3 in order to properly size and design the BMPs for the site. For new developments and significant redevelopments, designers should provide treatment of the WQCV with a slow release designed in accordance with criteria for the selected BMP. Additionally, sites that drain to impaired or sensitive receiving waters or that include onsite operations requiring additional treatment may need to implement measures that go beyond the minimum criteria provided in the Fact Sheets in this chapter.

2.0 Treatment BMP Fact Sheets

Fact sheets for each treatment BMP are provided as stand-alone sections of this chapter. The Fact Sheets are numbered with a "T" designation, indicating "Treatment" BMP. Fact Sheets typically include the following information:

- **Description**: Provides a basic description of the BMP.
- **Site Selection**: Identifies site-specific factors that affect the appropriateness of the BMP for the site.
- **Designing for Maintenance**: Identifies maintenance-related factors that should be considered during the BMP selection and design phase.
- **Design Procedure and Criteria:** Provides quantitative procedures and criteria for BMP design.
- **Construction Considerations**: Identifies construction-phase related factors that can affect long-term performance of the BMP.
- **Design Example**: Provides a design example corresponding to the UDFCD design spreadsheets accompanying this manual.

Designers should review each section of the Fact Sheet because successful long-term performance of the BMP includes all of these considerations, not simply the design procedure itself. Additionally, some Fact Sheets include call-out boxes with supplemental information providing design tips or other practical guidance that can enhance the benefits and performance of the BMP.

As part of the 2010 update of this manual, underground BMPs were added as treatment BMPs. UDFCD does not provide endorsement or approval of specific practices; instead, guidance is provided identifying when use of underground BMPs may be considered and the minimum criteria that should be met when site constraints do not enable aboveground treatment of runoff or when underground devices are used to provide pretreatment for site-specific or watershed-specific purposes.

Table 4-1. General Overview of Treatment BMPs Included in Volume 3

Overview	Grass Swale	Grass Buffer	Bioretention (Rain Garden)	Green Roof[5]	Extended Detention Basin	Sand Filter	Retention Pond	Constructed Wetland Pond	Constructed Wetland Channel	Permeable Pavement	Underground BMPs
Functions											
LID/Volume Red.	Yes	Yes	Yes	Yes	Somewhat	Yes	Somewhat	Somewhat	Somewhat	Yes	Variable
WQCV Capture	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Variable
WQCV+Flood Control	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Variable
Fact Sheet Includes EURV Guidance	No	No	No	No	Yes	No	Yes	Yes	No	No	No
Typical Effectiveness for Targeted Pollutants[3]											
Sediment/Solids	Good	Good	Very Good[1]	Unknown	Good	Very Good[1]	Very Good	Very Good	Unknown	Very Good[1]	Variable
Nutrients	Moderate	Moderate	Moderate	Unknown	Moderate	Good	Moderate	Moderate	Unknown	Good	Variable
Total Metals	Good	Good	Good	Unknown	Moderate	Good	Moderate	Good	Unknown	Good	Variable
Bacteria	Poor	Poor	Moderate	Unknown	Poor	Moderate	Moderate	Poor	Moderate	Unknown	Variable
Other Considerations											
Life-cycle Costs[4]	Low	Low	Moderate	Unknown	Moderate	Moderate	Moderate	Moderate	Low	High[2]	Moderate

[1] Not recomended for watersheds with high sediment yields (unless pretreatment is provided).

[2] Does not consider the life cycle cost of the conventional pavement that it replaces.

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

[5] Water quality data for green roofs are not yet robust enough to provide meaningful conclusions about pollutant removal. By reducing volume, green roofs have the de facto capability to reduce pollutant loads; however, on a concentration basis, more data is needed to better define effectiveness.

3.0 References

Wright Water Engineers and Geosyntec Consultants. 2010. *International Stormwater Best Management Practices Database Pollutant Category Summary: Fecal Indicator Bacteria*. Prepared for WERF, FHWA and EWRI-ASCE.

Quantifying Runoff Reduction T-0

Description

This Fact Sheet provides criteria to quantify stormwater volume reduction when employing runoff reduction practices. The intent of this approach is to avoid the direct connection of impervious areas to the storm drain and instead, guide runoff from pavement and roofs to vegetated areas such as grass buffers and grass swales in a manner that maintains sheet flow conditions.

Photograph RR-1. Disconnecting impervious areas and distributing runoff over grass buffers and swales reduces runoff volume and downstream treatment requirements.

The runoff reduction practices described in this fact sheet can be used to eliminate or reduce the size of volumetric BMPs required for water quality capture volume (WQCV) treatment. For the purpose of stormwater management, the volume of stormwater reduced through runoff reduction using infiltration, depression storage, and evapotranspiration is synonymous to volume treated.

Reducing runoff is the first step of the four-step process for minimizing adverse impacts of urbanization as detailed in Chapter 1, *Stormwater Management and Planning*. Minimizing directly connected impervious areas (MDCIA) by allowing runoff from impervious areas to sheet flow through grass reduces pollutant loading in the receiving water and helps restore predevelopment hydrology.

Runoff Reduction	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Good
Total Metals	Good
Bacteria	Good
Other Considerations	
Life-cycle Costs	Low

[3] Based primarily on grass buffer data from the International Stormwater BMP Database (www.bmpdatabase.org).

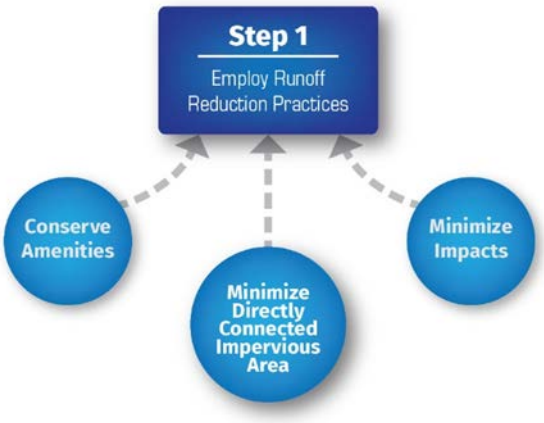


Figure RR-1. Employ runoff reduction practices. The first step in stormwater management is to create less stormwater runoff. We do this through minimizing directly connected impervious areas, conserving amenities such as trees and riparian corridors, and minimizing impacts by not adding more impervious areas than necessary.

Reducing runoff via sheet flow is frequently accomplished using grass buffers (with or without level spreaders) and grass swales where very shallow flow can be maintained. Fact Sheets T-1 and T-2 provide descriptions and additional criteria for grass buffers and swales; however, runoff reduction may be quantified for grass areas meeting criteria in this fact sheet even when all criteria in Fact Sheets T-1 and T-2 are not fully achieved.

Figure RR-2 shows a comparison of conventional stormwater practice to that of runoff reduction and demonstrates terminology used in this factsheet. In the conventional approach (shown left), a directly connected impervious area (DCIA) drains into a storm drain and bypasses the separate pervious area (SPA). In the runoff reduction approach (shown right) unconnected impervious area (UIA) drain to a slotted curb that distributes runoff evenly through a receiving pervious area (RPA).

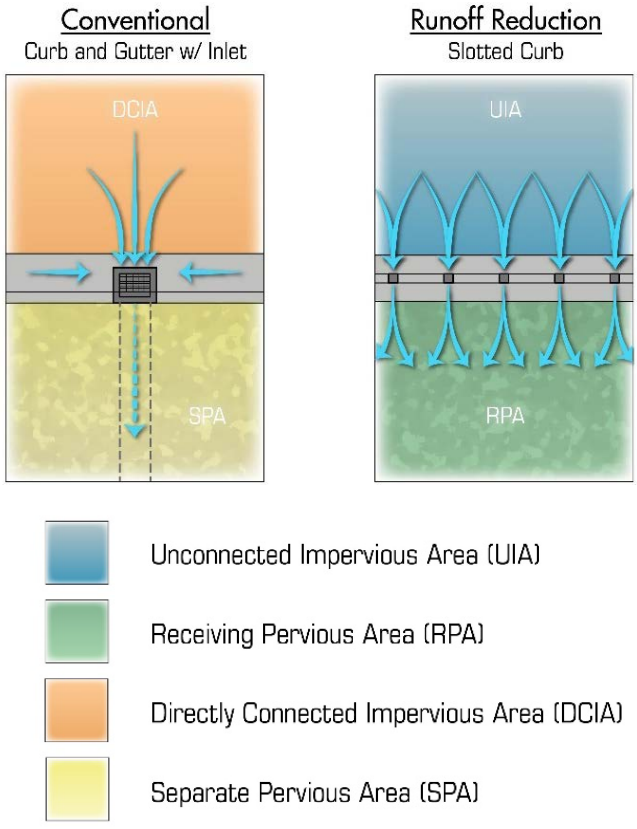


Figure RR-2. Comparison of conventional versus runoff reducing approach.

Benefits

- This practice often makes use of green space already planned as part of a site.
- Low cost.
- Straightforward maintenance requirements that can occur coincident with other landscape maintenance needs.

Limitations

- Frequently damaged by vehicles when adjacent to roadways and unprotected.
- Full vegetative cover, i.e., turf, is required to achieve volume reduction using these criteria.
- High loadings of coarse solids, trash, and debris require pretreatment or more frequent maintenance.
- Space may not be available in ultra-urban areas (lot-line-to-lot-line). In these cases, planters may be an alternative way to disconnect impervious areas

Site Selection

Review all sites to evaluate opportunities for MDCIA. These criteria are recommended where stormwater from impervious areas can be spread out as sheet flow onto pervious turf areas and where grass swales are used for conveyance.

Designing for Maintenance

During design, the following should be considered to ensure ease of maintenance over the long-term:

- Consider a level spreader that allows for removal of sediment such as the one shown in photo RR-2.
- Place the top of the RPA 4 to 6 inches below the adjacent UIA so that growth of vegetation and accumulation of sediment at the edge of the strip does not prevent runoff from entering the buffer.
- Provide temporary or permanent irrigation and adjust as necessary to provide water in amounts appropriate for the selected vegetation. Irrigation needs will change from month to month and year to year.
- Protect the RPA from vehicular traffic when using these criteria adjacent to roadways. This can be done with a slotted curb (or other type of barrier).
- Evaluate potential for sediment loading based on specifics of the site and provide a forebay to facilitate maintenance.

Photograph RR-2. This level spreader accepts and distributes concentrated flow while providing a place for sediment to be removed with a flat shovel. Note: When using this concept for quantifying volume reduction, use a grass RPA and create a free draining condition from the lowest flow point onto the RPA.

Design Procedure

Table RR-1 provides a summary of criteria and the following steps outline the procedure for quantifying stormwater volume reduction associated with MDCIA. The design example provided later in this Fact Sheet utilizes the *UD-BMP* workbook which performs the below calculations and also provides the composite volume reduction for a site with multiple UIA:RPA pairs as well as DCIA and SPA areas. The workbook tab provides the total volume reduced for the site as well as the percentage of WQCV treated.

Table RR-1. Parameters for quantifying runoff reduction.

Unconnected Impervious Area (UIA)	UIA should be approximately 1-acre or smaller although larger areas may be applicable with proper grading and flow distribution to the RPA. Multiple level spreaders may be needed for larger areas.
Wetted area of the Receiving Pervious Area (RPA) and flow characteristics	RPA must receive evenly distributed flow (sheet flow) from the UIA. Consider only the wetted area when delineating the RPA. Only the area that is directly within the flow path should be considered RPA. For swales, only the bottom width is considered RPA. See the design procedure for additional criteria and considerations for swales and buffers.
Vegetation of RPA	RPA vegetation should be turf grass (from seed or sod) with a uniform density of at least 80%. Dense native turf-forming grasses are recommended where a more natural look is desired. Turf grasses such as Kentucky bluegrass are also an option although require more irrigation. See the *Revegetation* chapter in Volume 2 of this manual with regard to seed mix selection, planting, and ground preparation. Depending on anticipated flows, consider erosion control measures until vegetation has been established.
Interface between UIA and RPA	The RPA must be protected from vehicle traffic and the interface between the UIA and the RPA must provide a vertical step to ensure runoff from UIA to RPA as sediment and grasses build up over time. See conceptual details provided in Figures RR–4 and RR-5.
Length-to Width of UIA:RPA pair	SWMM modeling for the development of this Fact Sheet was limited to a length-to-width ratio of the UIA:RPA pair between 0.06 and 16.0. When using this criteria outside of these limits, results may vary.
Slope of RPA	The slope of the RPA should be no greater than 3:1 (H:V).
UIA/RPA ratio	The recommended maximum UIA/RPA ratio is 10:1. Ratios greater than this may be appropriate with pretreatment and level spreaders in series. Pretreatment should also be considered as the ratio of UIA/RPA increases.
Soil Type and Preparation	These criteria are applicable to all hydrologic soil groups although performance is not equivalent. Conduct agronomic soil tests to determine required soil amendments and consult an ecologist or plant specialist for recommendations specific for the site and type of grass selected.
Underdrains	Analysis conducted for this Fact Sheet did not consider grass swales with underdrains. Data in the International BMP Database indicates presence of an underdrain reduces reduction of the WQCV in bioretention basins (Geosyntec Consultants and Wright Water Engineers, 2012). For this reason, UDFCD recommends these criteria not be used for quantification of volume reduction in bioretention basins (or similar BMPs) with underdrains.
Irrigation	Provide temporary or permanent irrigation systems, depending on the type of vegetation selected. Adjust irrigation application rates and schedules throughout the establishment and growing season as appropriate to meet the needs of the selected plant species. Initially, native grasses require the same irrigation requirements as bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced.

1. **Locate and Delineate all UIA and RPA pairs on the site.** Locate vegetated areas down-gradient of impervious areas to maximize UIA and RPA and minimize DCIA and SPA. Note that lower UIA/ RPA ratios provide increased volume reduction and decreased maintenance. It is also effective to break up large areas of UIA to provide a better distribution for the available RPA and reduce UIA flow lengths.

   Calculate the individual areas for each UIA and RPA pair. Determine all remaining DCIA and SPA and calculate individual areas of each.

   a. Swales: For UIA draining to a vegetated swale, spread flow the full bottom width of the swale. Discharge from the outlet of a pipe may need a structural measure to ensure flow from the pipe makes contact with the full bottom width of the swale. Consider energy dissipation and use of a forebay to slow and spread pipe discharge while providing a location for sediment removal. See Figure RR-4 for a concept detail of a sediment pad placed upgradient of a grass swale. Note the 4" vertical drop on entry to the sediment pad. This ensures flow will enter the RPA and not pond in the pavement when sediment and grasses build up over time.

   b. Buffers: For UIA draining to a vegetated buffer, flow may or may not be concentrated. Provide a level spreader or use the same guidance found in T-1 to assess the need for a level spreader (repeated below for convenience).

   Concentrated flows can occur when the width of the watershed (measured perpendicular to flow) differs from that of the grass buffer. Additionally, when the product of the watershed flow length and the interface slope (the slope of the watershed normal to flow at the grass buffer) exceeds approximately one, flows may become concentrated. Use the following equations to determine flow characteristics and reference *T-1 Grass Buffers* for a graphic representation of the variables:

   Sheet Flow: $FL(SI) \leq 2$ Equation GB-2 (from Fact Sheet T-1)

   Concentrated Flow: $FL(SI) > 2$ Equation GB-3(from Fact Sheet T-1)

   Where:

   FL = watershed flow length (measured parallel to flow) (ft)

   SI = interface slope (slope of UIA/RPA interface normal to flow from the UIA) (ft/ft)

2. **Delineate the RPA and determine the UIA:RPA ratio:** Only pervious areas receiving flow from the UIA should be included in the calculated RPA. For swales, only the flat bottom width should be included. For buffers, only the area receiving stormwater in a distributed manner such that stormwater wets the entire width of the RPA should be used for this calculation. Land forms or variation in slope that could concentrate flows within the buffer or divert flows to other portions of the buffer should not be included. These criteria assume uniform sheet flow across the buffer.

   A level spreader should be used when flows from the UIA are concentrated. A level spreader can be a slotted drain designed to discharge flow through the slot as shown in Photo RR-2. It could be an exfiltration trench filled with gravel, which allows some stormwater to infiltrate prior to discharging

over a level concrete curb. There are many ways to design and construct a level spreader. They can also be used in series when the length of the buffer allows flows to re-concentrate. See conceptual details for level spreaders provided in the T-1 Grass Buffers Fact Sheet.

3. **Protect the UIA:RPA Interface and Provide a Vertical Drop:** The RPA must be protected from vehicular traffic. A slotted curb, as shown in Figure RR–5, can be used for this purpose. To ensure distributed flow across the RPA, place curb openings no more than 2 feet on center. The lip shown on the back side of the curb in Figure RR-5 establishes a vertical drop of 4 inches. This is required to ensure positive drainage from the UIA to RPA. This also provides a location for maintenance. Over time sediment will deposit in this location and the turf of the RPA may start to grow over this lip.

   For grass swales, referred to Figure RR-6. This figure shows a sediment pad at the entrance of the swale and also details a vertical drop of 4 inches.

Photograph RR-2. A perforated pipe packed in gravel receives concentrated flow from the roof top of an office building and discharges the flow to a grass buffer. Photo courtesy SEMSWA.

4. **Characterize on-site topsoil and determine suitability of topsoil for the RPA:** The NRCS Web Soil Survey is a good resource for an initial investigation of site soils. However, only soil sampling and testing will confirm the actual NRCS Hydrologic Soil Group (HSG). Inexpensive lab tests quantify particle size based on sieve and hydrometer analyses to determine sand gradation and percent sand, silt, and clay for texture determination, and include agronomic tests for organic content, pH, salinity, and nutrients.

   UDFCD recommends onsite topsoil sampling and testing as a standard of practice on every project and as a requirement for sites utilizing this Fact Sheet. It is essential that soil conditions be characterized in order to select the most suitable soils for the RPA and determine appropriate amendments (some local governments may also require proof of soil conditions/amendment in landscaped areas for water conservation reasons). Characterization is also required to ensure use of the proper coefficients in equation RR-1.

   Plot the percent sand, silt, and clay of each sample on a USDA soil triangle and use this to confirm soil texture and HSG. Table RR-2 and Figure RR-3 indicate HSG based on percent sand, silt and clay according to the NRCS National Engineering Handbook (USDA, 2009). Based on the results of onsite soil sampling and testing, refer to Table RR-3 to select the most suitable soil from the site for use in the RPA.

See recommendations under Design Step 7, Soil Preparation, for recommendations where soils do not meet criteria for suitability for RPA.

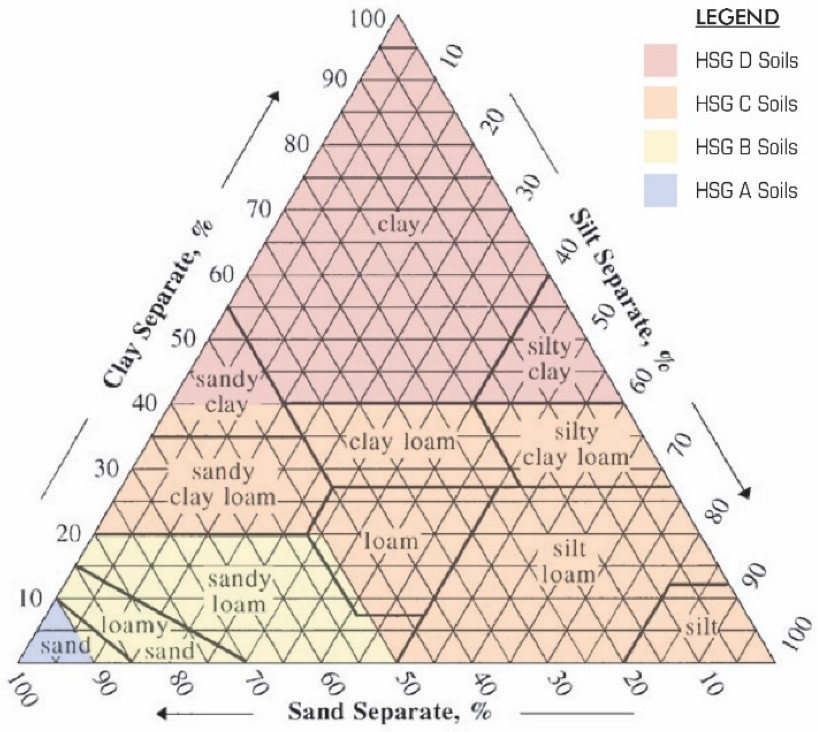


Figure RR-3. USDA Soil Triangle with USDA NRCS Soil Texture Classes overlain by USDA NEH Hydrologic Soil Groups

Table RR-2. Percent Sand, Silt, and Clay for HSG A through D.

HSG Group	% Sand	% Clay	% Silt
A	> 90%	< 10%	0 % < A < 10%
B	50 % < B < 90%	10 % < B < 20%	10 % < B < 50%
C	< 50%	20 % < C < 40%	0 % < C < 100%
D	< 50%	> 40%	0 % < D < 60%

Table RR-3. Topsoil Suitability Criteria for RPA.

Soil Parameter	Suitable	Less Suitable	Marginal	Unsuitable
Electrical Conductivity (EC)	0-4	4-8	8-12	>12
Sodium Adsorption Ratio (SAR)	0-4	4-8	8-13	>13
Exchangeable Sodium % (ESP)	<15		15-20	>20
Saturation Percentage	25-50		20-25 and 50-80	<20 and >80
Calcium Carbonate Percentage	<10%		10-20%	>20%
pH	6.0-8.0	5.0-5.5 and 8.0-8.5	5.0-5.5 and 8.5-9.0	<5.0
Texture	sandy loam, loam	sandy clay loam, silt loam, well-aggregated silty clay loam and clay loam	sandy clay, loamy sand, silty clay,silt, clay (<60%), disggreagated silty clay loam and clay loam	sand, clay (>60%)
Coarse Fragments (gravels, cobbles, boulders)	<25%		25-35%	>35
Nitrate Nitrogen (as accelerant for weed growth)	<10 ppm	10-15 ppm	>15 ppm	
Organic Matter	>2%	1%-2%	<1%	

5. **Calculate Runoff from each UIA:RPA pair:** In the UDFCD region, the precipitation depth associated with the WQCV event is 0.6 inches. For areas outside of the Denver Metro region, the precipitation depth for the WQCV event may differ. It should be noted that the methodology provided below is only valid for WQCV precipitation depths between 0.25 and 0.95 inches. Depths above 0.95 inches start to produce runoff from direct rainfall onto pervious areas which invalidates the methodology described below.

   Calculate the total runoff from each UIA:RPA pair using equation RR-1.

$$Q = C_0 + C_1(0.95 - P_2) + C_2(A) + C_3(L{:}W) + C_4(S) + C_5(I) + C_6(I^2) \quad \text{Equation RR-1}$$

   Where:

   Q = Runoff from the total subarea (watershed inches)

   P_2 = Precipitation for 2-hour WQCV event (inches)

   A = total subarea, sum of UIA and RPA (ft^2)

   $L{:}W$ = Ratio of total flow length to catchment width

   S = average overland slope (ft/ft)

I = subarea imperviousness (percent expressed as a decimal) calculated as (UIA / (UIA+RPA))

Cx = coefficients in Table RR-4 (determined through regression analysis)

Table RR-4. Coefficients for quantifying runoff from a UIA:RPA pair

Soil Type	Constant C_0	Precip, P_2 (in) C_1	Area (ac) C_2	L:W C_3	Slope (ft/ft) C_4	%Imp C_5	%Imp^2 C_6
A	5.81E-01	-7.79E-01	-3.34E-07	-1.93E-03	7.03E-02	-2.49E+00	2.64E+00
B	-7.77E-02	-9.25E-01	-2.45E-07	-1.45E-03	5.02E-02	-1.36E-02	9.24E-01
C/D	-1.13E-02	-8.99E-01	-2.68E-07	-1.57E-03	5.45E-02	3.55E-01	4.64E-01

The Technical Memorandum entitled *Determination of Runoff Reduction Method Equations (UIA to RPA) based on Multivariable SWMM Analysis*, dated March 15, 2018 documents the derivation of these equations. This is available at www.udfcd.org.

Calculate the volume of runoff from the UIA:RPA pair by multiplying the watershed inches determined in equation RR-1 by the total area of the UIA:RPA pair as shown in Equation RR-2.

$$V_{UIA:RPA} = \left[\frac{Q}{12}\right] A_{UIA:RPA} \qquad \text{Equation RR-2}$$

Where:

$V_{UIA:RPA}$ = Volume of runoff from UIA:RPA pair (ft^3)

$A_{UIA:RPA}$ = Area of UIA:RPA pair (ft^2)

6. **Compare runoff from each UIA:RPA pair to runoff from UIA alone:** For this step *UD-BMP* assumes a depression storage on the UIA of 0.1 inches. Using a WQCV precipitation of 0.6 inches, this equates to 0.5 watershed inches over the area of the UIA. For a runoff volume from the UIA multiply this value by the area of the UIA as shown in equation RR-3.

$$V_{UIA} = \left[\frac{(P_2 - d_{storage})}{12}\right] A_{UIA} \qquad \text{Equation RR-3}$$

Where:

V_{UIA} = Volume of runoff from the UIA (ft^3)

P_2 = Precipitation for 2-hour WQCV event (inches)

$d_{storage}$ = impervious depression storage (inches)

A_{UIA} = Area of the UIA (ft^2)

The difference between this value (V_{UIA}) and that of Equation RR-2 is the volume reduction associated with the UIA:RPA configuration. The percentage of runoff reduction is represented by Equation RR-4.

$$\%\ \text{Runoff Reduction} = \frac{V_{UIA} - V_{UIA:RPA}}{V_{UIA}} \qquad \text{Equation RR-4}$$

Within the UDFCD region (WQCV precipitation depth of 0.60 inches), the runoff reduction percentage is equivalent to the WQCV reduction percentage. However, outside the UDFCD region, these percentages may differ based on the relationship between the 2-hour WQCV precipitation depth and the average runoff producing storm's precipitation depth, d_6 (Figure 3-1 in USDCM Vol. 3) which is used to adjust the calculated WQCV (Equation 3-2 in USDCM Vol. 3).

How much is enough?

When using this BMP as standalone treatment for the WQCV, the MS4 Phase 2 Permit requires reduction of 60% of what the calculated WQCV would be if all impervious area for the applicable development site discharged without infiltration. However, some municipalities may have more stringent requirements. In either case, downstream BMPs may be required and the *UD-BMP* tool can help size those while accounting for volume reduction utilizing this method.

Use Table RR-5 for a quick reference when sizing RPAs to reduce 60% or 100% of the WQCV.

Table RR-5. Quick Reference for Sizing RPAs[1]

Soil Type	UIA:RPA Ratio for 60% WQCV Reduction	UIA:RPA Ratio for 100% WQCV Reduction
A	7.2:1	3.7:1
B	3.4:1	1.9:1
C	2:1	1:1

[1]Table RR-5 assumes a WQCV precipitation of 0.6 inch. Ratios are valid for slopes up to 33 percent.

7. **Soil Preparation:** Soil preparation is required in addition to sampling and testing because construction tends to disturb soil horizons, remove organic topsoil, and overly compacted site soils. On the design plans, specify construction practices to achieve desirable soil conditions. If on-site topsoil is suitable as determined by Table RR-3, strip, stockpiled, and reuse it. Note that topsoil falling under the categories of "Less Suitable" and "Marginal" in this table will require amendments. Based on the onsite topsoil sampling and testing, use the most suitable topsoil from the site in the RPA.

   On most development sites, vegetation comprises only a portion of the site; enabling the depth of topsoil placed in these areas to be greater than the average depth stripped over the site. With this in mind, place as much topsoil as available. Where this results in a depth of topsoil less than 12-inches, subgrade soils should be sampled and tested for salinity. Regardless of topsoil thickness, subgrade should be tilled to a depth of at least 18 inches below the finished ground surface. Where topsoil was found to be less suitable or marginal refer to the recommendations of an ecologist or plant specialist and the recommendations listed below.

High salinity. High salinity, in particular excessive sodium, is the most serious problem that can render a soil unsuitable. In this case, alternative sources of topsoil should be located either from the site or from an imported source. However, if an imported source is considered, all the same sampling, testing, and remedial actions described herein for onsite soils are should be undertaken for the proposed source of imported topsoil during the design phase when HSG needs to be determined for use in the workbook tab.

Low pH (acidic soils). The traditional solution for low-pH soils is addition of agricultural lime.

Sand texture. Sand is problematic for use in the RPA due to poor moisture holding capacity to support vegetation and low capacity to adsorb dissolved pollutants. Topsoil comprised of fine sand (at least 70% passing the #35 (0.5 mm) sieve) may be able to be mixed with finer textured topsoil to move into a more suitable texture class). Courser sand (less than 70% passing the #35 (0.5 mm) sieve) is not considered suitable for use in the RPA.

Clay texture. Clay is problematic for use in the RPA due to extremely low infiltration rates and the tendency to lead to boggy conditions in the RPA that are difficult to maintain. Preservation of an aggregated soil structure, if present in onsite topsoil, and avoidance of compaction can help. Addition of weed free Class A compost or light-weight expanded clay products (perlite, vermiculite, and other products made by heating naturally occurring clays) may be useful in improving clayey soil textures, but topsoil with a clay content in excess of 60% is generally unsuitable for use in the RPA regardless of remedial actions. In this case, alternative sources of topsoil should be located either from the site or from an imported source, and any imported source must be thoroughly sampled and tested during the design phase to confirm its suitability for use in the RPA.

High nitrate nitrogen. Because nitrate nitrogen can encourage weed proliferation even at levels considered low by agricultural standards, care is necessary to avoid selecting topsoil with high nitrate nitrogen, and especially to use caution when considering lab results that may recommend application of nitrogen fertilizers, typically based on agricultural considerations.

Low organic matter. Low organic matter can be addressed, at least for the short term via addition of weed-free Class A compost. Another option for addressing low organic matter is the addition of Biosol, a slow-release organic fertilizer.

7. **Vegetation:** This is the most critical component for reduction and improved water quality. These criteria are based on a vegetative cover of approximately 80% (i.e., grass cover). Select durable, dense, and drought tolerant grasses. Turf grasses such as Kentucky bluegrass are often selected due to these qualities[1]. Dense native turf grasses may also be selected where a more natural look is desirable. Once established, these provide the benefit of lower irrigation requirements. See the *Revegetation* chapter in Volume 2 of this manual with regard to seed mix selection, planting and ground preparation. Depending on soils and anticipated flows, consider erosion control measures until vegetation has been established.

[1] Although Kentucky bluegrass has relatively high irrigation requirements to maintain a lush, green aesthetic, it also withstands drought conditions by going dormant. Over-irrigation of Kentucky bluegrass is a common problem along the Colorado Front Range, and it can be healthy, although less lush, with much less irrigation than is typically applied.

8. **Irrigation**: Equip each RPA with an irrigation systems to promote establishment and survival in Colorado's semi-arid environment. Systems may be temporary or permanent, depending on the type of vegetation selected. Irrigation application rates and schedules should be developed and adjusted throughout the establishment and growing season to meet the needs of the selected plant species. Initially, native grasses require the same irrigation requirements as bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced. Irrigation practices have a significant effect on the function of the grass buffer. Overwatering decreases the permeability of the soil, reducing the infiltration capacity and contributing to nuisance baseflows. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less volume reduction and increased susceptibility to rill erosion over the long term.

9. **Outflow Collection**: Provide a means for downstream conveyance of flows in excess of that which will be reduced through infiltration and evapotranspiration. Also note that the *UD-BMP* tool will calculate total volume reduction for the WQCV event as well as percentage of the WQCV treated through reduction. However, it is important to understand that these design points may be in different locations and additional treatment may be required for the remaining WQCV.

Construction Considerations

Success depends not only on a good design and long-term maintenance, but also on construction of the BMP to function as designed. Construction considerations are listed below.

Photograph RR-3. Landscaping in the RPA (the grass swale) is too high to allow stormwater into the vegetation. Ensure a grade differential where UIA meets RPA. Photo courtesy of SEMSWA.

- The final grade of the RPA must be lower than the UIA. A grade differential of 4 to 6 inches is recommended to ensure sediment deposit over time does not impede flow into the RPA. Oftentimes, following soil amendment and placement of sod, the final grade is too high to accept sheet flow. The RPA should be inspected prior to placement of seed or sod to ensure appropriate grading.
- Perform soil amending, fine grading, and seeding after tributary areas have been stabilized and utility work crossing the buffer has been completed.
- When using sod tiles stagger the ends of the tiles to prevent the formation of channels along the joints. Use a roller on the sod to ensure there are no air pockets between the sod and soil.
- Avoid over compaction of soils during construction to preserve infiltration capacities.
- Erosion and sediment control measures on upgradient disturbed areas must be maintained to prevent excessive sediment loading.

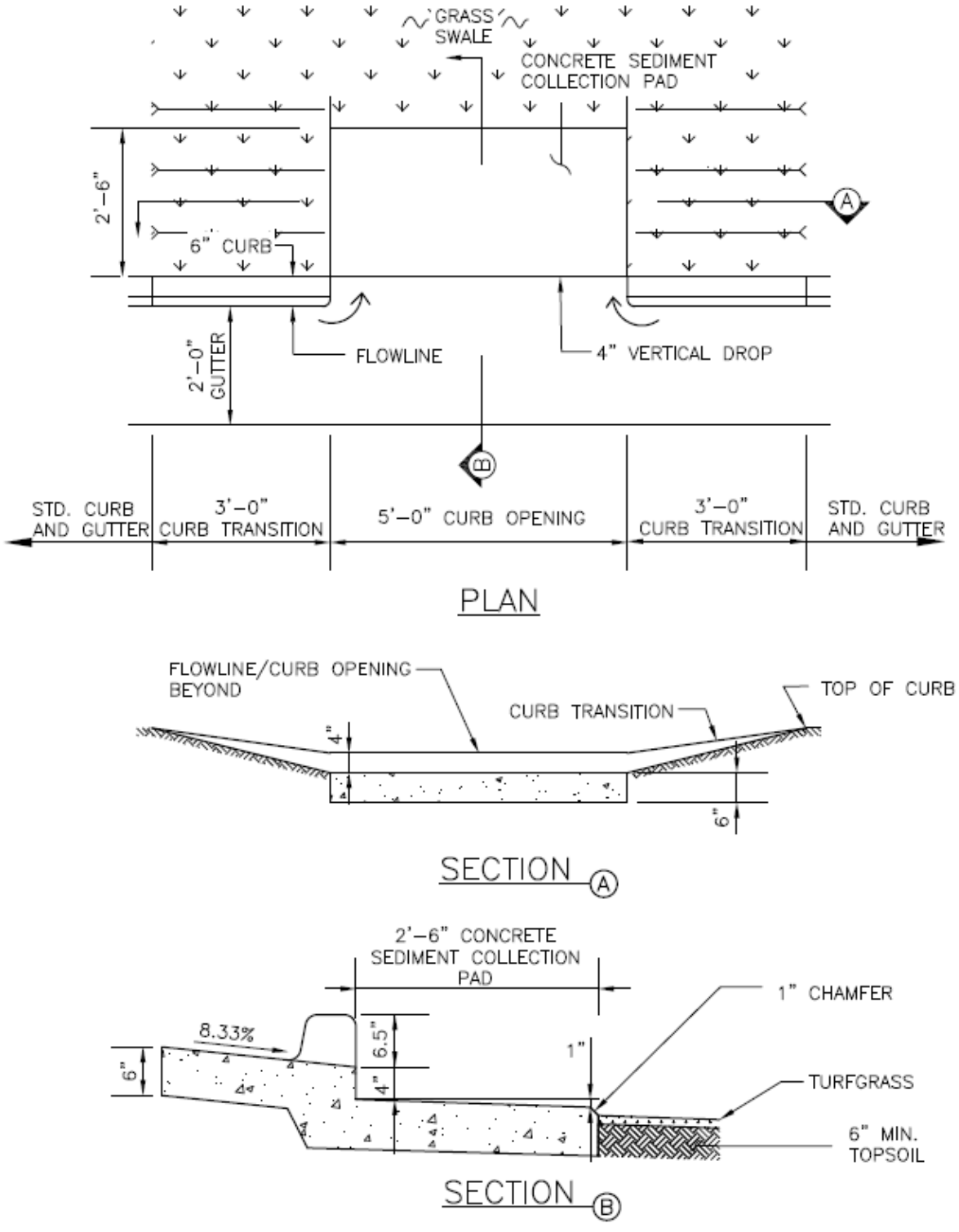


Figure RR-4. Sediment pad for curb opening to grass swale.

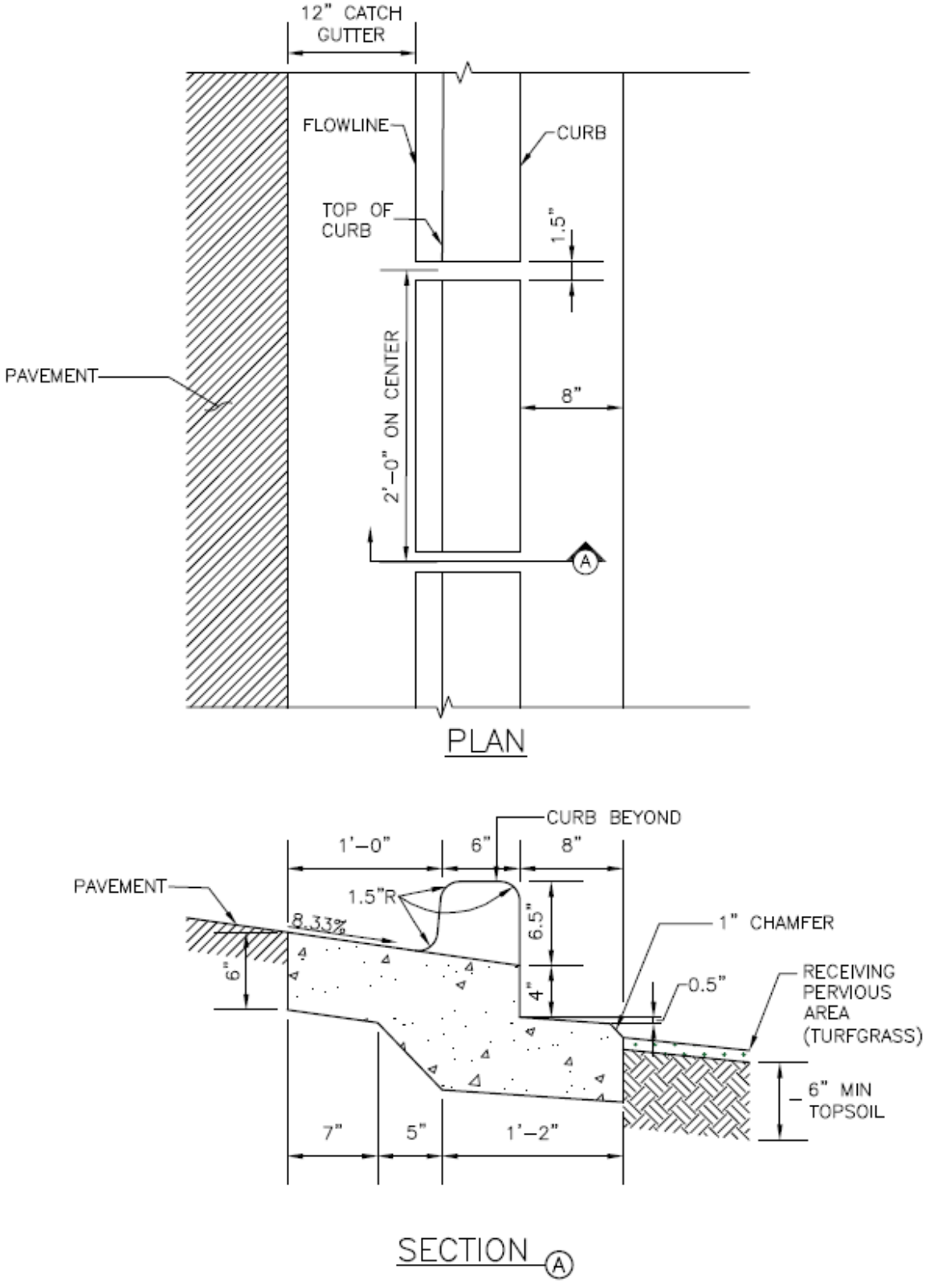


Figure RR-5. Slotted curb.

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.UDFCD.org. This section provides a completed design form from this workbook as an example.

A small commercial property has been divided into UIA:RPA pairs, DCIA and SPA. Soil type for all RPA and SPA is HSG C/D. Note that not all grassed areas can be counted as RPA, in the case of a buffer or grass swale, sheet flow must be maintained. What percentage of the WQCV can be treated by quantifying volume reduction associated with the UIA:RPA configuration?

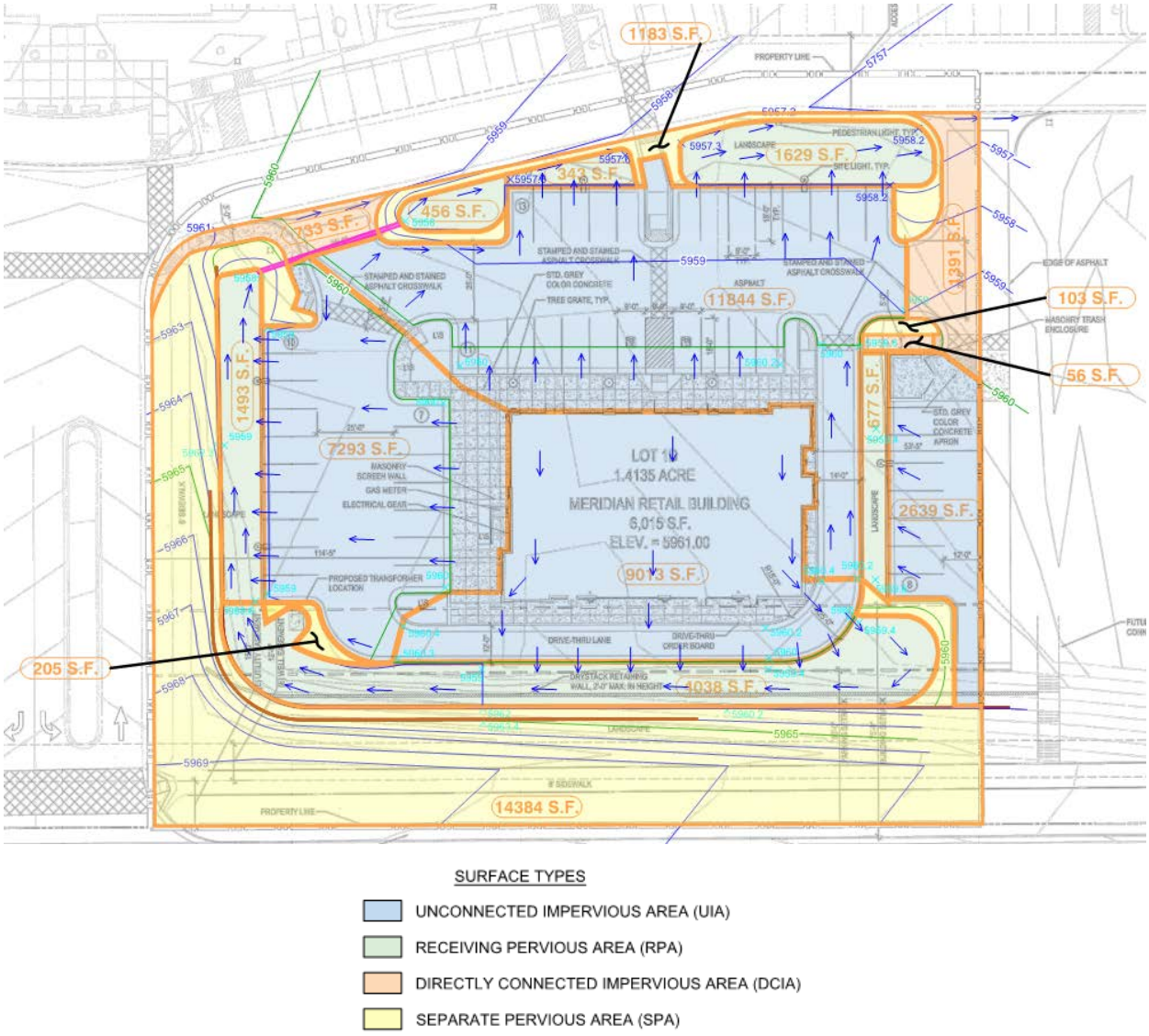


Figure RR-6. Example site runoff reduction configuration.

Step 1. Input Site Information (depending on "Area Type" the user will populate blue fields). Use the *Downstream Design Point ID* field to identify a common location where individual sub areas (separate columns) meet. In this example, some areas flow directly offsite (columns 1 through 3) while the remainder (columns 4 through 9) are all directed to an outfall at the northeast corner of the site.

SITE INFORMATION (User Input in Blue Cells)

WQCV Rainfall Depth	0.60	inches
Depth of Average Runoff Producing Storm, d_6 =	0.43	inches (for Watersheds Outside of the Denver Region, Figure 3-1 in USDCM Vol. 3)

Area Type	DCIA	DCIA	SPA	SPA	SPA	UIA:RPA	UIA:RPA	UIA:RPA	UIA:RPA
Area ID	1	2	3	4	5	6	7	8	9
Downstream Design Point ID	offsite	offsite	offsite	NE corner	NE corner	NE corner	NE corner	NE corner	NE corner
Downstream BMP Type	None	None	None	None	None	None	None	None	None
DCIA (ft^2)	733	1,391	--	--	--	--	--	--	--
UIA (ft^2)	--	--	--	--	--	9,013	7,293	11,844	2,639
RPA (ft^2)	--	--	--	--	--	4,038	1,493	2,428	677
SPA (ft^2)	--	--	14,589	1,183	103	--	--	--	--
HSG A (%)	--	--	0%	0%	0%	0%	0%	0%	0%
HSG B (%)	--	--	0%	0%	0%	0%	0%	0%	0%
HSG C/D (%)	--	--	100%	100%	100%	100%	100%	100%	100%
Average Slope of RPA (ft/ft)	--	--	--	--	--	0.050	0.050	0.050	0.050
UIA:RPA Interface Width (ft)	--	--	--	--	--	154.00	88.00	105.00	78.00

Step 2. Calculate Runoff Results for each sub-area (no additional data entry required)

CALCULATED RUNOFF RESULTS

Area ID	1	2	3	4	5	6	7	8	9
UIA:RPA Area (ft^2)	--	--	--	--	--	13,051	8,786	14,272	3,316
L / W Ratio	--	--	--	--	--	0.55	1.13	1.29	0.55
UIA / Area	--	--	--	--	--	0.6906	0.8301	0.8299	0.7958
Runoff (in)	0.50	0.50	0.00	0.00	0.00	0.14	0.29	0.29	0.25
Runoff (ft^3)	31	58	0	0	0	151	210	339	70
Runoff Reduction (ft^3)	0	0	729	59	5	224	94	154	40

Step 3. Calculate WQCV Results for each sub-area (no additional data entry required)

CALCULATED WQCV RESULTS

Area ID	1	2	3	4	5	6	7	8	9
WQCV (ft^3)	31	58	0	0	0	376	304	494	110
WQCV Reduction (ft^3)	0	0	0	0	0	224	94	154	40
WQCV Reduction (%)	0%	0%	0%	0%	0%	60%	31%	31%	37%
Untreated WQCV (ft^3)	31	58	0	0	0	151	210	339	70

Step 4. Calculate reduction and WQCV results for each design point (no additional data entry required)

CALCULATED DESIGN POINT RESULTS (sums results from all columns with the same Downstream Design Point ID)

Downstream Design Point ID	offsite	NE corner						
DCIA (ft^2)	2,124	0						
UIA (ft^2)	0	30,789						
RPA (ft^2)	0	8,636						
SPA (ft^2)	14,589	1,286						
Total Area (ft^2)	16,713	40,711						
Total Impervious Area (ft^2)	2,124	30,789						
WQCV (ft^3)	89	1,283						
WQCV Reduction (ft^3)	0	512						
WQCV Reduction (%)	0%	40%						
Untreated WQCV (ft^3)	89	771						

Step 5. Calculate reduction and WQCV results for the site (no additional data entry required)

CALCULATED SITE RESULTS (sums results from all columns in worksheet)

Total Area (ft^2)	57,424
Total Impervious Area (ft^2)	32,913
WQCV (ft^3)	1,371
WQCV Reduction (ft^3)	512
WQCV Reduction (%)	37%
Untreated WQCV (ft^3)	859

Summary and Discussion. Using MDCIA at this site, we treat 37 percent of the WQCV. A small bioretention basin could be placed at the northeast corner of the site to treat remaining flows at the "NE corner" design point. To do this, return to Step 1 and use the pull-down menu to select a BMP in the *Downstream BMP Type* field. The spreadsheet will size treatment volume based on the drain time of the BMP (while still accounting for the volume reduction). BMP sizing is detailed in Chapter 3 of the manual.

True site configuration and grading were used for this example. Site grading limited how much of the site could be used for RPA versus SPA. If more of the SPA could be converted to RPA, WQCV requirements could be satisfied with this method alone, even with Type C\D soils. Note that using this same example with Type B and Type A soils results in treatment of 57 percent and 86 percent respectively.

References

Barrett, M., Lantin, A. and S. Austrheim-Smith. 2004. Stormwater Pollutant Removal in Roadside Vegetated Buffer Strips. Prepared for the Transportation Research Board: Washington, DC.

Geosyntec Consultants and Wright Water Engineers (May 2012) Addendum 1 to Volume Reduction Technical Summary (January 2011) Expanded Analysis of Volume Reduction in Bioretention BMPs (accessible at www.bmpdatabase.org)

Pitt, R., Chen, S., and Clark, S. July 2001. *Infiltration Through Compacted Urban Soils and Effects on Bioretention Design.* Presented at the Low Impact Development Roundtable Conference, Baltimore, M.D.

Piza, H., and Rapp, D. (March 15, 2018) Memorandum titled *Determination of Runoff Reduction Equations (UIA to RPA) based on Multivariable SWMM Analysis*.

USDA Natural Resources Conservation Service. January, 2009. National Engineering Handbook Hydrology Chapters, Chapter 7 Hydrologic Soil Groups.

Wulliman, J. (May 23, 2017) Memorandum titled *Quantification approach for runoff reduction.*

Wulliman, J. (January 25, 2017) Memorandum titled *Guidance for Using Infiltration as a Stormwater Management Practice based on infiltration testing at four sites in Douglas County, Colorado.*

Wulliman, J. (January 6, 2014) Memorandum titled *Douglas County infiltration evaluation-Part 3.*

Wulliman, J. (August 25, 2012) Memorandum titled *Douglas County infiltration evaluation-Part 2.*

Wulliman, J. (February 6, 2012) Memorandum titled *Douglas County Large-cap lot Runoff Evaluation.*

Zivkovich, B., and Earles, A. (October 19, 2017) Memorandum titled *Runoff Reduction using the RPA Method*.

Grass Buffer T-1

Description

Grass buffers are densely vegetated strips of grass designed to accept sheet flow from upgradient development. Properly designed grass buffers play a key role in LID, enabling infiltration and slowing runoff. Grass buffers provide filtration (straining) of sediment. Buffers differ from swales in that they are designed to accommodate overland sheet flow rather than concentrated or channelized flow.

Photograph GB-1. A flush curb allows roadway runoff to sheet flow through the grass buffer. Flows are then further treated by the grass swale. Photo courtesy of Muller Engineering.

Site Selection

Grass buffers can be incorporated into a wide range of development settings. Runoff can be directly accepted from a parking lot, roadway, or the roof of a structure, provided the flow is distributed in a uniform manner over the width of the buffer. This can be achieved through the use of flush curbs, slotted curbs, or level spreaders where needed. Grass buffers are often used in conjunction with grass swales. They are well suited for use in riparian zones to assist in stabilizing channel banks adjacent to major drainageways and receiving waters. These areas can also sometimes serve multiple functions such as recreation.

Hydrologic Soil Groups (HSG) A and B provide the best infiltration capacity for grass buffers. For Type C and D soils, buffers still serve to provide filtration (straining) although infiltration rates are lower. Refer to Fact Sheet T-0 to quantify volume reduction in grass buffers and understand how HSG effects reduction.

Grass Buffer	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs	Low

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design the following should be considered to ensure ease of maintenance over the long-term:

- Where appropriate (where vehicle safety would not be impacted), install the top of the buffer 1 to 3 inches below the adjacent pavement so that growth of vegetation and accumulation of sediment at the edge of the strip does not prevent runoff from entering the buffer. Alternatively, a sloped edge can be used adjacent to vehicular traffic areas.
- Amend soils to encourage deep roots and reduce irrigation requirements, as well as promote infiltration.

- Design and adjust the irrigation system (temporary or permanent) to provide water in amounts appropriate for the selected vegetation. Irrigation needs will change from month to month and year to year.

- Protect the grass buffer from vehicular traffic when using this BMP adjacent to roadways. This can be done with a slotted curb (or other type of barrier) or by constructing a reinforced grass shoulder (see Fact Sheet T-10.5).

Design Procedure and Criteria

The following steps outline the grass buffer design procedure and criteria. Figure GB-1 is a schematic of the facility and its components:

1. **Design Discharge**: Use the hydrologic procedures described in the *Runoff* chapter of Volume 1 to determine the 2-year peak flow rate (Q_2) of the area draining to the grass buffer.

2. **Minimum Width:** The width (W), normal to flow of the buffer, is typically the same as the contributing basin (see Figure GB-1). An exception to this is where flows become concentrated. Concentrated flows require a level spreader to distribute flows evenly across the width of the buffer. The minimum width should be:

$$W = \frac{Q_2}{0.05} \qquad \text{Equation GB-1}$$

Where:

W = width of buffer (ft)

Q_2 = 2-year peak runoff (cfs)

3. **Length:** The recommended length (L), the distance along the sheet flow direction, should be a minimum of 14 feet. This value is based on the findings of Barrett et al. 2004 in *Stormwater Pollutant Removal in Roadside Vegetated Strips* and is appropriate for buffers with greater than 80% vegetative cover and slopes up to 10%. The study found that pollutant removal continues throughout a length of 14 feet. Beyond this length, a point of diminishing returns in pollutant reduction was found. It is important to note that shorter lengths or slightly steeper slopes will also provide some level of removal where site constraints dictate the geometry of the buffer.

Benefits

- Filters (strains) sediment and trash.
- Reduces directly connected impervious area. (See Chapter 3 for quantifying benefits.)
- Can easily be incorporated into a treatment train approach.
- Provides green space available for multiple uses including recreation and snow storage.
- Straightforward maintenance requirements when the buffer is protected from vehicular traffic.

Limitations

- Frequently damaged by vehicles when adjacent to roadways and unprotected.
- A thick vegetative cover is needed for grass buffers to be effective.
- Nutrient removal in grass buffers is typically low.
- High loadings of coarse solids, trash, and debris require pretreatment.
- Space for grass buffers may not be available in ultra urban areas (lot-line-to-lot-line).

4. **Buffer Slope:** The design slope of a grass buffer in the direction of flow should not exceed 10%. Generally, a minimum slope of 2% or more in turf is adequate to facilitate positive drainage. For slopes less than 2%, consider including an underdrain system to mitigate nuisance drainage.

5. **Flow Characteristics (sheet or concentrated)**: Concentrated flows can occur when the width of the watershed differs from that of the grass buffer. Additionally, when the product of the watershed flow length and the interface slope (the slope of the watershed normal to flow at the grass buffer) exceeds approximately one, flows may become concentrated. Use the following equations to determine flow characteristics:

Use of Grass Buffers

Sheet flow of stormwater through a grassed area provides some benefit in pollutant removal and volume reduction even when the geometry of the BMP does not meet the criteria provided in this Fact Sheet. These criteria provide a design procedure that should be used when possible; however, when site constraints are limiting, this treatment concept is still encouraged.

Sheet Flow: $FL(SI) \leq 2$ Equation GB-2

Concentrated Flow: $FL(SI) > 2$ Equation GB-3

Where:

FL = watershed flow length (ft)

SI = interface slope (normal to flow) (ft/ft)

6. **Flow Distribution:** Flows delivered to a grass buffer must be sheet flows. Slotted or flush curbing, permeable pavements, or other devices can be used to spread flows. The grass buffer should have relatively consistent slopes to avoid concentrating flows within the buffer.

A level spreader should be used when flows are concentrated. A level spreader can be a slotted drain designed to discharge flow through the slot as shown in Photo GB-2. It could be an exfiltration trench filled with gravel, which allows water to infiltrate prior to discharging over a level concrete or rock curb. There are many ways to design and construct a level spreader. They can also be used in series when the length of the buffer allows flows to re-concentrate. See Figure GB-2 for various level spreader sections.

Photograph GB-2. This level spreader carries concentrated flows into a slotted pipe encased in concrete to distribute flows evenly to the grass buffer shown left in the photo. Photo courtesy of Bill Wenk.

Photos GB-3 and GB-4 show a level spreader that includes a basin for sedimentation. Concentrated flows enter the basin via stormsewer. The basin is designed to drain slowly while overflow is spread evenly to the downstream vegetation. A small notch, orifice, or pipe can be used to drain the level spreader completely. The opening should be small to encourage frequent flows to overtop the level spreader but not so small that it is frequently clogged.

Photograph GB-3. This level spreader includes the added benefit of a sedimentation basin prior to even distribution of concentrated flows from the roadway into the grass buffer. Photo courtesy of Bill Wenk.

7. **Soil Preparation**: In order to encourage establishment and long-term health of the selected vegetation, it is essential that soil conditions be properly prepared prior to installation. Following site grading, poor soil conditions often exist. When possible, remove, strip, stockpile, and reuse on-site topsoil. If the site does not contain topsoil, the soils should be amended prior to vegetation. Typically 3 to 5 cubic yards of soil amendment (compost) per 1,000 square feet, tilled 6 inches into the soil is required in order for vegetation to thrive, as well as to enable infiltration of runoff. Additionally, inexpensive soil tests can be conducted to determine required soil amendments. (Some local governments may also require proof of soil amendment in landscaped areas for water conservation reasons.)

Photograph GB-4. Maintenance access is provided via the ramp located at the end of the basin. Photo courtesy of Bill Wenk.

8. **Vegetation:** This is the most critical component for treatment within a grass buffer. Select durable, dense, and drought tolerant grasses to vegetate the buffer. Also consider the size of the watershed as larger watersheds will experience more frequent flows. The goal is to provide a dense mat of vegetative cover. Grass buffer performance falls off rapidly as the vegetation coverage declines below 80% (Barrett et al.2004).

Turf grasses such as Kentucky bluegrass are often selected due to these qualities[1]. Dense native turf grasses may also be selected where a more natural look is desirable. Once established, these provide the benefit of lower irrigation requirements. See the *Revegetation* chapter in Volume 2 of this manual with regard to seed mix selection, planting and ground preparation. Depending on soils and anticipated flows, consider erosion control measures until vegetation has been established.

9. **Irrigation**: Grass buffers should be equipped with irrigation systems to promote establishment and survival in Colorado's semi-arid environment. Systems may be temporary or permanent, depending on the type of vegetation selected. Irrigation application rates and schedules should be developed and adjusted throughout the establishment and growing season to meet the needs of the selected plant species. Initially, native grasses require the same irrigation requirements as bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced. Irrigation practices have a significant effect on the function of the grass buffer. Overwatering decreases the permeability of the soil, reducing the infiltration capacity and contributing to nuisance baseflows. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less filtering and increased susceptibility to erosion and rilling over the long term.

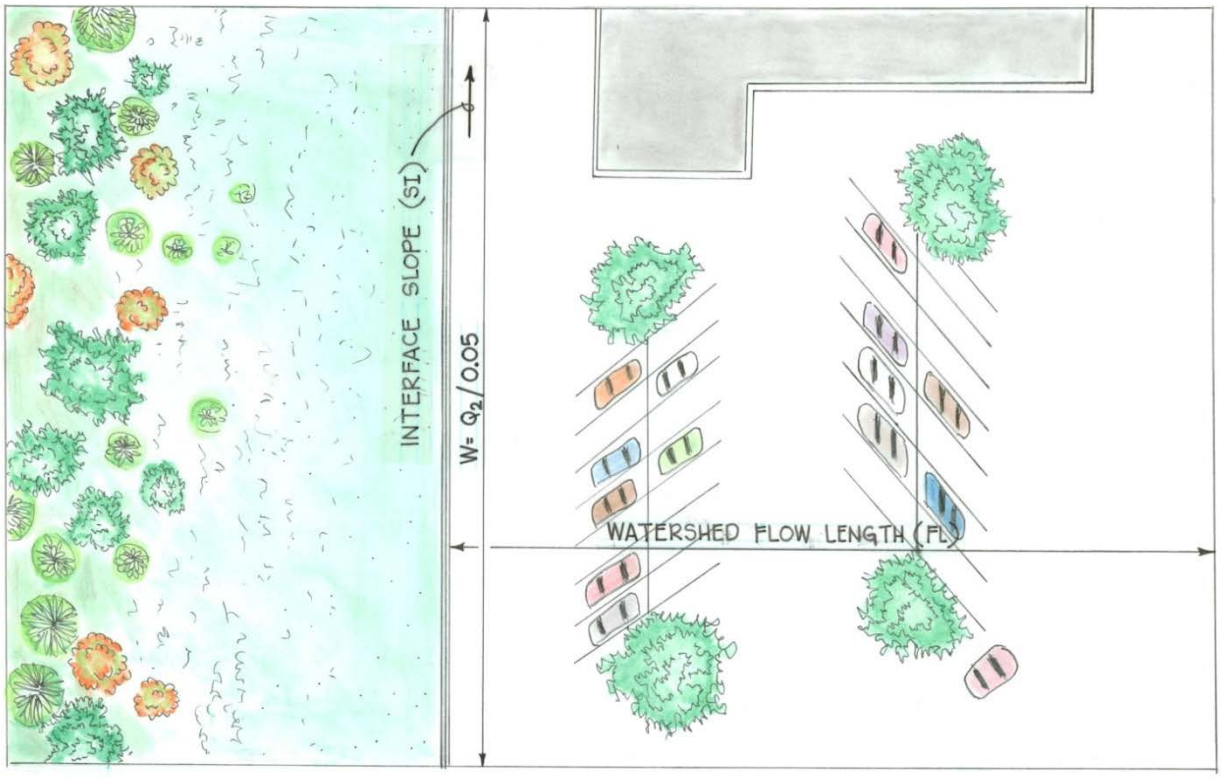
10. **Outflow Collection**: Provide a means for downstream conveyance. A grass swale can be used for this purpose, providing additional LID benefits.

Construction Considerations

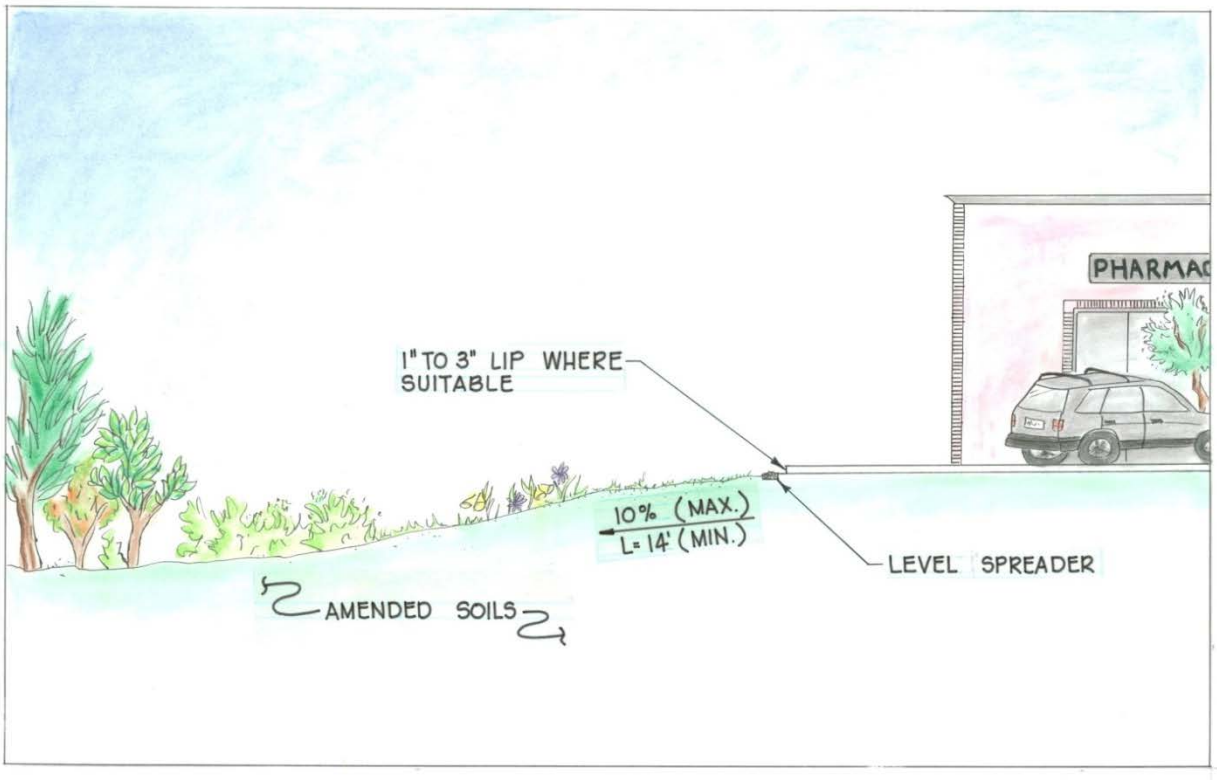
Success of grass buffers depends not only on a good design and long-term maintenance, but also on installing the facility in a manner that enables the BMP to function as designed. Construction considerations include:

- The final grade of the buffer is critical. Oftentimes, following soil amendment and placement of sod, the final grade is too high to accept sheet flow. The buffer should be inspected prior to placement of seed or sod to ensure appropriate grading.
- Perform soil amending, fine grading, and seeding only after tributary areas have been stabilized and utility work crossing the buffer has been completed.
- When using sod tiles stagger the ends of the tiles to prevent the formation of channels along the joints. Use a roller on the sod to ensure there are no air pockets between the sod and soil.
- Avoid over compaction of soils in the buffer area during construction to preserve infiltration capacities.
- Erosion and sediment control measures on upgradient disturbed areas must be maintained to prevent excessive sediment loading to grass buffer.

[1] Although Kentucky bluegrass has relatively high irrigation requirements to maintain a lush, green aesthetic, it also withstands drought conditions by going dormant. Over-irrigation of Kentucky bluegrass is a common problem along the Colorado Front Range, and it can be healthy, although less lush, with much less irrigation than is typically applied.



PLAN



PROFILE

Figure GB-1. Typical Grass Buffer Graphic by Adia Davis.

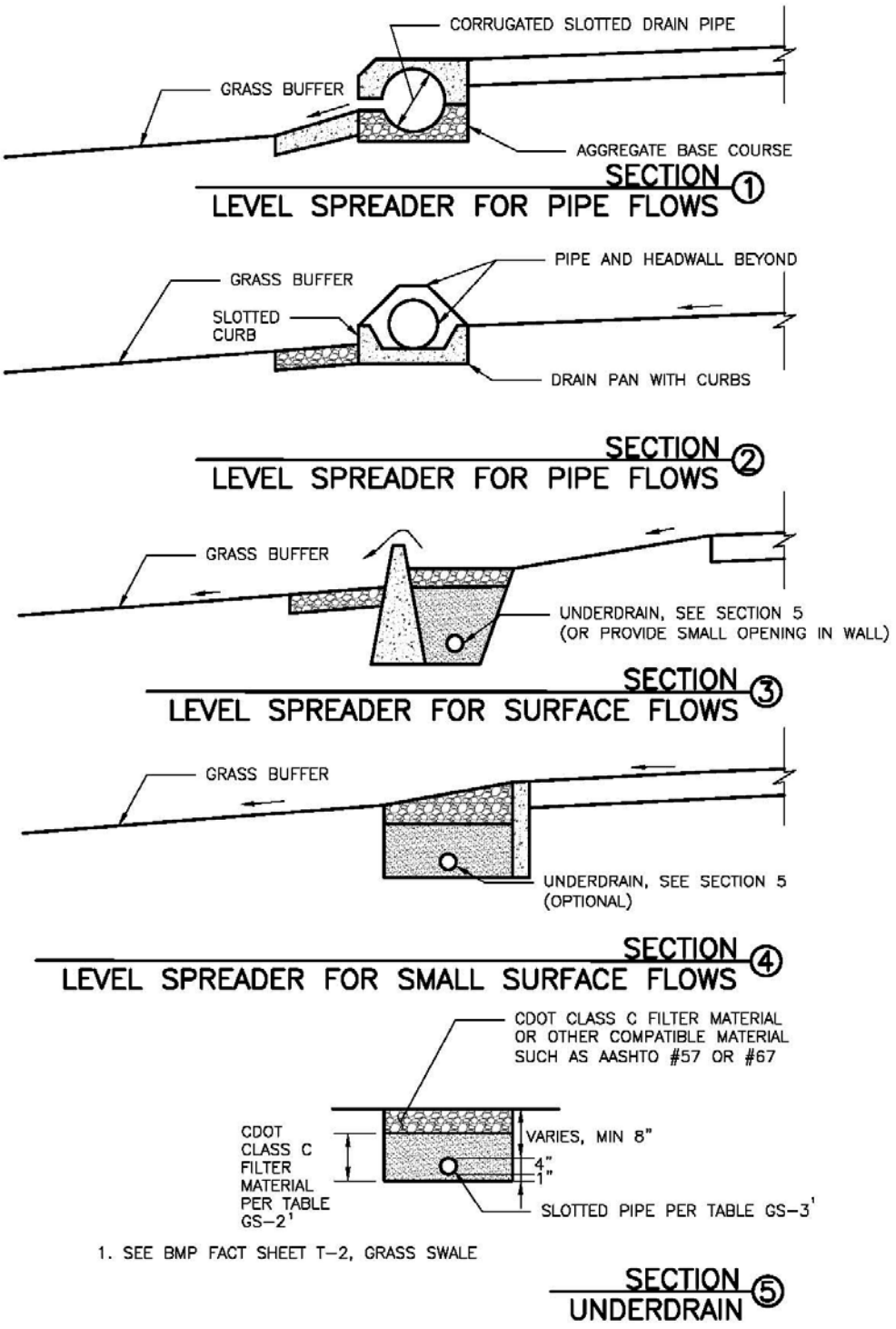


Figure GB-2. Typical Level Spreader Details

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Grass Buffer (GB)

Sheet 1 of 1

Designer: R. Dunn
Company: BMP, Inc.
Date: November 24, 2010
Project: Filing 37
Location: NE Corner of 34th Ave. and 105th St., north entrance road

1. Design Discharge A) 2-Year Peak Flow Rate of the Area Draining to the Grass Buffer	Q_2 = 5.0 cfs
2. Minimum Width of Grass Buffer	W_G = 100 ft
3. Length of Grass Buffer (14' or greater recommended)	L_G = 15 ft
4. Buffer Slope (in the direction of flow, not to exceed 0.1 ft / ft)	S_G = 0.100 ft / ft
5. Flow Characteristics (sheet or concentrated) A) Does runoff flow into the grass buffer across the entire width of the buffer?	Choose One: (◉) Yes ( ) No
B) Watershed Flow Length	F_L = 20 ft
C) Interface Slope (normal to flow)	S_I = 0.020 ft / ft
D) Type of Flow Sheet Flow: $F_L * S_I \leq 1$ Concentrated Flow: $F_L * S_I > 1$	SHEET FLOW
6. Flow Distribution for Concentrated Flows	Choose One: (◉) None (sheet flow) ( ) Slotted Curbing ( ) Level Spreader ( ) Other (Explain):
7 Soil Preparation (Describe soil amendment)	Till 5 CY of compost per 1000 SF to a depth of 6 inches.
8 Vegetation (Check the type used or describe "Other")	Choose One: ( ) Existing Xeric Turf Grass (◉) Irrigated Turf Grass ( ) Other (Explain):
9. Irrigation (*Select None if existing buffer area has 80% vegetation AND will not be disturbed during construction.)	Choose One: (◉) Temporary ( ) Permanent ( ) None*
10. Outflow Collection (Check the type used or describe "Other")	Choose One: (◉) Grass Swale ( ) Street Gutter ( ) Storm Sewer Inlet ( ) Other (Explain):
Notes:	

References

Barrett, M., Lantin, A. and S. Austrheim-Smith. 2004. *Stormwater Pollutant Removal in Roadside Vegetated Buffer Strips.* Prepared for the Transportation Research Board: Washington, DC.

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook, Vegetated Buffer Strip*.

Description

Grass swales are densely vegetated trapezoidal or triangular channels with low-pitched side slopes designed to convey runoff slowly. Grass swales have low longitudinal slopes and broad cross-sections that convey flow in a slow and shallow manner, thereby facilitating sedimentation and filtering (straining) while limiting erosion. Berms or check dams may be incorporated into grass swales to reduce velocities and encourage settling and infiltration. When using berms, an underdrain system should be provided. Grass swales are an integral part of the Low Impact Development (LID) concept and may be used as an alternative to a curb and gutter system.

Photograph GS-1. This grass swale provides treatment of roadway runoff in a residential area. Photo courtesy of Bill Ruzzo.

Site Selection

Grass swales are well suited for sites with low to moderate slopes. Drop structures or other features designed to provide the same function as a drop structures (e.g., a driveway with a stabilized grade differential at the downstream end) can be integrated into the design to enable use of this BMP at a broader range of site conditions. Grass swales provide conveyance so they can also be used to replace curb and gutter systems making them well suited for roadway projects.

Grass Swale	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs	Low

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:

- Consider the use and function of other site features so that the swale fits into the landscape in a natural way. This can encourage upkeep of the area, which is particularly important in residential areas where a loss of aesthetics and/or function can lead to homeowners filling in and/or piping reaches of this BMP.

- Provide access to the swale for mowing equipment and design sideslopes flat enough for the safe operation of equipment.
- Design and adjust the irrigation system (temporary or permanent) to provide appropriate water for the selected vegetation.
- An underdrain system will reduce excessively wet areas, which can cause rutting and damage to the vegetation during mowing operations.
- When using an underdrain, do not put a filter sock on the pipe. This is unnecessary and can cause the slots or perforations in the pipe to clog.

Benefits

- Removal of sediment and associated constituents through filtering (straining)
- Reduces length of storm sewer systems in the upper portions of a watershed
- Provides a less expensive and more attractive conveyance element
- Reduces directly connected impervious area and can help reduce runoff volumes.

Limitations

- Requires more area than traditional storm sewers.
- Underdrains are recommended for slopes under 2%.
- Erosion problems may occur if not designed and constructed properly.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for stormwater treatment in a grass swale. Figure GS-1 shows trapezoidal and triangular swale configurations.

1. **Design Discharge**: Determine the 2-year flow rate to be conveyed in the grass swale under fully developed conditions. Use the hydrologic procedures described in the *Runoff* Chapter in Volume 1.

2. **Hydraulic Residence Time**: Increased hydraulic residence time in a grass swale improves water quality treatment. Maximize the length of the swale when possible. If the length of the swale is limited due to site constraints, the slope can also be decreased or the cross-sectional area increased to increase hydraulic residence time.

3. **Longitudinal Slope**: Establish a longitudinal slope that will meet Froude number, velocity, and depth criteria while ensuring that the grass swale maintains positive drainage. Positive drainage can be achieved with a minimum 2% longitudinal slope or by including an underdrain system (see step 8). Use drop structures as needed to accommodate site constraints. Provide for energy dissipation downstream of each drop when using drop structures.

4. **Swale Geometry**: Select geometry for the grass swale. The cross section should be either trapezoidal or triangular with side slopes not exceeding 4:1 (horizontal: vertical), preferably flatter. Increase the wetted area of the swale to reduce velocity. Lower velocities result in improved pollutant removal efficiency and greater volume reduction. If one or both sides of the grass swale are also to be used as a grass buffer, follow grass buffer criteria.

5. **Vegetation**: Select durable, dense, and drought tolerant grasses. Turf grasses, such as Kentucky bluegrass, are often selected due to these qualities[1]. Native turf grasses may also be selected where a more natural look is desirable. This will also provide the benefit of lower irrigation requirements, once established. Turf grass is a general term for any grasses that will form a turf or mat as opposed to bunch grass, which will grow in clumplike fashion. Grass selection should consider both short-term (for establishment) and long-term maintenance requirements, given that some varieties have higher maintenance requirements than others. Follow criteria in the *Revegetation* Chapter of Volume 2, with regard to seed mix selection, planting, and ground preparation.

Native grasses provide a more natural aesthetic and require less water once established.

6. **Design Velocity**: Maximum flow velocity in the swale should not exceed one foot per second. Use the Soil Conservation Service (now the NRCS) vegetal retardance curves for the Manning coefficient (Chow 1959). Determining the retardance coefficient is an iterative process that the UD-BMP workbook automates. When starting the swale vegetation from sod, curve "D" (low retardance) should be used. When starting vegetation from seed, use the "E" curve (very low vegetal retardance).

7. **Design Flow Depth**: Maximum flow depth should not exceed one foot at the 2-year peak flow rate. Check the conditions for the 100-year flow to ensure that drainage is being handled without flooding critical areas, structures, or adjacent streets.

Table GS-1. Grass Swale Design Summary for Water Quality

Design Flow	Maximum Froude Number	Maximum Velocity	Maximum Flow Depth
2-year event	0.5	1 ft/s	1 ft

Use of Grass Swales

Vegetated conveyance elements provide some benefit in pollutant removal and volume reduction even when the geometry of the BMP does not meet the criteria provided in this Fact Sheet. These criteria provide a design procedure that should be used when possible; however, when site constraints are limiting, vegetated conveyance elements designed for stability are still encouraged.

[1] Although Kentucky bluegrass has relatively high irrigation requirements to maintain a lush, green aesthetic, it also withstands drought conditions by going dormant. Over-irrigation of Kentucky bluegrass is a common problem along the Colorado Front Range. It can be healthy, although less lush, with much less irrigation than is typically applied.

8. **Underdrain:** An underdrain is necessary for swales with longitudinal slopes less than 2.0%. The underdrain can drain directly into an inlet box at the downstream end of the swale, daylight through the face of a grade control structure or continue below grade through several grade control structures as shown in Figure GS-1.

   The underdrain system should be placed within an aggregate layer. If no underdrain is required, this layer is not required. The aggregate layer should consist of an 8-inch thick layer of CDOT Class C filter material meeting the gradation in Table GS-2. Use of CDOT Class C Filter material with a slotted pipe that meets the slot dimensions provided in Table GS-3 will eliminate the need for geotextile fabrics. Previous versions of this manual detailed an underdrain system that consisted of a 3- to 4-inch perforated HDPE pipe in a one-foot trench section of AASHTO #67 coarse aggregate surrounded by geotextile fabric. If desired, this system continues to provide an acceptable alternative for use in grass swales. Selection of the pipe size may be a function of capacity or of maintenance equipment. Provide cleanouts at approximately 150 feet on center.

Table GS-2. Gradation Specifications for Class C Filter Material
(Source: CDOT Table 703-7)

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

Table GS-3. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4”	1-1/16”	0.032”	0.413”	1.90 in^2
6”	1-3/8”	0.032”	0.516”	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

9. **Soil preparation:** Poor soil conditions often exist following site grading. When the section includes an underdrain, provide 4 inches of sandy loam at the invert of the swale extending up to the 2-year water surface elevation. This will improve infiltration and reduce ponding. For all sections, encourage establishment and long-term health of the bottom and side slope vegetation by properly preparing the soil. If the existing site provides a good layer of topsoil, this should be striped, stockpiled, and then replaced just prior to seeding or placing sod. If not available at the site, topsoil can be imported or the existing soil may be amended. Inexpensive soil tests can be performed following rough grading, to determine required soil amendments. Typically, 3 to 5 cubic yards of soil amendment per 1,000 square feet, tilled 4 to 6 inches into the soil is required in order for vegetation to thrive, as well as to enable infiltration of runoff.

10. **Irrigation:** Grass swales should be equipped with irrigation systems to promote establishment and survival in Colorado's semi-arid environment. Systems may be temporary or permanent, depending on the type of grass selected. Irrigation practices have a significant effect on the function of the grass swale. Overwatering decreases the permeability of the soil, reducing the infiltration capacity of the soil and contributing to nuisance baseflows. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less filtering (straining) and increased susceptibility to erosion and riling over the long term.

Construction Considerations

Success of grass swales depends not only on a good design and maintenance, but also on construction practices that enable the BMP to function as designed. Construction considerations include:

- Perform fine grading, soil amendment, and seeding only after upgradient surfaces have been stabilized and utility work crossing the swale has been completed.
- Avoid compaction of soils to preserve infiltration capacities.
- Provide irrigation appropriate to the grass type.
- Weed the area during the establishment of vegetation by hand or mowing. Mechanical weed control is preferred over chemical weed killer.
- Protect the swale from other construction activities.
- When using an underdrain, ensure no filter sock is placed on the pipe. This is unnecessary and can cause the slots or perforations in the pipe to clog.

Photograph GS-2. This community used signage to mitigate compaction of soils post-construction. Photo courtesy of Nancy Styles.

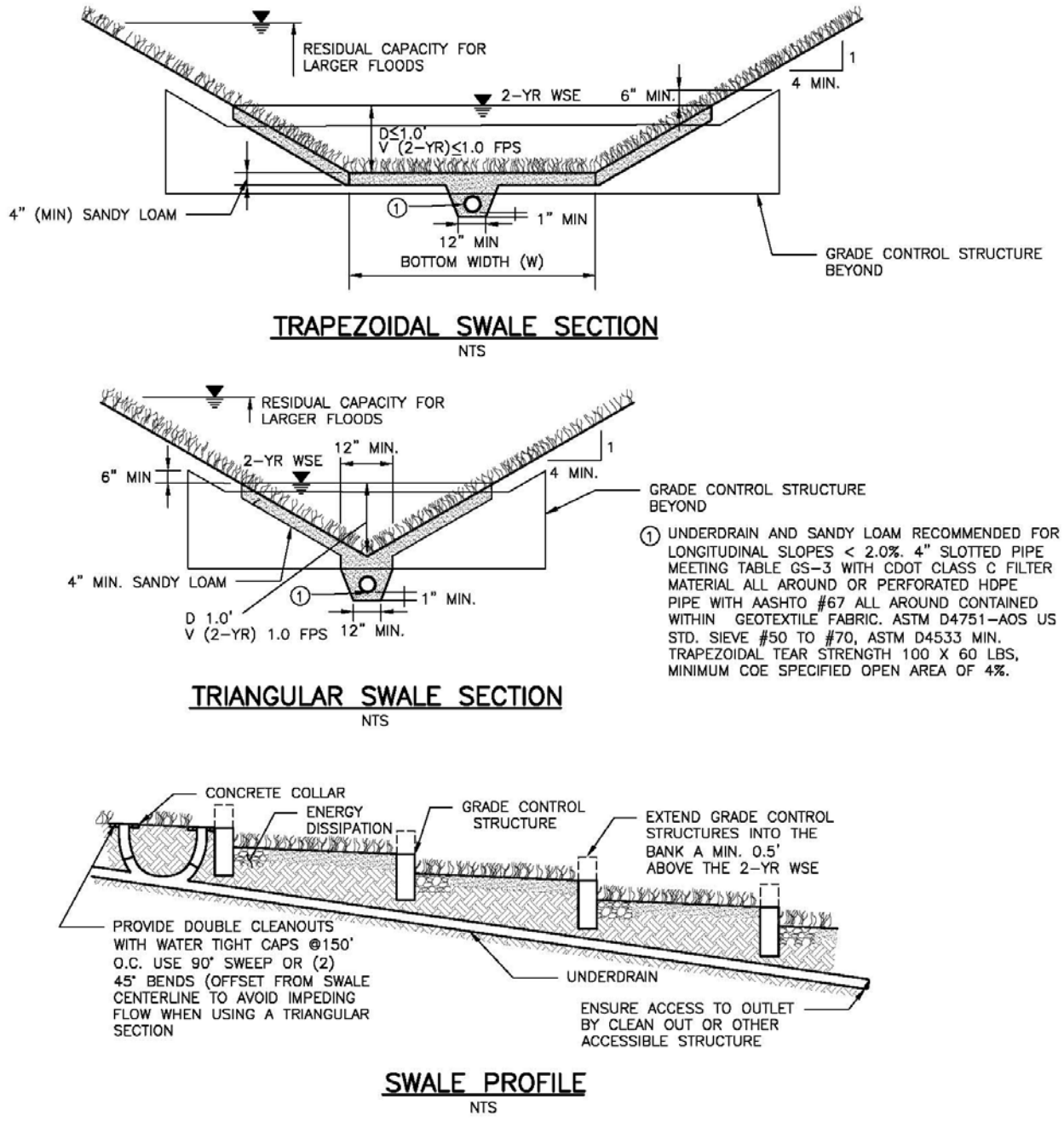


Figure GS-1. Grass Swale Profile and Sections

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Grass Swale (GS)

Sheet 1 of 1

Designer:	**M. Levine**
Company:	**BMP Inc.**
Date:	**November 24, 2010**
Project:	**Filing 30**
Location:	**Swale between north property line and 52nd Ave.**

1. Design Discharge for 2-Year Return Period	Q_2 = 4.00 cfs
2. Hydraulic Residence Time	
A) : Length of Grass Swale	L_S = 400.0 ft
B) Calculated Residence Time (based on design velocity below)	T_{HR} = 6.7 minutes
3. Longitudinal Slope (vertical distance per unit horizontal)	
A) Available Slope (based on site constraints)	S_{avail} = 0.020 ft / ft
B) Design Slope	S_D = 0.010 ft / ft
4. Swale Geometry	
A) Channel Side Slopes (Z = 4 min., horiz. distance per unit vertical)	Z = 4.00 ft / ft
B) Bottom Width of Swale (enter 0 for triangular section)	W_B = 4.00 ft
5. Vegetation A) Type of Planting (seed vs. sod, affects vegetal retardance factor)	Choose One: ○ Grass From Seed ◉ Grass From Sod
6. Design Velocity (1 ft / s maximum)	V_2 = 1.00 ft / s
7. Design Flow Depth (1 foot maximum)	D_2 = 0.62 ft
A) Flow Area	A_2 = 4.0 sq ft
B) Top Width of Swale	W_T = 9.0 ft
C) Froude Number (0.50 maximum)	F = 0.26
D) Hydraulic Radius	R_H = 0.44
E) Velocity-Hydraulic Radius Product for Vegetal Retardance	VR = 0.44
F) Manning's n (based on SCS vegetal retardance curve D for sodded grass)	n = 0.088
G) Cumulative Height of Grade Control Structures Required	H_D = 4.00 ft
8. Underdrain (Is an underdrain necessary?)	Choose One: ◉ YES ○ NO — AN UNDERDRAIN IS REQUIRED IF THE DESIGN SLOPE < 2.0%
9. Soil Preparation (Describe soil amendment)	Till 5 CY of compost per 1000 SF to a depth of 6 inches.
10. Irrigation	Choose One: ◉ Temporary ○ Permanent

Notes:

References

Chow, Ven Te. 1959. *Open Channel Flow*. McGraw Hill: New York, NY.

Description

A BMP that utilizes bioretention is an engineered, depressed landscape area designed to capture and filter or infiltrate the water quality capture volume (WQCV). BMPs that utilize bioretention are frequently referred to as rain gardens or porous landscape detention areas (PLDs). The term PLD is common in the UDFCD region as this manual first published the BMP by this name in 1999. In an effort to be consistent with terms most prevalent in the stormwater industry, this document generally refers to the treatment process as *bioretention* and to the BMP as a *rain garden*.

Photograph B-1. This recently constructed rain garden provides bioretention of pollutants, as well as an attractive amenity for a residential building. Treatment should improve as vegetation matures.

The design of a rain garden may provide detention for events exceeding that of the WQCV. There are generally two ways to achieve this. The design can provide the flood control volume above the WQCV or the design can provide and slowly release the flood control volume in an area downstream of one or more rain gardens. See the *Storage* chapter in Volume 2 of the USDCM for more information.

This infiltrating BMP requires consultation with a geotechnical engineer when proposed adjacent to a structure. A geotechnical engineer can assist with evaluating the suitability of soils, identifying potential impacts, and establishing minimum distances between the BMP and structures.

Terminology

The term *bioretention* refers to the treatment process although it is also frequently used to describe a BMP that provides biological uptake and retention of the pollutants found in stormwater runoff. This BMP is sometimes referred to as a *porous landscape detention (PLD) area* or *rain garden*.

Bioretention (Rain Garden)	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Moderate
Total Metals	Good
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Benefits

- Bioretention uses multiple treatment processes to remove pollutants, including sedimentation, filtering, adsorption, evapotranspiration, and biological uptake of constituents.
- Stormwater treatment occurs within attractive landscaped areas.
- There is a potential reduction of irrigation requirements by taking advantage of site runoff.

Limitations

- Additional design and construction steps are required for placement of any ponding or infiltration area near or upgradient from a building foundation and/or when expansive (low to high swell) soils exist. This is discussed in the design procedure section.
- In developing or otherwise erosive watersheds, high sediment loads can clog the facility.

Site Selection

This BMP allows WQCV treatment within one or more areas designated for landscape (see design step 7 for suggusted vegetation). In this way, it is an excellent alternative to extended detention basins for small sites. A typical rain garden serves a tributary area of one impervious acre or less, although they can be designed for larger tributary areas. Multiple installations can be used within larger sites. Rain gardens should not be used when a baseflow is anticipated. They are typically small and installed in locations such as:

- Parking lot islands
- Street medians
- Landscape areas between the road and a detached walk
- Planter boxes that collect roof drains

Bioretention requires a stable watershed. Retrofit applications are typically successful for this reason. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils, consider another BMP or provide pretreatment before runoff from these areas reaches the rain garden.

The surface of the rain garden should be flat. For this reason, rain gardens can be more difficult to incorporate into steeply sloping terrain; however, terraced applications of these facilities have been successful in other parts of the country.

When bioretention (and other BMPs used for infiltration) are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. Oversaturated subgrade soil underlying a structure can cause the structure to settle or result in moisture-related problems. Wetting of expansive soils or bedrock can cause swelling, resulting in structural movements. A geotechnical engineer should evaluate the potential impact of the BMP on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. Additional minimum requirements include:

- In locations where subgrade soils do not allow infiltration and/or where infiltration could adversely impact adjacent structures, include a drainage layer (with underdrain) under the growing medium.
- In locations where potentially expansive soils or bedrock exist, placement of a rain garden adjacent to structures and pavement should only be considered if the BMP includes a drainage layer (with underdrain) and an impermeable geomembrane liner designed to restrict seepage.

Designing for Maintenance

Recommended maintenance practices for all BMPs are in Chapter 6 of this manual. During design, consider the following to ensure ease of maintenance over the long-term:

- Do not put a filter sock on the underdrain. This is not necessary and can cause the underdrain to clog.
- The best surface cover for a rain garden is full vegetation. Use rock mulch sparingly within the rain garden because rock mulch limits infiltration and is more difficult to maintain. Wood mulch handles sediment build-up better than rock mulch; however, wood mulch floats and may clog the overflow depending on the configuration of the outlet or settle unevenly. Some municipalities may not allow wood mulch for this reason.

Is Pretreatment Needed?

Designing the inflow gutter to the rain garden at a minimal slope of 0.5% can facilitate sediment and debris deposition prior to flows entering the BMP. Be aware, this will reduce maintenance of the BMP, but may require more frequent sweeping of the gutter to ensure that the sediment does not impede flow into the rain garden.

- Consider all potential maintenance requirements such as mowing (if applicable) and replacement of the growing medium. Consider the method and equipment for each task required. For example, in a large rain garden where the use of hand tools is not feasible, does the shape and configuration of the rain garden allow for removal of the growing medium using a backhoe?
- Provide pre-treatment when it will reduce the extent and frequency of maintenance necessary to maintain function over the life of the BMP. For example, if the tributary is larger than one acre, prone to debris or the use of sand for ice control, consider a small forebay.
- Make the rain garden as shallow as possible. Increasing the depth unnecessarily can create erosive side slopes and complicate maintenance. Shallow rain gardens are also more attractive.
- Design and adjust the irrigation system (temporary or permanent) to provide appropriate water for the establishment and maintenance of selected vegetation.

Design Procedure and Criteria

1. **Subsurface Exploration and Determination of a No-Infiltration, Partial Infiltration, or Full Infiltration Section**: Infiltration BMPs can have three basic types of sections. The appropriate section will depend on land use and activities, proximity to adjacent structures and soil characteristics. Sections of each installation type are shown in Figure B-1.
   - **No-Infiltration Section**: This section includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils. Consider using this section when any of the following conditions exist:
     - The site is a stormwater hotspot and infiltration could result in contamination of groundwater.
     - The site is located over contaminated soils and infiltration could mobilize these contaminants.
     - The facility is located over potentially expansive soils or bedrock that could swell due to infiltration and potentially damage adjacent structures (e.g., building foundation or pavement).
   - **Partial Infiltration Section**: This section does not include an impermeable liner, and allows some infiltration. Stormwater that does not infiltrate is collected and removed by an underdrain

system.

- **Full Infiltration Section**: This section is designed to infiltrate the water stored in the basin into the subgrade below. UDFCD recommends a minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours. A conservative design could utilize the partial infiltration section with the addition of a valve at the underdrain outlet. In the event that infiltration does not remain adequate following construction, the valve could be opened and allow this section to operate as a partial infiltration section.

A geotechnical engineer should scope and perform a subsurface study. Typical geotechnical investigation needed to select and design the section includes:

- Prior to exploration review geologic and geotechnical information to assess near-surface soil, bedrock and groundwater conditions that may be encountered and anticipated ranges of infiltration rate for those materials. For example, if the facility is located adjacent to a structure and the site is located in a general area of known shallow, potentially expansive bedrock, a no-infiltration section will likely be required. It is also possible that this BMP may be infeasible, even with a liner, if there is a significant potential for damage to the adjacent structures (e.g., areas of dipping bedrock).
- Drill exploratory borings or exploratory pits to characterize subsurface conditions beneath the subgrade and develop requirements for subgrade preparation. Drill at least one boring or pit for every 40,000 ft^2, and at least two borings or pits for sites between 10,000 ft^2 and 40,000 ft^2. The boring or pit should extend at least 5 feet below the bottom of the base, and at least 20 feet in areas where there is a potential of encountering potentially expansive soils or bedrock. More borings or pits at various depths may be required by the geotechnical engineer in areas where soil types may change, in low-lying areas where subsurface drainage may collect, or where the water table is likely within 8 feet below the planned bottom of the base or top of subgrade. Installation of temporary monitoring wells in selected borings or pits for monitoring groundwater levels over time should be considered where shallow groundwater is encountered.
- Perform laboratory tests on samples obtained from the borings or pits to initially characterize the subgrade, evaluate the possible section type, and to assess subgrade conditions for supporting traffic loads. Consider the following tests: moisture content (ASTM D 2216); dry density (ASTM D 2936); Atterberg limits (ASTM D 4318); gradation (ASTM D 6913); swell-consolidation (ASTM D 4546); subgrade support testing (R-value, CBR or unconfined compressive strength); and hydraulic conductivity. A geotechnical engineer should determine the appropriate test method based on the soil type.
- For sites where a full infiltration section may be feasible, perform on-site infiltration tests using a double-ring infiltrometer (ASTM D 3385). Perform at least one test for every 160,000 ft^2 and at least two tests for sites between 40,000 ft^2 and 160,000 ft^2. The tests should be located near completed borings or pits so the test results and subsurface conditions encountered in the borings can be compared, and at least one test should be located near the boring or pit showing the most unfavorable infiltration condition. The test should be performed at the planned top of subgrade underlying the growing media.
- Be aware that actual infiltration rates are highly variable dependent on soil type, density and moisture content and degree of compaction as well as other environmental and construction influences. Actual rates can differ an order of magnitude or more from those indicated by infiltration or permeability testing. Select the type of section based on careful assessment of the subsurface exploration and testing data.

The following steps outline the design procedure and criteria, with Figure B-1 providing a corresponding cross-section.

2. **Basin Storage Volume**: Provide a storage volume based on a 12-hour drain time.

   Find the required WQCV (watershed inches of runoff). Using the imperviousness of the tributary area (or effective imperviousness where LID elements are used upstream), use Figure 3-2 located in Chapter 3 of this manual to determine the WQCV based on a 12-hour drain time.

   Calculate the design volume as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation B-1}$$

   Where:

   V= design volume (ft^3)

   A = area of watershed tributary to the rain garden (ft^2)

3. **Basin Geometry:** UDFCD recommends a maximum WQCV ponding depth of 12 inches to maintain vegetation properly. Provide an inlet or other means of overflow at this elevation. Depending on the type of vegetation planted, a greater depth may be utilized to detain larger (more infrequent) events. The bottom surface of the rain garden, also referred to here as the filter area, should be flat. Sediment will reside on the filter area of the rain garden; therefore, if the filter area is too small, it may clog prematurely. If the filter area is not flat, the lowest area of the filter is more likely to clog as it will have a higher sediment loading. Increasing the filter area will reduce clogging and decrease the frequency of maintenance. Equation B-2 provides a minimum filter area allowing for some of the volume to be stored beyond the area of the filter (i.e., above the sideslopes of the rain garden).

Note that the total surcharge volume provided by the design must also equal or exceed the design volume. Where needed to meet the the required volume, also consider the porosity of the media at 14 percent. Use vertical walls or slope the sides of the basin to achieve the required volume. Sideslopes should be no steeper than 4:1 (horizontal:vertical).

$$A_F = 0.02AI \qquad \text{Equation B-2}$$

Where:

A_F= minimum (flat) filter area (ft^2)

A = area tributary to the rain garden (ft^2)

I = imperviousness of area tributary to the rain garden (percent expressed as a decimal)

4. **Growing Medium:** Provide a minimum of 18 inches of growing medium to enable establishment of the roots of the vegetation (see Figure B-1). A previous version of this manual specified a mixture consisting of 85% coarse sand and a 15% compost/shredded paper mixture (by volume). Based on field monitoring of this medium, compost was removed to reduce export of nutrients and fines and silts were added to both benefit the vegetation and increase capture of metals in stormwater.

Table B-1 specifies the growing media as well as other materials discussed in this Fact Sheet**.** Growing media is engineered media that requires a high level of quality control and must almost always be imported. Obtaining a particle size distribution and nutrient analysis is the only way to ensure that the media is acceptable. UDFCD has identified placement of media not meeting the specification as the most frequent cause of failure. Sample the media after delivery and prior to placement or obtain a sample from the supplier in advance of delivery and placement and have this analyzed prior to delivery.

Other Rain Garden Growing Medium Amendments

The specified growing medium was designed for filtration ability, clogging characteristics, and vegetative health. It is important to preserve the function provided by the rain garden growing medium when considering additional materials for incorporation into the growing medium or into the standard section shown in Figure B-1. When desired, amendments may be included to improve water quality or to benefit vegetative health as long as they do not add nutrients, pollutants, or modify the infiltration rate. For example, a number of products, including steel wool, capture and retain dissolved phosphorus (Erickson 2009). When phosphorus is a target pollutant, proprietary materials with similar characteristics may be considered. Do not include amendments such as top soil, sandy loam, and compost.

Table B-1. Material specification for bioretention/rain garden facilities

Material		Specification			Submittals	Testing	Notes
Bioretention Growing Media (soil + organics)	Bioretention soil	Particle size distribution: 80-90% sand (0.05 - 2.0 mm diameter) 3-17% silt (0.002-0.5 mm diameter) 3-17% clay (<0.002 diameter) Chemical attribute and nutrient analysis: pH 6.8 - 7.5 organic matter < 1.5% nitrogen <15 ppm phosphorus < 15 ppm salinity < 6 mmhos/cm			Particle size distribution and nutrient analysis required.		Percentages are in weight.
	Bioretention organics	3 to 5% shredded mulch (by weight of growing media)					bioretention soil required. Aged 6 months (minimum).
Landscape mulch		Shredded hardwood					Aged 6 months (minimum). No weed fabric allowed.
Underdrain aggregate	CDOT filter material (Class B or C as specified)		Mass Percent Passing Square Mesh Siev				
		Sieve Size	Class B	Class C	Particle size distribution required.		
		37.5 mm (1.5")	100				
		19.0 mm (0.75")		100			
		4.75 mm (No.4)	20-60	60-100			
		1.18 um (No. 16)	10-30				
		300 um (No. 50)	0-10	10-30			
		150 um (No. 100)		0-10			
		75 um (No. 200)	0-3	0-3			
Underdrain Pipe		Pipe diameter and type	Maximum slot width (inches)	Minimum open area (per foot)	Required	Pipe must conform to requirements of ASTM designation F949. There shall be no evidence of splitting, cracking, or breaking when the pipe is tested per ASTM test method D2412 in accordance with F949 section 7.5 and ASTM F794 section 8.5.	Contech A-2000 slotted pipe (or equal)
		4-inch slotted PVC	0.032	1.90 in.²			
		6-inch slotted PVC	0.032	1.98 in.²			
Impermeable liner			Thickness 0.76 mm (30 mil)	Test method	Required	Thermal welding required for fully lined facilities (not a cutain). Leak testing in the field required.	
		Thickness, % Tolerance	+/-5	ASTM D 1593			
		Tensile strength, kN/m (lb/in)	12.25 (70)	ASTM D8 82, method B			
		Modulus at 100% elongation, kN/m	5.25 (30)	ASTM D8 82, method B			
		Ultimate elongation, %	350	ASTM D8 82, method A			
		Tear resistance, N(lbs)	38 (8.5)	ASTM D 1004			
		Low temperature impact, ° C (° F)	-29 (-20)	ASTM D 1790			
		Volatile loss, % maximum	0.7	ASTM D8 82, method A			
		Pinholes, no. per 8 m² (no. per 10 yd.²)	1 (max)	N/A			
		Bonded seam strength, % of tensile	80	N/A			

5. **Underdrain System**: When using an underdrain system, provide a control orifice sized to drain the design volume in 12 hours or more (see Equation B-3). Use a minimum orifice size of 3/8 inch to avoid clogging. This will provide detention and slow release of the WQCV, providing water quality benefits and reducing impacts to downstream channels. Space underdrain pipes a maximum of 20 feet on center. Provide cleanouts to enable maintenance of the underdrain. Cleanouts can also be used to conduct an inspection (by camera) of the underdrain system to ensure that the pipe was not crushed or disconnected during construction.

Calculate the diameter of the orifice for a 12-hour drain time using Equation B-3 (Use a minimum orifice size of 3/8 inch to avoid clogging.):

$$D_{12\text{ hour drain time}} = \sqrt{\frac{V}{1414\ y^{0.41}}} \qquad \text{Equation B-3}$$

Where:

D = orifice diameter (in)

y = distance from the lowest elevation of the storage volume (i.e., surface of the filter) to the center of the orifice (ft)

V = volume (WQCV or the portion of the WQCV in the rain garden) to drain in 12 hours (ft^3)

In previous versions of this manual, UDFCD recommended that the underdrain be placed in an aggregate layer and that a geotextile (separator fabric) be placed between this aggregate and the growing medium. This version of the manual replaces that section with materials that, when used together, eliminate the need for a separator fabric.

The underdrain system should be placed within an 6-inch-thick section of CDOT Class B or Class C filter material meeting the gradation in Table B-1. Use slotted pipe that meets the slot dimensions provided in Table B-3.

6. **Impermeable Geomembrane Liner and Geotextile Separator Fabric:** For no-infiltration sections, install a 30 mil (minimum) PVC geomembrane liner, per Table B-1, on the bottom and sides of the basin, extending up at least to the top of the underdrain layer. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration. The geomembrane should be field-seamed using a dual track welder, which allows for non-destructive testing of almost all field seams. A small amount of single track is allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs. The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. Place CDOT Class B geotextile separator fabric above the geomembrane to protect it from being punctured during the placement of the filter material above the liner. If the subgrade contains angular rocks or other material that could puncture the geomembrane, smooth-roll the surface to create a suitable surface. If smooth-rolling the surface does not provide a suitable surface, also place the separator fabric between the geomembrane and the underlying subgrade. This should only be done when necessary because fabric placed under the geomembrane can increase seepage losses through pinholes or other geomembrane defects. Connect the geomembrane to perimeter concrete walls around the basin perimeter, creating a watertight seal between the geomembrane and the walls using a continuous batten bar and anchor connection (see Figure B-3). Where the need for the impermeable membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Use watertight PVC boots for underdrain pipe penetrations through the liner (see Figure B-2) or the technique shown in photo B-3.

Photograph B-2. The impermeable membrane in this photo has ripped from the bolts due to placement of the media without enough slack in the membrane.

Photograph B-3. Ensure a water-tight connection where the underdrain penetrated the liner. The heat-welded "boot" shown here is an alternative to the clamped detail shown in Figure B-2.

Table B-2. Physical requirements for separator fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs.)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs.)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs.)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction

[2] As measured in accordance with ASTM D 4632

7. **Inlet and Outlet Control:** In order to provide the proper drain time, the bioretention area can be restricted at the underdrain outlet with an orifice plate or can be designed without an underdrain (provided the subgrade meets the requirements above). Equation B-3 is a simplified equation for sizing an orifice plate for a 12-hour drain time. UD-BMP or UD-Detention, available at www.udfcd.org, also perform this calculation.

   How flow enters and exits the BMP is a function of the overall drainage concept for the site. Curb cuts can be designed to both allow stormwater into the rain garden as well as to provide release of stormwater in excess of the WQCV. Roadside rain gardens located on a steep site might pool and overflow into downstream cells with a single curb cut, level spreader, or outlet structure located at the most downstream cell. When selecting the

Photograph B-4. The curb cut shown allows flows to enter this rain garden while excess flows bypass the facility.

type and location of the outlet structure, ensure runoff will not short-circuit the rain garden. This is a frequent problem when using a curb inlet located outside the rain garden for overflow.

For rain gardens with concentrated points of inflow, provide a forebay and energy dissipation. A depressed concrete slab works best for a forebay. It helps maintain a vertical drop at the inlet and allows for easily removal of sediment using a square shovel. Where rock is used for energy dissipation, provide separator fabric between the rock and growing medium to minimize subsidence.

8. **Vegetation:** UDFCD recommends that the filter area be vegetated with drought tolerant species that thrive in sandy soils. Table B-3 provides a suggested seed mix for sites that will not need to be irrigated after the grass has been established.

   Mix seed well and broadcast, followed by hand raking to cover seed and then mulched. Hydromulching can be effective for large areas. Do not place seed when standing water or snow is present or if the ground is frozen. Weed control is critical in the first two to three years, especially when starting with seed.

   When using sod, specify sand–grown sod. Do not use conventional sod. Conventional sod is grown in clay soil that will seal the filter area, greatly reducing overall function of the BMP.

   When using an impermeable liner, select plants with diffuse (or fibrous) root systems, not taproots. Taproots can damage the liner and/or underdrain pipe. Avoid trees and large shrubs that may interfere with restorative maintenance. Plant these outside of the area of growing medium. Use a cutoff wall to ensure that roots do not grow into the underdrain or place trees and shrubs a conservative distance from the underdrain.

9. **Irrigation:** Provide spray irrigation at or above the WQCV elevation or place temporary irrigation on top of the rain garden surface. Do not place sprinkler heads on the flat surface. Remove temporary irrigation when vegetation is established. If left in place this will become buried over time and will be damaged during maintenance operations.

   Adjust irrigation schedules during the growing season to provide the minimum water necessary to maintain plant health and to maintain the available pore space for infiltration.

Designing for Flood Protection

Provide the WQCV in rain gardens that direct excess flow into to a landscaped basin designed for flood control or design a single basin to provide water quality and flood control. See the *Storage* chapter in Volume 2 of the USDCM for more information. UD-Detention, available at www.udfcd.org, will facilitate design either alternative.

Table B-3. Native seed mix for rain gardens

Common Name	Scientific Name	Variety	PLS[2] lbs per Acre	Ounces per Acre
Sand bluestem	Andropogon hallii	Garden	3.5	
Sideoats grama	Bouteloua curtipendula	Butte	3	
Prairie sandreed	Calamovilfa longifolia	Goshen	3	
Indian ricegrass	Oryzopsis hymenoides	Paloma	3	
Switchgrass	Panicum virgatum	Blackwell	4	
Western wheatgrass	Pascopyrum smithii	Ariba	3	
Little bluestem	Schizachyrium scoparium	Patura	3	
Alkali sacaton	Sporobolus airoides		3	
Sand dropseed	Sporobolus cryptandrus		3	
Pasture sage[1]	Artemisia frigida			2
Blue aster[1]	Aster laevis			4
Blanket flower[1]	Gaillardia aristata			8
Prairie coneflower[1]	Ratibida columnifera			4
Purple prairieclover[1]	Dalea (Petalostemum) purpurea			4
Sub-Totals:			27.5	22
Total lbs per acre:			**28.9**	

[1] Wildflower seed (optional) for a more diverse and natural look.
[2] PLS = Pure Live Seed.

Aesthetic Design

In addition to effective stormwater quality treatment, rain gardens can be attractively incorporated into a site within one or several landscape areas. Aesthetically designed rain gardens will typically either reflect the character of their surroundings or become distinct features within their surroundings. Guidelines for each approach are provided below.

Reflecting the Surrounding

- Determine design characteristics of the surrounding. This becomes the context for the drainage improvement. Use these characteristics in the structure.
- Create a shape or shapes that "fix" the forms surrounding the improvement. Make the improvement part of the existing surrounding.
- The use of material is essential in making any new improvement an integral part of the whole. Select materials that are as similar as possible to the surrounding architectural/engineering materials. Select materials from the same source if possible. Apply materials in the same quantity, manner, and method as original material.
- Size is an important feature in seamlessly blending the addition into its context. If possible, the overall size of the improvement should look very similar to the overall sizes of other similar objects in the improvement area.

Reflective Design

A reflective design borrows the characteristics, shapes, colors, materials, sizes and textures of the built surroundings. The result is a design that fits seamlessly and unobtrusively in its environment.

- The use of the word texture in terms of the structure applies predominantly to the selection of plant material. The materials used should as closely as possible, blend with the size and texture of other plant material used in the surrounding. The plants may or may not be the same, but should create a similar feel, either individually or as a mass.

Creating a Distinct Feature

Designing the rain garden as a distinct feature is limited only by budget, functionality, and client preference. There is far more latitude in designing a rain garden that serves as a distinct feature. If this is the intent, the main consideration beyond functionality is that the improvement create an attractive addition to its surroundings. The use of form, materials, color, and so forth focuses on the improvement itself and does not necessarily reflect the surroundings, depending on the choice of the client or designer.

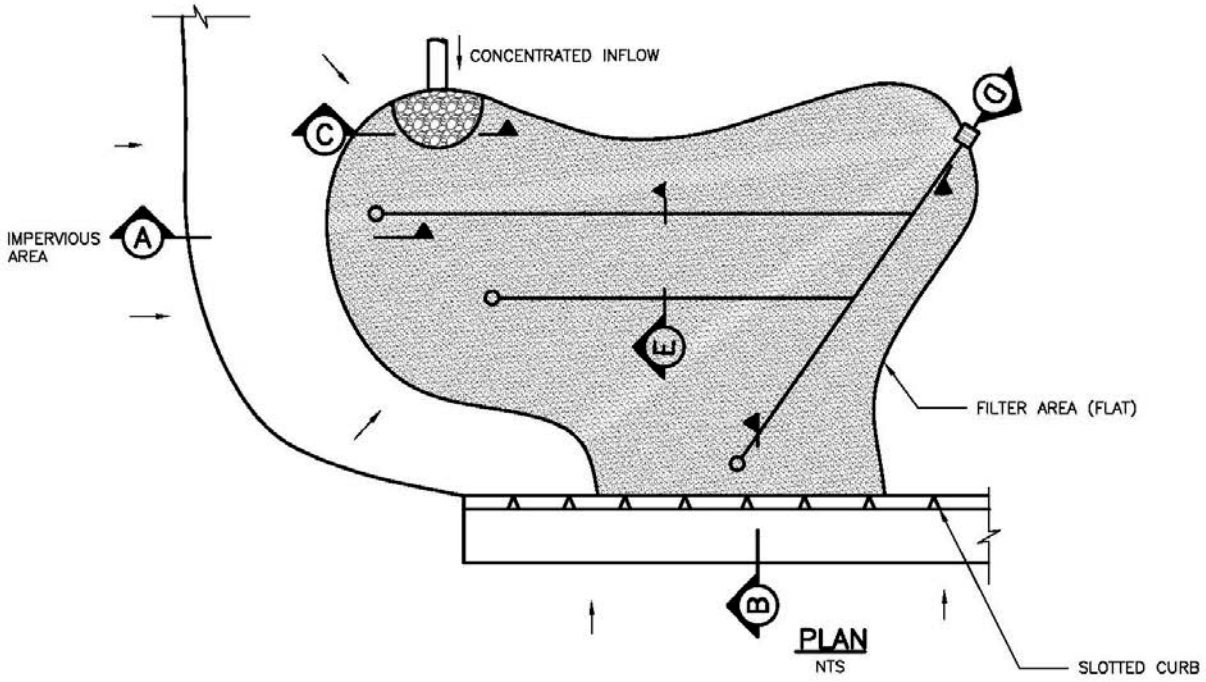
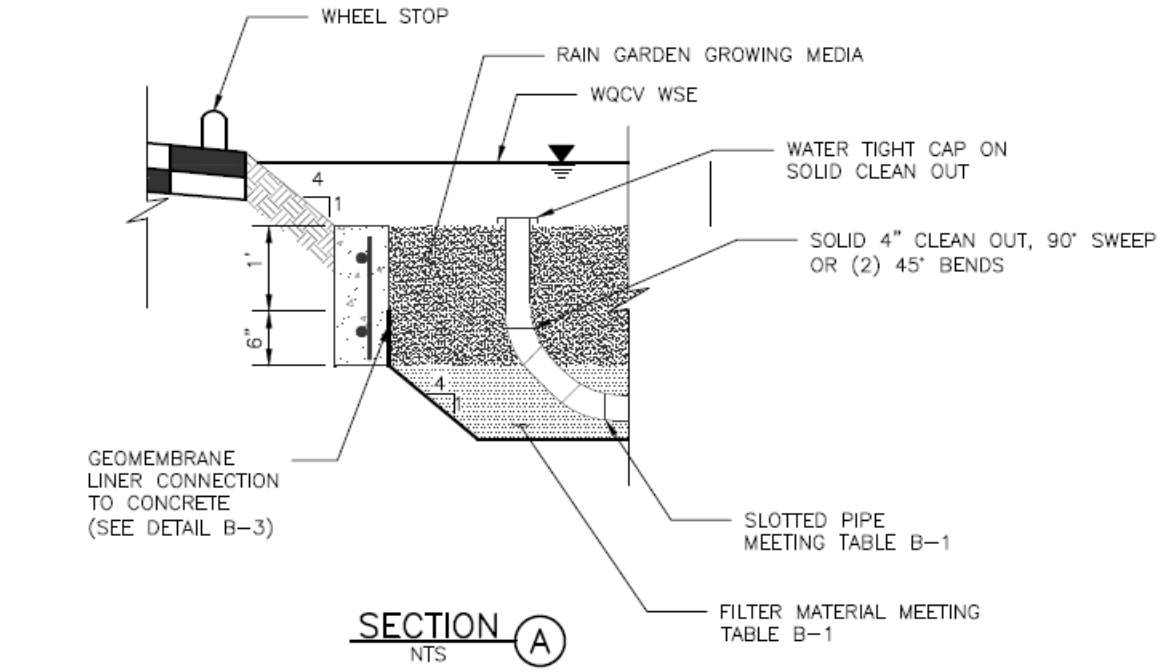
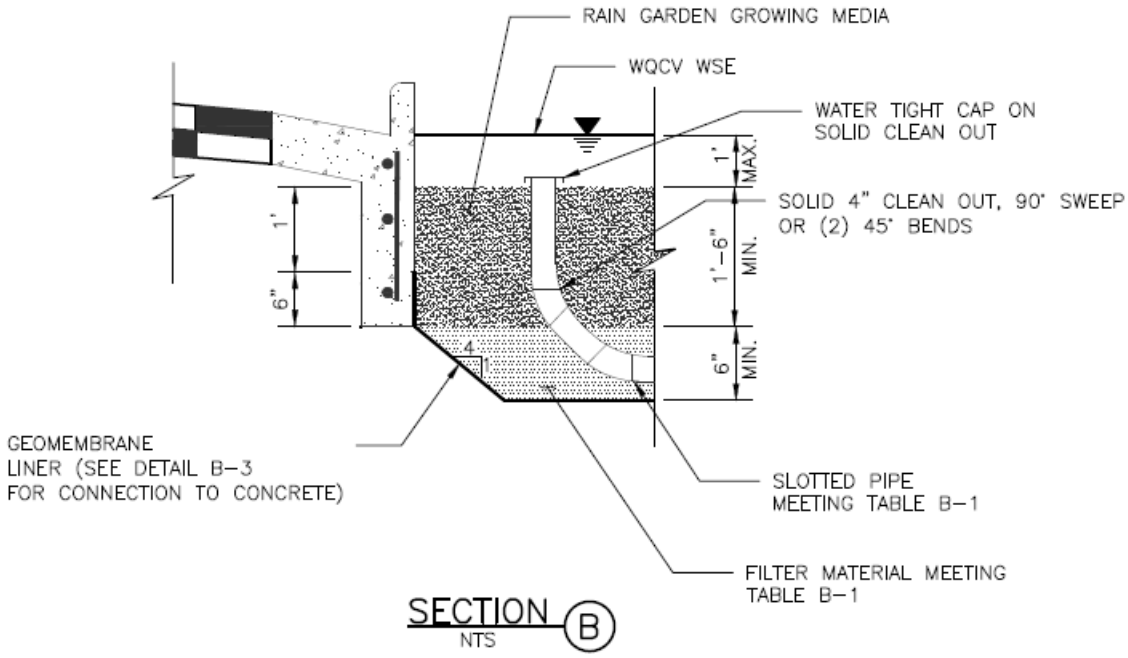
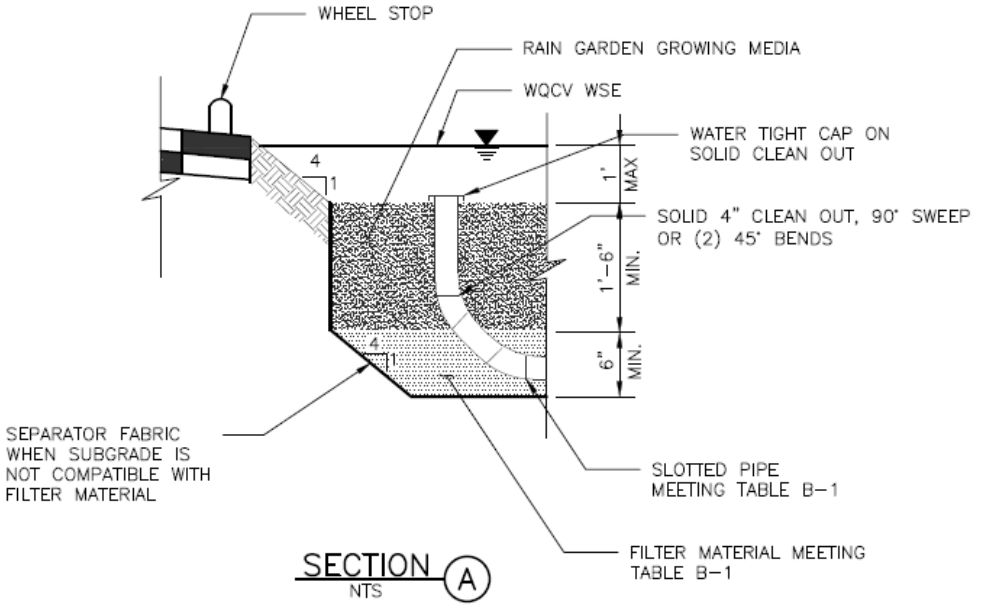


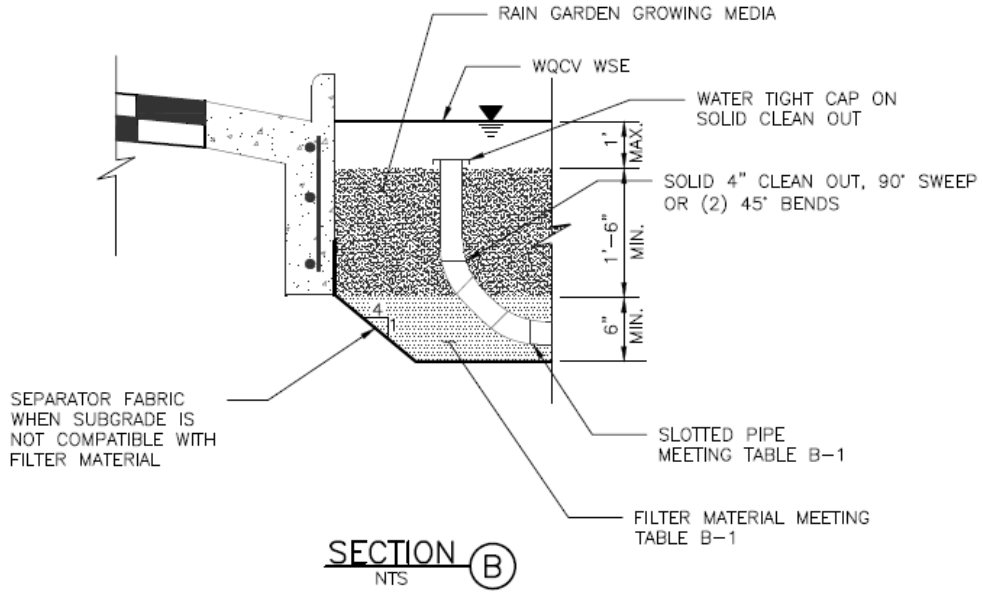
Figure B-1 – Typical rain garden plan and sections



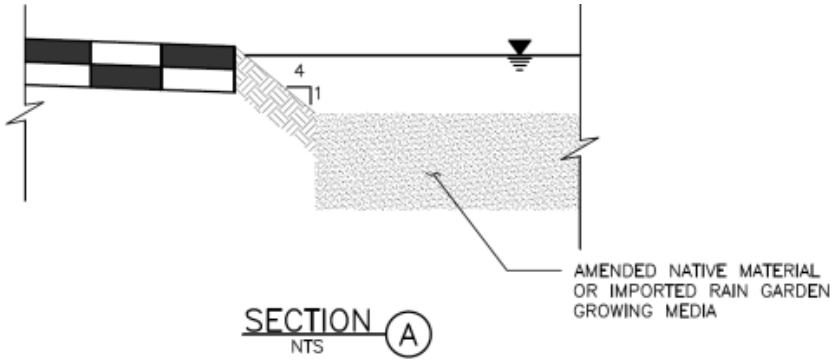


NO-INFILTRATION SECTIONS

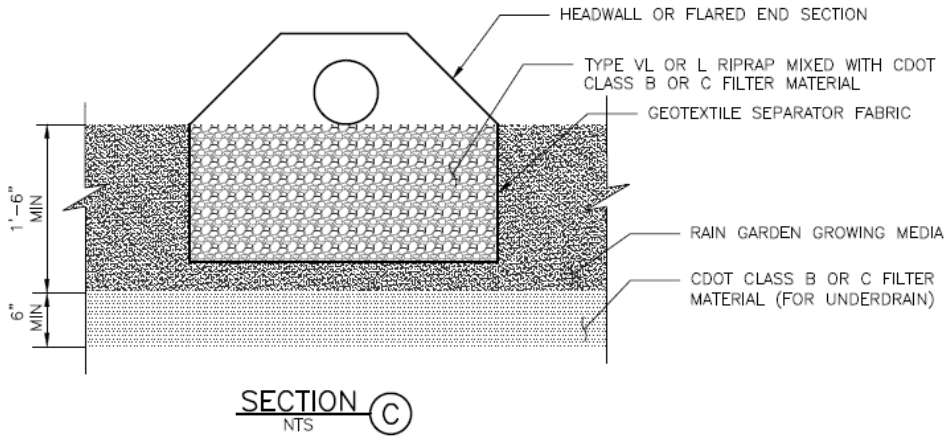




PARTIAL INFILTRATION SECTIONS



FULL INFILTRATION SECTION



SECTION C
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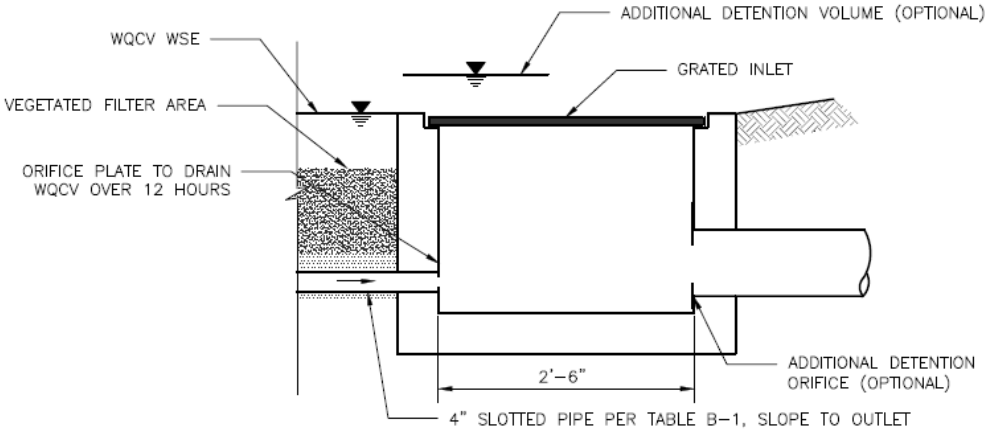

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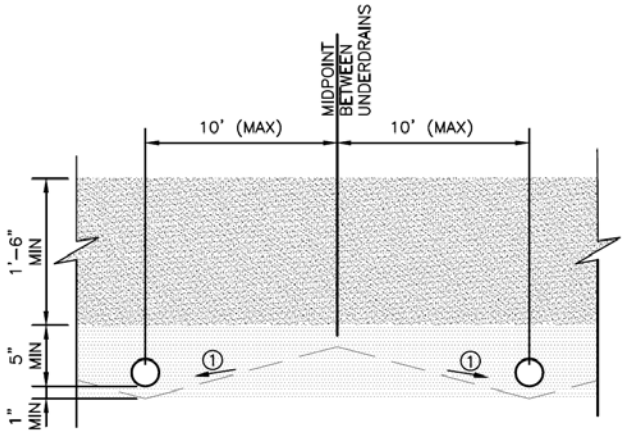

① SLOPE (STRAIGHT GRADE) SUBGRADE (2–10%) TO UNDERDRAIN TO REDUCE SATURATED SOIL CONDITIONS BETWEEN STORM EVENTS (OPTIONAL)

SECTION E
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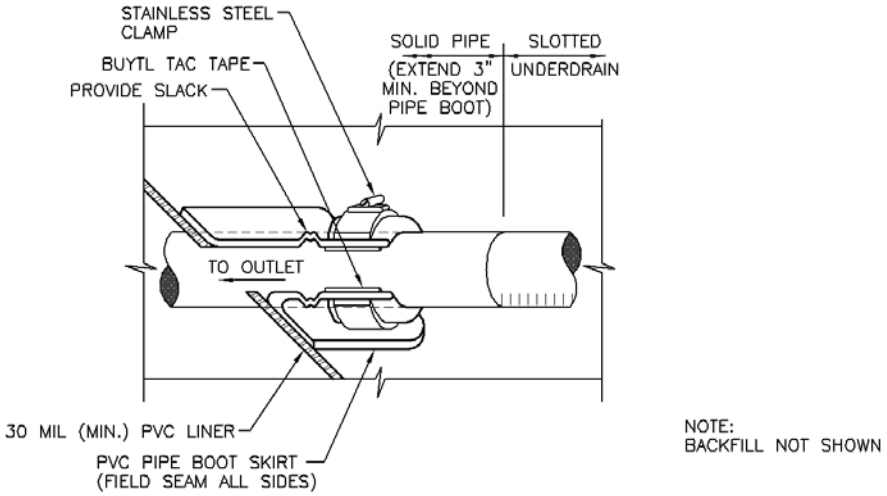


Figure B-2. Geomembrane Liner/Underdrain Penetration Detail

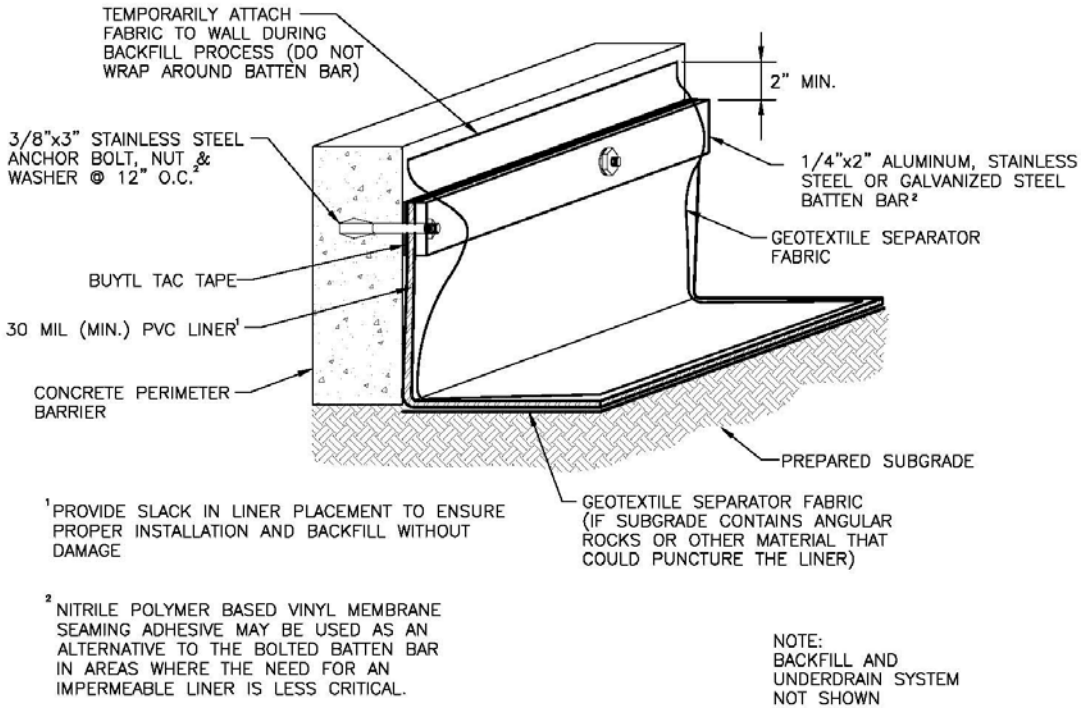


Figure B-3. Geomembrane Liner/Concrete Connection Detail

Construction Considerations

Proper construction of rain gardens involves careful attention to material specifications, final grades, and construction details. For a successful project, implement the following practices:

- Protect area from excessive sediment loading during construction. This is the most common cause of clogging of rain gardens. The portion of the site draining to the rain garden must be stabilized before allowing flow into the rain garden. This includes completion of paving operations.
- Avoid over compaction of the area to preserve infiltration rates (for partial and full infiltration sections).
- Provide construction observation to ensure compliance with design specifications. Improper installation, particularly related to facility dimensions and elevations and underdrain elevations, is a common problem with rain gardens.
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner.
- Provide necessary quality assurance and quality control (QA/QC) when constructing an impermeable geomembrane liner system, including but not limited to fabrication testing, destructive and non-destructive testing of field seams, observation of geomembrane material for tears or other defects, and air lace testing for leaks in all field seams and penetrations. QA/QC should be overseen by a professional engineer. Consider requiring field reports or other documentation from the engineer.

Photograph B-3. Inadequate construction staking may have contributed to flows bypassing this rain garden.

Photograph B-4. Runoff passed the upradient rain garden, shown in Photo B-3, and flooded this downstream rain garden.

- Provide adequate construction staking to ensure that the site properly drains into the facility, particularly with respect to surface drainage away from adjacent buildings. Photo B-3 and Photo B-4 illustrate a construction error for an otherwise correctly designed series of rain gardens.

References

Erickson, Andy. 2009. Field Applications of Enhanced Sand Filtration. University of Minnesota *Stormwater Management Practice Assessment Project Update*. http://wrc.umn.edu.

Hunt, William F., Davis, Allen P., Traver, Robert. G. 2012. "Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design" *Journal of Environmental Engineering*. (2012) 138:698-707. Print.

Green Roof T-4

Description

Green roofs could be defined as "contained" living systems on top of human-made structures. This green space can be below, at, or above grade involving systems where plants are not planted in the ground (Source: Green Roofs for Healthy Cities).

Photograph GR-1. EPA Region 8 building in downtown Denver. Photo courtesy of Weston Solutions.

There are two main types of green roofs: extensive and intensive. Extensive green roofs are shallow, usually with 4 inches of substrate, and do not typically support a large diversity of plant species because of root zone limitations. Intensive green roofs are more like rooftop gardens with deep substrate (from 4 inches to several feet) and a wide variety of plants. Most buildings are not designed to withstand the additional weight loading for intensive roofs. For this reason, they are typically limited to new construction. Extensive green roofs are shallower and generally much better suited to the structural capabilities of existing buildings and therefore, are installed more often. Because of this, extensive green roofs are the focus of this design guidance.

The design of a green roof involves many disciplines in addition to stormwater engineers, including structural engineers, architects, landscape architects, horticulturists, and others. This Fact Sheet is intended only to provide an overview of green roof information relative to stormwater quality and quantity management that is applicable in the Denver Metropolitan area. *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West,* prepared by the University of Colorado Denver with input from UDFCD, should be used as a more comprehensive design and maintenance document. This document is available at www.growwest.org.

As Low Impact Development (LID) strategies have been emphasized increasingly throughout the U.S., green roofs have been implemented in some parts of the country, most frequently in areas with humid climates and relatively high annual rainfall. Although there are some green roofs in Colorado, they have not been widely installed, and research is in progress regarding the best design approach and plant list for the metro Denver climate. Colorado's low annual precipitation, low average relative humidity, high solar radiation due to elevation, high wind velocities and predominantly sunny days make growing plants on a roof more difficult than in other climates. Because of this, plant selection, growing medium, and supplemental irrigation requirements are key considerations for which design criteria continue to evolve. Because the technical community has expressed interest in exploring the water quality and volume

Green Roof [5]	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	Unknown
Nutrients	Unknown
Total Metals	Unknown
Bacteria	Unknown
Other Considerations	
Life-cycle Costs	Unknown

[5] Water quality data for green roofs are not yet robust enough to provide meaningful conclusions about pollutant removal. By reducing volume, green roofs have the de facto capability to reduce pollutant loads; however, on a concentration basis more data are needed to better define effectiveness.

reduction benefits of this technique, information on green roofs is provided in this Fact Sheet based on industry literature and academic research.

It should be noted that the U.S. Green Building Council LEED rating system recognizes a second kind of green roof that includes reflective, high albedo roof materials that are not designed for stormwater purposes.

Green roofs provide multiple environmental, social, economic, and aesthetic benefits that extend beyond stormwater management objectives.

Benefits

- Reduces runoff rates and volumes.
- Reduces heat island effect in urban areas.
- May qualify for multiple LEED credits.
- May extend roof lifespan by reducing daily temperature fluctuations and providing shading from ultraviolet light.
- May provide energy savings from additional insulation & evapotranspirative cooling.
- Provides aesthetically pleasing open space in ultra urban areas.

Limitations

- Limited experience in Colorado.
- Initial installation costs are greater than conventional roof (although lifecycle costs may be less).
- Supplemental irrigation required in semi-arid climate.
- Maintenance during vegetation establishment (first two years) may be significant.

Site Selection

Green roofs can be installed on commercial or residential buildings as well as on underground structures such as the parking garage shown in Photo GR-6. Green roofs may be particularly well suited for ultra urban areas where development is typically lot-line-to-lot-line and garden space is at a premium. Green roofs are particularly valuable when their use extends to a place of enjoyment for those that inhabit the building. Several Colorado examples are provided at the end of this Fact Sheet.

For existing buildings, the structural integrity of the building must be verified prior to consideration of retrofitting the building with a green roof. For both existing and new construction, it is essential that the design team be multi-disciplinary. This team may include a structural engineer, stormwater engineer, architect, landscape architect, and horticulturist. It is recommended that all members of the design team be involved early in the process to ensure the building and site conditions are appropriate for green roof installation.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6. During design, the following should be considered upfront to ensure ease of maintenance for green roofs over the long-term:

- Access for equipment and inspections following construction.
- The irrigation system, growing media, and plant selection are critical factors determining long-term maintenance requirements and survival of the green roof vegetation under hot, dry conditions; otherwise, vegetation may have to be repeatedly replanted and/or the irrigation system replaced.
- If an underdrain system is used, provide cleanouts as appropriate for both inspection and maintenance. There is potential over the long term for the roof underdrain system to become clogged with soil/media that migrates down beneath the plant root zone. The ability to access the underdrain system for cleanout is important.

Design Procedure and Criteria

Green roofs contain a high quality water proofing membrane and root barrier system, drainage system, filter fabric, a lightweight growing media, and plants. Green roofs can be modular, already prepared in trays, including drainage layers, growing media and plants, or each component of the system can be installed separately on top of the structure.

As shown in Figure GR-1, basic elements of green roof design include:

- **Structural Support**: Roof structure that supports the growing medium, vegetation, and live loads associated with rainfall, snow, people, and equipment.
- **Waterproof Membrane:** This prevents water from entering the building.
- **Root Barrier:** This protects the waterproof membrane by preventing roots from reaching the membrane.
- **Drainage Layer**: This is sometimes an aggregate layer or a proprietary product.
- **Filter Membrane**: This prevents fine soil and substrate from being washed out into the drainage layer.
- **Growing Medium**: Although the growing medium is typically not "soil," the terms *soil matrix*, *soil media* and *growth substrate* are sometimes used.
- **Vegetation**: Native/naturalized, drought-tolerant grasses, perennials, and shrubs with relatively shallow root depths are possibilities for roof plantings.
- **Irrigation**: Even vegetation with low water requirements will require supplemental irrigation in Denver.

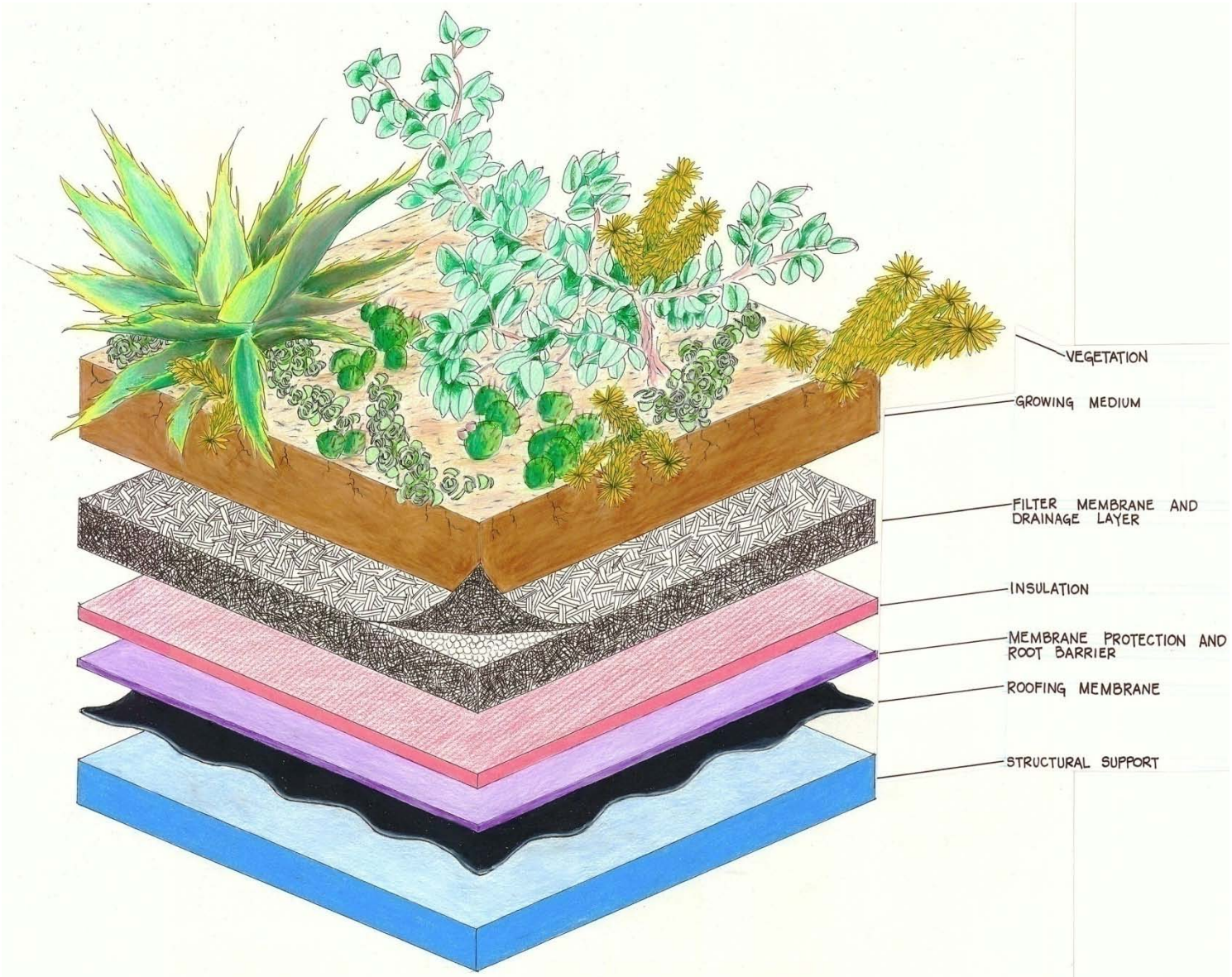


Figure GR-1. Typical Green Roof Cross Section. Graphic by Adia Davis.

Design considerations for green roofs include:

1. **Providing Stormwater Treatment and Slow Release**: An early version of the USDCM provided guidance on rooftop detention. This was removed because rooftop controls can be easily modified by maintenance personnel unfamiliar with its purpose. In contrast, green roof vegetation benefits from stormwater detained in the growing medium and the volume the system detains should be recognized when designing for the water quality capture volume (WQCV).

   The WQCV for the Denver area is the runoff resulting from a storm event of approximately 0.6 inches of rainfall. Based on the data that the EPA has collected to date from the Region 8 green roof in Denver, it appears the green roof retains and evapotranspires 98 to 100% of the WQCV even without a restriction on the outlet for drain time control. This is largely due to wetting and subsequent evapotranspiration in the growing media. The data show few exceptions to this, which may be attributed to successive rain events. For this reason, UDFCD recognizes green roofs as a volumetric BMP, able to capture the WQCV for the area of the green roof, without constructing a controlled release at the outlet. This is for roofs that meet or exceed the EPA green roof section, which is a modular system using trays that allow for 4 inches of growing medium. An intensive roof should also be considered to capture the WQCV.

   Volume Reduction Data for the EPA Green Roof in Denver

   Stormwater performance data collected from the EPA Region 8 office green roof in Denver, Colorado has indicated that green roofs can be effective at detaining and infiltrating stormwater runoff. This is especially true for snowmelt events and for smaller precipitation events (generally <1" rainfall in a 24-hour period).

   Data from the EPA green roof are available for download and analysis at **www.epa.gov/region8/greenroof**. These data may be useful in considering additional volume reductions associated with the growing media and evapotranspiration from the vegetation.

   A green roof can also be designed to accept runoff from a traditional roof. This can be done for additional water quality and/or irrigation benefits or, if designed with a slow controlled release, the green roof can provide the WQCV for an area in excess of the area of the green roof. Use Figure 3-2 located in Chapter 3 to determine the WQCV (watershed inches) based on a 12-hour drain time. The design volume can be calculated as follows:

   $$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation GR-1}$$

   Where:

   V = design volume (ft^3)

   A = the watershed area tributary to the green roof (ft^2)

   The volume should be provided within the void space of the drainage layer and the growing media. This is a function of the material selected. The outlet can be controlled by an orifice or orifices located at one central location or at each roof drain. This is also a function of the overall drainage design.

2. **Structural Integrity**: Consult a structural engineer to ensure the load bearing capacity of the existing roof is adequate for the system to be installed. If new construction, the green roof should be part of the building design.

3. **Impermeable Membrane and Waterproofing**: Check waterproofing warranty and consult the warranty company to ensure the policy will not be voided by a green roof application. A leak test is recommended following installation of the impermeable membrane.

4. **Drainage System:** A filter membrane is required to keep the growing media from clogging the drainage media; however, roots can pass through the filter membrane. Roots are not expected to pass through the waterproof/repellant membrane. Other components of the drainage system must be kept free of debris and plant material in order to convey drainage properly.

   Photos GR-2 and Photo GR-3 show a stainless steel edge that separates growing media from the rock that surrounds the roof drains. This provides both material separation as well as a root barrier. The plate is perforated to allow the growing media to drain.

   Roof outlets, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft. A drainage barrier should also be used at the roof border with the parapet wall and for any joints where the roof is penetrated, or joins with vertical structures.

Photograph GR-2. The metal edge shown in Photo GR-2 has perforations near the bottom to allow flow into the drain.

Photograph GR-3. Metal edging separates growing media from rock that surrounds the roof drain. It also serves to facilitate regular maintenance by limiting plant and root growth near the drain.

5. **Growing Medium**: Growing medium is a key issue with regard to plant health, irrigation needs, and potential stormwater benefits. The growing medium is not the same thing as "soil." Most extensive green roof substrate is predominantly made up of expanded slate, expanded shale, expanded clay, or another lightweight aggregate such as pumice. However, such lightweight aggregates have some limitations. These materials typically drain very quickly and leave little water or nutrients available to plants. Therefore, additional research is necessary on substrate mixes appropriate for use on extensive green roofs in Colorado. For intensive green roof applications where weight is explicitly factored into the structural design, the soil matrix can include materials with higher water retention characteristics such as organic matter (e.g., compost), provided the structural design accounts for the saturated load.

6. **Planting Method**: In general, the planting method will be either "modular" (tray approach) or "continuous" (planted *in situ*).

   - Modular systems are self-contained trays, which can vary in size, and have relatively shallow depth (2 to 8 inches deep). When modular trays are planted with groundcover and placed close together, the roof often has the appearance of a continuous system once the vegetation is established. Due to the variations in green roof designs, it is important to consult with a multi-disciplinary team to determine the type of roof design most appropriate for the short-term and long-term conditions expected at the site.

   - Continuous systems are "built in place" on the roof with layers designed to work together to provide a healthy environment for plants. Continuous roof approaches range from rolled sedum mats to hand-planted buffalograss plugs.

7. **Plant Selection:** General categories of potentially viable plants for Colorado green roofs include native, alpine (grows in shallow rocky soils), and xeric plants (e.g., sedum). Plants must meet certain criteria to optimize their chance of survival on a green roof. Due to the shallow, well-drained materials in extensive green roof systems, plants must be drought resistant. However, not all drought resistant plants are well-suited for green roofs. For example, some plants avoid drought by rooting deeply to access a more stable supply of water. Such plants would not be suitable for a shallow green roof. Grasses with strong rhizome growth such as bamboo and varieties of Chinese reeds should be avoided, as these have the potential to compromise the roof membrane. While there are several species that could potentially adapt to extensive green roof systems, the most commonly used species are stonecrops or sedums because of their prostrate growth form, shallow root systems, and drought tolerance. Another favorable attribute of sedums is that the foliage tends to remain greener than grasses throughout the entire year, even in northern climates. However, drawbacks to a monoculture for green roofs are the same as for a monoculture in agricultural applications – risk of widespread vegetation loss if conditions (e.g., drought, disease, temperature, etc.) change from the anticipated range.

   Characteristics of plants, which tend to work well on green roofs in a semi-arid climate include:

   - Self seeding,
   - Perennial,
   - Low or compact growth format,
   - Diffuse or fibrous root system,
   - Low water use, and
   - Cressulacean Acid Metabolism (CAM), which is common in sedums (stonecrops) where plant stomata are closed during the day to conserve water.

Growing Media Research by Colorado State University at the EPA Green Roof in Denver

CSU researchers are evaluating alternative growing media for green roofs and report that most extensive green roof media are predominantly made up of expanded slate, shale, or clay. While these materials are generally very well-drained, lightweight, and resistant to blowing away and decomposing, they do have some limitations. They typically drain too quickly (too much macro-pore space, not enough micro-pore space) and do not hold nutrients very well (low cation exchange capacity [CEC]). A material that has all of the benefits of expanded slate, shale and clay, while having more micro-pore space and higher CEC is ideal. One example of a material that may fit this description is zeolite. Zeolites are currently being utilized as amendments for shallow, well-drained golf greens (see http://greenroof.agsci.colostate.edu/).

8. **Irrigation:** Irrigation is needed for successful green roofs in Colorado. The decision to use drip or overhead spray irrigation is determined based on growing media characteristics and plant needs. Drip irrigation is more efficient when installed below the vegetation layer to avoid heating of the drip line and to get a more effective watering of the roots. Overhead irrigation should be considered for shallow depth applications because drip irrigation may not spread laterally when applied over a rapidly draining media. Current CSU experiments are determining the extent of irrigation requirements for various plants. Initial results suggest non-succulents dry out faster (need more frequent irrigation), whereas the sedums and other succulent plants require less frequent irrigation; however, sedums and succulents tend to die rather than go dormant during prolonged dry periods.

9. **Wind:** Select growing media and install material layers in a manner to withstand expected average and storm wind conditions.

10. **Roof Microclimates**: Consider the effect of roof microclimates on the vegetation, including factors such as shading, localized strong winds, and reflected solar radiation from surrounding buildings. Solar panels can provide partial shade to vegetation that may not perform well when exposed to the typical green roof environment.

Combining solar panels with green roofs is mutually beneficial. Solar panels stay cooler and vegetation receives partial shade, reducing irrigation requirements.

11. **Roof Gradient**: Green roofs may be installed on flat or steep roofs. For flat roofs (e.g., roof slopes less than 2%) a deeper drainage course is recommended to avoid water logging. For steep roofs (e.g., slopes greater than 30%), structural anti-shear protection will normally be needed to prevent sloughing of materials.

12. **Protection of Roof Drainage Features**: Drainage features on the roof such as area drains, scuppers, downspouts, etc. must be kept free of debris and plant material in order to convey drainage properly. Roof outlets, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft. A drainage barrier should also be used at the roof border with the parapet wall and for any joints where the roof is penetrated or where the roof joins with vertical structures.

Additional Design Guidance

Until more experience is gained in Colorado with regard to green roofs, the following design guidance documents may provide additional assistance; with the understanding that the guidelines may need adjustment for Denver's climate:

- **"FLL Guidelines"**: The FLL Guidelines are green roof standards developed by the German Research Society for Landscape Development and Landscape Design. (FLL is derived from the German title: "Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.") These guidelines include the planning, execution and upkeep of green-roof sites. The 2002 edition of these widely consulted guidelines is available for purchase in English through http://www.roofmeadow.com/technical/fll.php.

- **ASTM Book of Standards, v. 04-12, 2005:**

  - ASTM E2396-E2399: ASTM has recently developed a new set of standards for green roofs; however, it is important to recognize these standards were developed outside of Colorado.

  - ASTM E2396-05: Standard test method for saturated water permeability of granulated drainage media (falling-head method) for green roof systems.

  - ASTM E-2398-05: Standard test method for water capture and media retention of geocomposite drain layers for green roof systems.

  - ASTM E2397-05: Standard practice for determination of dead loads and live loads associated with green roof systems.

- **BOCA Codes**, International Code Council (ICC): Building Officials and Code Administrators International Inc. (BOCA), now known as the International Code Council (ICC), publish codes that establish minimum performance requirements for all aspects of the construction industry. BOCA codes at the Library of Congress are located in the Law Library Reading Room. Some state codes are available at no cost through the eCodes sections of the ICC Website, while others must be purchased http://www.iccsafe.org/.

- **Leadership in Energy and Environmental Design (LEED):** The LEED Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED standards are available through the U.S. Green Building Council: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19. Attainment of a desired LEED building rating (e.g., gold, platinum) is based on accumulation of "points" achieved by implementing practices in six different credit categories. A variety of LEED points are potentially achievable through use of green roofs. For example, under the "Sustainable Sites" category, eligible points could include Site Development credits for protecting or restoring habitat and maximizing open space, Stormwater Design credits for quality and quantity, and Heat Island Effect credits for roofs. Green roofs may also contribute to achievement of "Energy and Atmosphere" points for optimizing energy performance for buildings. Green roofs may play a supporting role in a variety of other credits, as well as being eligible for "Innovation in Design" credits.

Websites for Additional Design Ideas

Colorado

Colorado State University: http://greenroof.agsci.colostate.edu/
Green Roofs of Colorado: http://www.greenroofsco.com/
Denver Botanic Gardens: http://www.botanicgardens.org/content/green-roof

Other Research Programs and Resources

Pennsylvania State University
Michigan State University
North Carolina State University
Southern Illinois University
LBJ Wildflower Center/University of Texas at Austin
Green Roofs for Healthy Cities

GreenRoofs.com

American Society of Landscape Architects: http://land.asla.org/050205/greenroofcentral.html
Low Impact Development Center: http://www.lid-stormwater.net/

Construction Considerations

Success of green roofs depends not only on a good design and maintenance, but also on construction practices that enable the BMP to function as designed. Construction considerations include:

- **Permit Requirements, General Coordination, and Warranties:** Investigate permitting requirements for green roofs in the local jurisdiction. Significant coordination between architects, engineers, roofers, and landscapers is needed. Contractually, it is common to have the roofer warranty the impermeable membrane, whereas the landscaper would be responsible for the growing media, vegetation, and other landscaping. Typically, irrigation systems have warranties, but plants do not, with the exception of situations where a maintenance contract is in place. Where a maintenance contract is in place, some landscapers or greenhouses will provide plant warranties.

- **Roof Membrane:** Inspect the roof membrane (the most crucial element of a green roof) and conduct a leak test prior to installing the remaining layers of the roof.

- **Installation Safety:** Most landscapers are accustomed to working on the ground, so safety training is important. If the green roof will be accessible to the public, safety at roof edges should be of paramount concern.

Colorado Examples

There are several green roof installations in Colorado designed to achieve varying goals that include reductions in stormwater volume, pollutants, and/or urban heat island effects, as well as aesthetic goals. These are briefly described below.

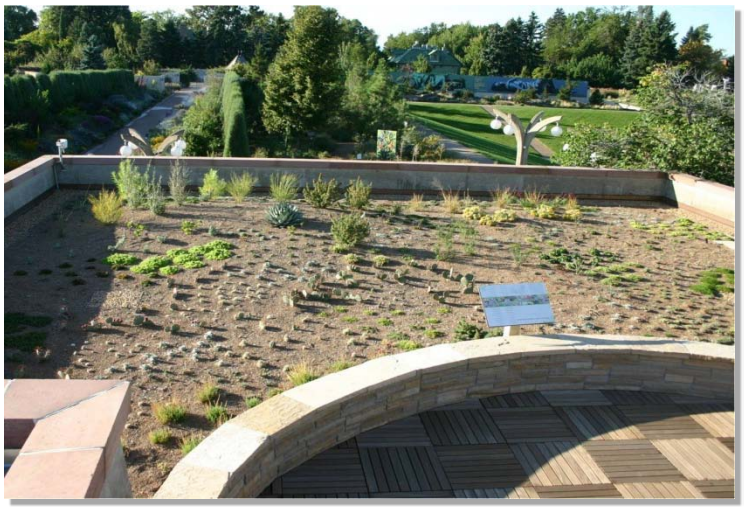
- **EPA Building (Denver):** Installed in 2006, this is a modular, 20,000 square foot, extensive green roof, currently planted primarily with sedum and equipped with spray irrigation. This roof is designed to be monitored for several purposes:
  - Biological/horticultural viability,
  - Stormwater benefits, and
  - Heat island reduction effects.

  The extensive planting scheme consists of sedums selected in accordance with USDA hardiness zone classification in 2-inch by 4-inch modules with a 4-inch depth.

Photograph GR- 4: A modular, extensive green roof in the spring on the Environmental Protection Agency Region 8 Headquarters in downtown Denver. Photo courtesy of Jennifer Bousselot.

- **Denver Botanic Gardens:** Located inside Denver Botanic Gardens, this publicly accessible green roof, installed in 2007, is a semi-intensive retrofit of a 1950s structure. The main purpose of the roof is to identify and test a broad palette of plants that may be feasible for Colorado green roofs. The roof is fully exposed to the south and currently features approximately 60 genera.

  The roof is fitted with both drip and spray irrigation. Four irrigation zones are monitored and adjusted according to weather and temperature. All green roof irrigation is recorded and stored in a central database.



Photograph GR-5. A continuous green roof system at the Denver Botanic Gardens. It is a predominantly extensive system with some intensive areas. Photo courtesy of Denver Botanic Gardens

- **REI Parking Garage Roof (Denver):** This is an example of an intensive roof, where a deeper growing media is present. The roof is irrigated.
- **Denver Museum of Contemporary Art:** Installed in 2006, this intensive green roof was designed for aesthetic appeal more than stormwater benefits. Also known as the "Sky Trapezium," it was designed primarily as an art exhibit inspired by the prairie and features native grasses. This roof is equipped with irrigation.
- **CSU Building Roof (Fort Collins):** A small modular extensive green roof installed in 2008 is present on the microbiology building at CSU.

Photograph GR-6. Intensive green roof installation above a parking garage.

- **Residential Applications:** There are numerous residential applications in Colorado; however, information on the design, vegetation, and performance has not been compiled.

References

Dunnett, N. 2004. *Planting Green Roofs and Living Walls*. Timber Press, Inc: Portland, Oregon.

Green Roofs for Healthy Cities website. http://www.greenroofs.org/index.php/about-green-roofs accessed 17 March 2010.

Snodgrass, E. 2006. *Green Roof Plants: A Resource and Planting Guide*. Timber Press, Inc.: Portland, Oregon.

Werthmann, C. 2007 *Green Roof: A Case Study: Michael Van Valkenburgh Associates' Design for the Headquarters of the American Society of Landscape Architects*. Princeton Architectural Press: New York, New York.

Extended Detention Basin (EDB) T-5

Description

An extended detention basin (EDB) is a sedimentation basin designed to detain stormwater for many hours after storm runoff ends. This BMP is similar to a detention basin used for flood control, however; the EDB uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal. The EDB's 40-hour drain time for the water quality capture volume (WQCV) is recommended to remove a significant portion of total suspended solids (TSS). Soluble pollutant removal is enhanced by providing a small wetland marsh or "micropool" at the outlet to promote biological uptake. The basins are sometimes called "dry ponds" because they are designed not to have a significant permanent pool of water remaining between storm runoff events.

Photograph EDB-1: This EDB includes a concrete trickle channel and a micropool with a concrete bottom and grouted boulder sideslopes. The vegetation growing in the sediment of the micropool adds to the natural look of this facility and ties into the surrounding landscape.

Site Selection

EDBs are well suited for watersheds with at least five impervious acres up to approximately one square mile of watershed. Smaller watersheds can result in an orifice size prone to clogging. Larger watersheds and watersheds with baseflows can complicate the design and reduce the level of treatment provided. EDBs are also well suited where flood detention is incorporated into the same basin. The depth of groundwater should be investigated. Groundwater depth should be 2 or more feet below the bottom of the basin in order to keep this area dry and maintainable.

Extended Detention Basin	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Moderate
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Designing for Maintenance

Recommended maintenance practices for all BMPs are provided in the BMP Maintenance chapter of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:

- Always provide a micropool (see step 7).
- Provide a design slope of at least 3% in the vegetated bottom of the basin (either toward the trickle channel or toward the micropool). This will help maintain the appearance of the turf grass in the bottom of the basin and reduce the possibility of saturated areas that may produce unwanted species of vegetation and mosquito breeding conditions. Verify slopes during construction, prior to vegetation.
- Follow trash rack sizing recommendations to determine the minimum area for the trash rack (see design step 9).
- Provide adequate initial surcharge volume for frequent inundation (see design step 3).
- Provide stabilized access to the forebay, outlet, spillway, and micropool for maintenance purposes.
- Provide access to the well screen. The well screen requires maintenance more often than any other EDB component. Ensure that the screen can be reached from a point outside of the micropool. When the well screen is located inside the outlet structure, provide an access port within the trash rack or use a sloped trash rack that consists of bearing bars (not horizontal) that create openings no more than five inches clear.
- Provide a hard-bottom forebay that allows for removal of sediment.
- Where baseflows are anticipated, consider providing a flow-measuring device (e.g. weir or flume with staff gage and rating curve) at the forebay to assist with future modifications of the water quality plate. Typically, the baseflow will increase as the watershed develops. It is important that the water quality plate continue to function, passing the baseflow while draining the WQCV over approximately 40 hours. Measuring the actual baseflow can be helpful in determining if and when the orifice place should be replaced.

Benefits

- The relatively simple design can make EDBs less expensive to construct than other BMPs, especially for larger basins.
- Maintenance requirements are straightforward.
- The facility can be designed for multiple uses.

Limitations

- Ponding time and depths may generate safety concerns.
- Best suited for tributary areas of 5 impervious acres or more. EDBs are not recommended for sites less than 2 impervious acres.
- Although ponds do not require more total area compared to other BMPs, they typically require a relatively large continuous area.

EDBs providing combined water quality and flood control functions can serve multiple uses such as playing fields or picnic areas. These uses are best located at higher elevation within the basin, above the WQCV pool level.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for an EDB and Figure EDB-3 shows a typical configuration. UD-BMP, available at www.udfcd.org, is an Excel based workbook that can be used to perform some of the below calculations and ensure conformance to these criteria. UD-Detention, another workbook developed by UDFCD can be used to develop and route a storm hydrograph through an EDB and design the outlet structure.

1. **Basin Storage Volume**: Provide a design volume equal to the WQCV or the EURV. This volume begins at the lowest orifice in the outlet structure.

   - Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).
   - Find the required storage volume. Determine the required WQCV or EURV (watershed inches of runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 (for EURV).
   - Calculate the design volume as follows:

   For WQCV:

   $$V = \left[\frac{\text{WQCV}}{12}\right] A$$ Equation EDB-1

   For EURV:

   $$V = \left[\frac{\text{EURV}}{12}\right] A$$ Equation EDB-2

   Where:

   V = design volume (acre ft)

   A = watershed area tributary to the extended detention basin (acres)

2. **Basin Shape**: Always maximize the distance between the inlet and the outlet. It is best to have a basin length (measured along the flow path from inlet to outlet) to width ratio of at least 2:1. A longer flow path from inlet to outlet will minimize short circuiting and improve reduction of TSS. To achieve this ratio, it may be necessary to modify the inlet and outlet points through the use of pipes or swales.

3. **Basin Side Slopes**: Basin side slopes should be stable and gentle to facilitate maintenance and access. Slopes that are 4:1or flatter should be used to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics. Side slopes should be no steeper than 3:1. The use of walls is highly discouraged due to maintenance constraints.

4. **Inlet**: Dissipate flow energy at concentrated points of inflow. This will limit erosion and promote particle sedimentation. Inlets should be designed in accordance with UDFCD drop structure criteria for inlets above the invert of the forebay, impact basin outlet details for at grade inlets, or other types of energy dissipating structures.

5. **Forebay Design**: The forebay provides an opportunity for larger particles to settle out in an area that can be easily maintained. The length of the flow path through the forebay should be maximized, and the slope minimized to encourage settling. The appropriate size of the forebay may be as much a function of the level of development in the tributary area as it is a percentage of the WQCV. When portions of the watershed may remain disturbed for an extended period of time, the forebay size will need to be increased due to the potentially high sediment load. Refer to Table EDB-4 for a design criteria summary. When using this table, the designer should consider increasing the size of the forebay if the watershed is not fully developed.

   The forebay outlet should be sized to release 2% of the undetained peak 100-year discharge. A soil riprap berm with 3:1 sideslopes (or flatter) and a pipe outlet or a concrete wall with a notch outlet should be constructed between the forebay and the main EDB. It is recommended that the berm/pipe configuration be reserved for watersheds in excess of 20 impervious acres to accommodate the minimum recommended pipe diameter of 8 inches. When using the berm/pipe configuration, round up to the nearest standard pipe size and use a minimum diameter of 8 inches. The floor of the forebay should be concrete or lined with grouted boulders to define sediment removal limits. With either configuration, soil riprap should also be provided on the downstream side of the forebay berm or wall if the downstream grade is lower than the top of the berm or wall. The forebay will overtop frequently so this protection is necessary for erosion control. All soil riprap in the area of the forebay should be seeded and erosion control fabric should be placed to retain the seed in this high flow area.

6. **Trickle Channel:** Convey low flows from the forebay to the micropool with a trickle channel. The trickle channel should have a minimum flow capacity equal to the maximum release from the forebay outlet.

   - **Concrete Trickle Channels:** A concrete trickle channel will help to establish the bottom of the basin long-term and may also facilitate regular sediment removal. It can be a "V" shaped concrete drain pan or a concrete channel with curbs. A flat-bottom channel facilitates maintenance. A slope between 0.4% - 1% is recommended to encourage settling while reducing the potential for low points within the pan.

   - **Soft-bottom Trickle Channels**: When designed and maintained properly, soft-bottom trickle channels can allow for an attractive alternative to concrete. They can also improve water quality. However, they are not appropriate for all sites. Be aware, maintenance of soft bottom trickle channels requires mechanical removal of sediment and vegetation. Additionally, this option provides mosquito habitat. For this reason, UDFCD recommends that they be considered on a case-by-case basis and with the approval of the local jurisdiction. It is recommended that soft bottom trickle channels be designed with a consistent longitudinal slope from forebay to micropool and that they not meander. This geometry will allow for reconstruction of the original design when sediment removal in the trickle channel is necessary. The trickle channel may also be located along the toe of the slope if a straight channel is not desired. The recommended minimum depth of a soft bottom trickle channel is 1.5 feet. This depth will help limit potential wetland growth to the trickle channel, preserving the bottom of the basin.

     Riprap and soil riprap lined trickle channels are not recommended due to past maintenance experiences, where the riprap was inadvertently removed along with the sediment during maintenance.

7. **Micropool and Outlet Structure**: Locate the outlet structure in the embankment of the EDB and provide a permanent micropool directly in front of the structure. Submerge the well screen to the bottom of the micropool. This will reduce clogging of the well screen because it allows water to flow though the well screen below the elevation of the lowest orifice even when the screen above the water surface is plugged. This will prevent shallow ponding in front of the structure, which provides a breeding ground for mosquitoes (large shallow puddles tend to produce more mosquitoes than a smaller, deeper permanent pond).

   Basins with micropools have fewer mosquitoes. Micropools reduce shallow wet areas where breeding is most favorable.

   Micropool side slopes may be vertical walls or stabilized slopes of 3:1 (horizontal:vertical). For watersheds with less than 5 impervious acres, the micropool can be located inside the outlet structure (refer to Figures OS-7 and OS-8 provided in Fact Sheet T-12). The micropool should be at least 2.5 feet in depth with a minimum surface area of 10 square feet. The bottom should be concrete unless a baseflow is present or anticipated or if groundwater is anticipated. Riprap is not recommended because it complicates maintenance operations.

   Where possible, place the outlet in an inconspicuous location as shown in Photo EDB-3. This urban EDB utilizes landscaped parking lot islands connected by a series of culverts (shown in Photo EDB-4) to provide the required water quality and flood control volumes.

   The outlet should be designed to release the WQCV over a 40-hour period. Draining a volume of water over a specified time can be done through an orifice plate as detailed in Fact Sheet T-12. Use reservoir routing calculations as discussed in the *Storage* Chapter of Volume 2 to assist in the design. Two workbooks tools have been developed by UDFCD for this purpose, UD-FSD and UD-Detention. Both are available at www.udfcd.org. UD-FSD is recommended for a typical EDB full spectrum detention design. UD-Detention uses the same methodology and can be used for a full spectrum detention basin or a WQCV only design. It also allows for a wider range of outlet controls should the user want to specify something beyond what is shown in Fact Sheet T-12.

   Refer to BMP Fact Sheet T-12 for schematics pertaining to structure geometry, grates, trash racks, orifice plate, and all other necessary components.

   The outlet may have flared or parallel wing walls as shown in Figures EDB-1 and EDB-2, respectively. Either configuration should be recessed into the embankment to minimize its profile. Additionally, the trash rack should be sloped with the basin side-slopes.

8. **Initial Surcharge Volume**: Providing a surcharge volume above the micropool for frequently occurring runoff minimizes standing water and sediment deposition in the remainder of the basin. This is critical to turf maintenance and mosquito abatement in the basin bottom. The initial surcharge volume is not provided in the micropool nor does it include the micropool volume. It is the available storage volume that begins at the water surface elevation of the micropool and extends upward to a grade break within the basin (typically the invert of the trickle channel).

Photograph EDB-2. The initial surcharge volume of this EDB is contained within the boulders that surround the micropool.

Photograph EDB-3. Although walls may complicate maintenance access, this outlet structure is relatively hidden from public view. This photo was taken shortly following a storm event.

The area of the initial surcharge volume, when full, is typically the same or slightly larger than that of the micropool. The initial surcharge volume should have a depth of at least 4 inches. For watersheds of at least 5 impervious acres, the initial surcharge volume should also be at least 0.3% of the WQCV. The initial surcharge volume is considered a part of the WQCV and does not need to be provided in addition to the WQCV. It is recommended that this area be shown on the grading plan or in a profile for the EDB. When baseflows are anticipated, it is recommended that the initial surcharge volume be increased. See the inset on page EDB-9 for additional guidelines for designing for baseflows.

Photograph EDB-4. A series of landscape islands connected by culverts provide water quality and flood control for this site.

9. **Trash Rack**: Provide a trash rack (or screen) of sufficient size at the outlet to provide hydraulic capacity while the rack is partially clogged. Openings should be small enough to limit clogging of the individual orifices. Size any overflow safety grate so it does not interfere with the hydraulic capacity of the outlet pipe. See BMP Fact Sheet T-12 for detailed trash rack and safety grate design guidance.

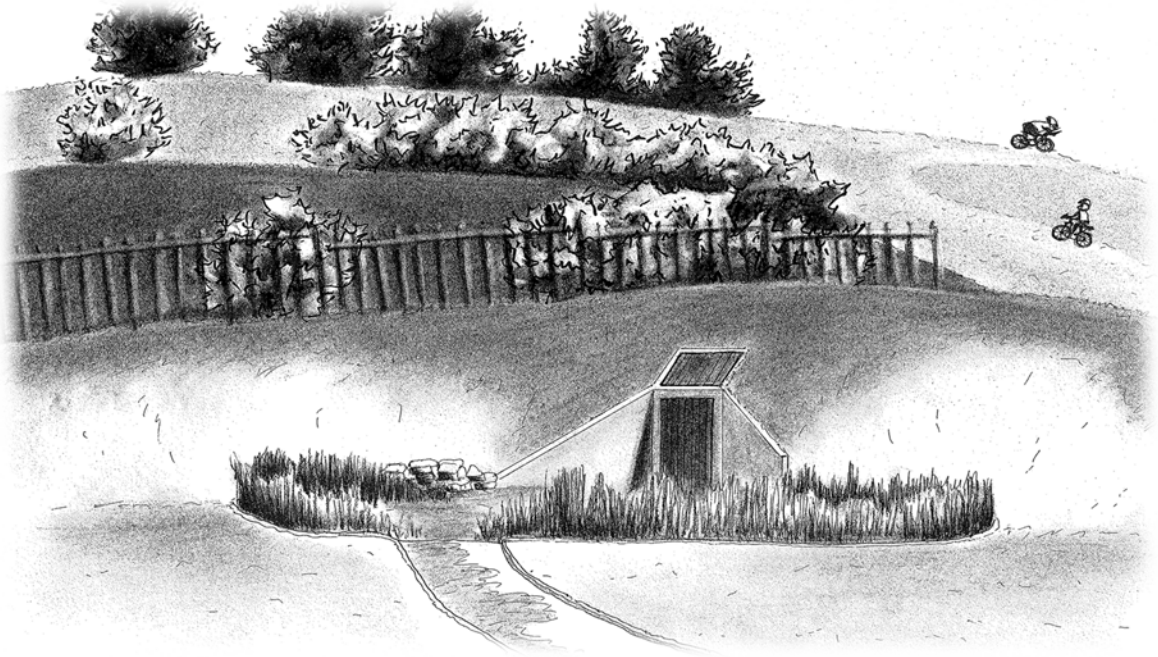


Figure EDB-1. Flared wall outlet structure configuration. Graphic by Adia Davis.

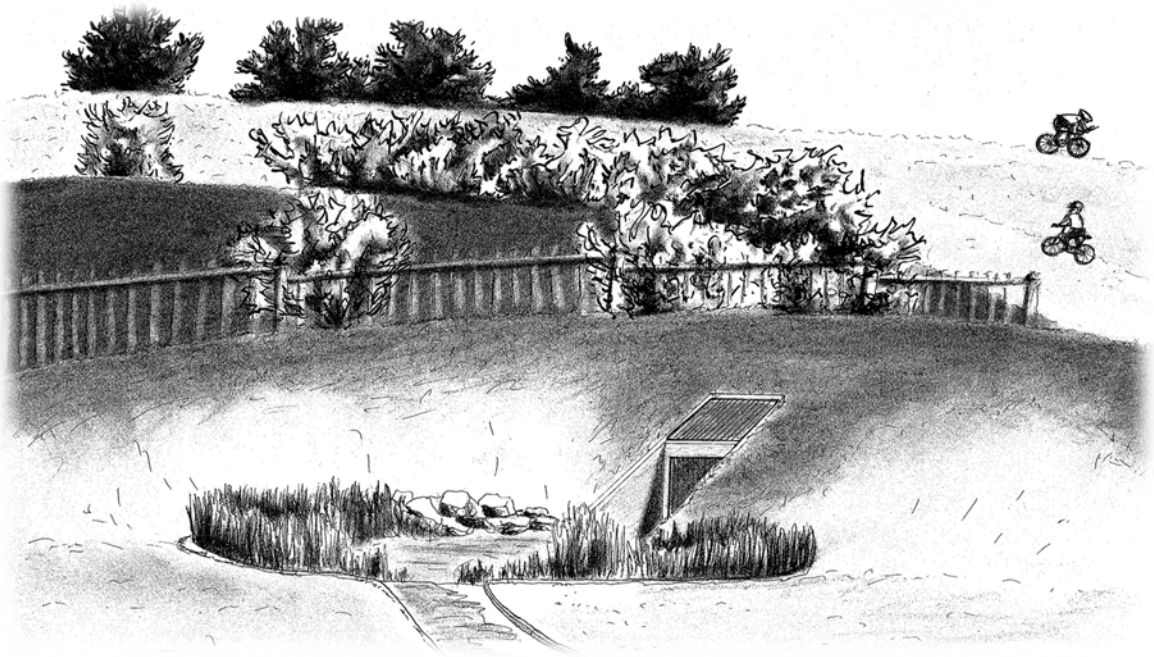


Figure EDB-2. Parallel wall outlet structure configuration. Graphic by Adia Davis.

10. **Overflow Embankment:** Design the embankment to withstand the 100-year storm at a minimum. If the embankment falls under the jurisdiction of the State Engineer's Office, it must be designed to meet the requirements of the State Engineer's Office. The overflow should be located at a point where waters can best be conveyed downstream. Slopes that are 4:1 or flatter should be used to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics. Side slopes should be no steeper than 3:1 and should be planted with turf forming grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to 95% of maximum dry density for ASTM D698 (Standard Proctor) or 90% for ASTM D1557 (Modified Proctor). Spillway structures and overflows should be designed in accordance with the *Storage* Chapter of Volume 2 as well as any local drainage criteria. Buried soil riprap or reinforced turf mats installed per manufacturer's recommendations can provide an attractive and less expensive alternative to concrete.

11. **Vegetation:** Vegetation provides erosion control and sediment entrapment. Basin bottom, berms, and side slopes should be planted with turf grass, which is a general term for any grasses that will form a turf or mat, as opposed to bunch grass which will grow in clumplike fashion. Xeric grasses with temporary irrigation are recommended to reduce maintenance requirements, including maintenance of the irrigation system as well as frequency of mowing. Where possible, place irrigation heads outside the basin bottom because irrigation heads in an EDB can become buried with sediment over time.

12. **Access:** Provide appropriate maintenance access to the forebay and outlet works. For larger basins, this means stabilized access for maintenance vehicles. If stabilized access is not provided, the maintenance plan should provide detail, including recommended equipment, on how sediment and trash will be removed from the outlet structure and micropool. Some communities may require

Designing for Baseflows

Baseflows should be anticipated for large tributary areas and can be accommodated in a variety of ways. Consider the following:

- If water rights are available, consider alternate BMPs such as a constructed wetland pond or retention pond.
- Anticipate future modifications to the outlet structure. Following construction, baseflows should be monitored periodically. Intermittent flows can become perennial and perennial flows can increase over time. It may be determined that outlet modifications are necessary long after construction of the BMP is complete.
- Design foundation drains and other groundwater drains to bypass the water quality plate directing these drains to a conveyance element downstream of the EDB. This will reduce baseflows and help preserve storage for the WQCV.
- When the basin is fully developed and an existing baseflow can be approximated prior to design, the water quality orifices should be increased to drain the WQCV in 40 hours while also draining the baseflow. This requires reservoir routing using an inflow hydrograph that includes the baseflow. The *UD-Detention* workbook available at www.udfcd.org may be used for this purpose.
- Increase the initial surcharge volume of the pond to provide some flexibility when baseflows are known or anticipated. Baseflows are difficult to approximate and will continue to increase as the watershed develops. Increasing the initial surcharge volume will accommodate a broader range of flows.

vehicle access to the bottom of the basin regardless of the size of the watershed. Grades should not exceed 10% for haul road surfaces and 20% for skid-loader and backhoe access. Stabilized access includes concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement. The recommended cross slope is 2%.

Aesthetic Design

Since all land owners and managers wish to use land in the most efficient manner possible, it is important that EDBs become part of a multi-use system. This encourages the design of EDBs as an aesthetic part of a naturalized environment or to include passive and/or active open space. Within each scenario, the EDB can begin to define itself as more than just a drainage facility. When this happens, the basin becomes a public amenity. This combination of public amenity and drainage facility is of much greater value to a landowner. Softened and varied slopes, interspersed irrigated fields, planting areas and wetlands can all be part of an EDB.

The design should be aesthetic whether it is considered to be an architectural or naturalized basin. Architectural basins incorporate design borrowed or reflective of the surrounding architecture or urban forms. An architectural basin is intended to appear as part of the built environment, rather than hiding the cues that identify it as a stormwater structure. A naturalized basin is designed to appear as though it is a natural part of the landscape. This section provides suggestions for designing a naturalized basin. The built environment, in contrast to the natural environment, does not typically contain the randomness of form inherent in nature. Constructed slopes typically remain consistent, as do slope transitions. Even dissipation structures are usually a hard form and have edges seldom seen in nature. If the EDB is to appear as though it is a natural part of the landscape, it is important to minimize shapes that provide visual cues indicating the presence of a drainage structure. For example, the side sides should be shaped more naturally and with varying slopes for a naturalized basin.

Suggested Methods for a Naturalized Basin

- Create a flowing form that looks like it was shaped by water.
- Extend one side of the basin higher than the other. This may require a berm.
- Shape the bottom of the basin differently than the top.
- Slope of one side of the basin more mildly than the opposing side.
- Vary slope transitions both at the top of the bank and at the toe.
- Use a soft-surface trickle channel if appropriate and approved.
- When using rock for energy dissipation, the rock should graduate away from the area of hard edge into the surrounding landscape. Other non-functional matching rock should occur in other areas of the basin to prevent the actual energy dissipation from appearing out of context.
- Design ground cover to reflect the type of water regime expected for their location within the basin.

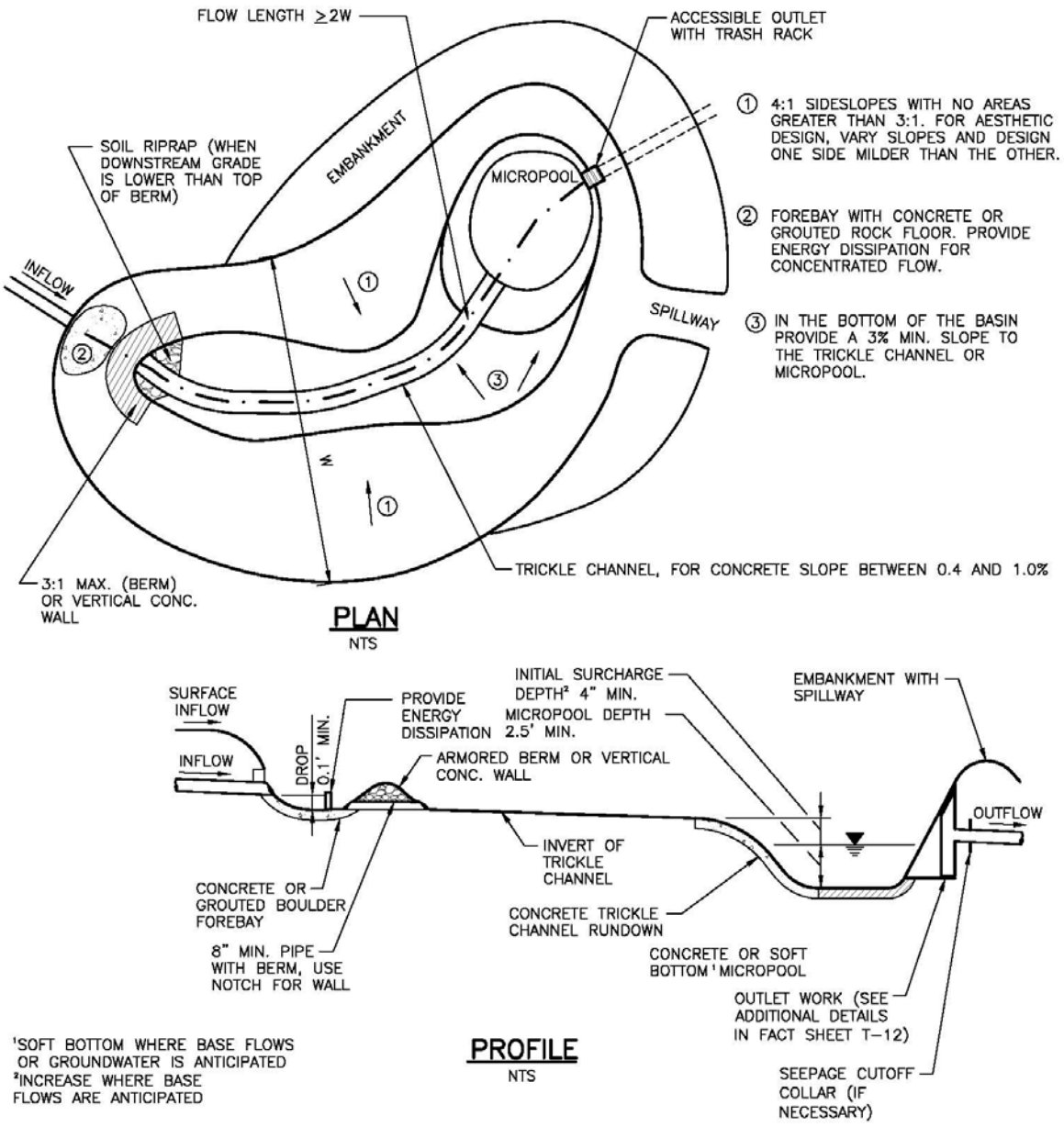


Figure EDB-3. Extended Detention Basin (EDB) Plan and Profile

Additional Details are provided in BMP Fact Sheet T-12. This includes outlet structure details including orifice plates and trash racks.

Table EDB-4. EDB component criteria

	On-Site EDBs for Watersheds up to 1 Impervious Acre[1]	EDBs with Watersheds between 1 and 2 Impervious Acres[1]	EDBs with Watersheds up to 5 Impervious Acres	EDBs with Watersheds over 5 Impervious Acres	EDBs with Watersheds over 20 Impervious Acres
Forebay Release and Configuration	EDBs should not be used for watersheds with less than 1 impervious acre.	Release 2% of the undetained 100-year peak discharge by way of a wall/notch configuration	Release 2% of the undetained 100-year peak discharge by way of a wall/notch configuration	Release 2% of the undetained 100-year peak discharge by way of a wall/notch configuration	Release 2% of the undetained 100-year peak discharge by way of a wall/notch or berm/pipe[2] configuration
Minimum Forebay Volume		1% of the WQCV	2% of the WQCV	3% of the WQCV	3% of the WQCV
Maximum Forebay Depth		12 inches	18 inches	18 inches	30 inches
Trickle Channel Capacity		≥ the maximum possible forebay outlet capacity	≥ the maximum possible forebay outlet capacity	≥ the maximum possible forebay outlet capacity	≥ the maximum possible forebay outlet capacity
Micropool		Area ≥ 10 ft^2	Area ≥ 10 ft^2	Area ≥ 10 ft^2	Area ≥ 10 ft^2
Initial Surcharge Volume		Depth ≥ 4 inches	Depth ≥ 4 inches	Depth ≥ 4 in. Volume ≥ 0.3% WQCV	Depth ≥ 4 in. Volume ≥ 0.3% WQCV

[1] EDBs are not recommended for sites with less than 2 impervious acres. Consider a sand filter or rain garden.

[2] Round up to the first standard pipe size (minimum 8 inches).

Sand Filter T-6

Description

A sand filter is a filtering or infiltrating BMP that consists of a surcharge zone underlain by a sand bed with an underdrain system. During a storm, accumulated runoff collects in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The underdrain gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm drain. It is similar to a BMP designed for bioretention in that it utilizes filtering, but differs in that it is not specifically designed for vegetative growth. The absence of vegetation in a sand filter allows for active maintenance at the surface of the filter, (i.e., raking for removing a layer of sediment). For this reason, sand filter criteria allows for a larger contributing area and greater depth of storage. A sand filter is also a dry basin, which can be designed to include the flood control volume above the WQCV or EURV. Sand filters can also be placed in a vault. Underground sand filters have additional requirements. See Fact Sheet T-11 for additional discussion on underground BMPs.

Photograph SF-1. This sand filter, constructed on two sides of a parking garage, is accessible for maintenance, yet screened from public view by a landscape buffer.

Sand/Media Filter	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Good
Total Metals	Good
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

Sand filters require a stable watershed. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils, consider another BMP or provide pretreatment before runoff from these areas reach the rain garden.

When sand filters (and other BMPs used for infiltration) are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. Oversaturated subgrade soil underlying a structure can cause the structure to settle or result in moisture-related problems. Wetting of expansive soils or bedrock can cause swelling, resulting in structural movements. A geotechnical engineer should evaluate the potential impact of the BMP on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site.

In locations where potentially expansive soils or bedrock exist, placement of a sand filter adjacent to a structure should only be considered if the BMP includes a drainage layer (with underdrain)

structure, and is lined with an impermeable geomembrane liner designed to restrict seepage.

Designing for Maintenance

Recommended maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:

- Do not put a filter sock on the underdrain. This is not necessary and can cause the BMP to clog.
- Install cleanouts. Cleanouts can be used for inspection (by camera) immediately following construction to ensure that the underdrain pipe was not crushed during construction. They can also be used to for ongoing maintenance practices. Consider locating cleanouts in the side slopes of the basin and above the depth of ponding.
- Provide vegetated side slopes to pre-treat runoff by filtering (straining). This will reduce the frequency of maintenance.

Benefits

- Filtering BMPs provide effective water quality enhancement including phosphorus removal.

Limitations

- This BMP may clog and require maintenance if a moderate to high level of silts and clays are allowed to flow into the facility.
- This BMP should not be located within 10 feet of a building foundation without an impermeable membrane. See *Bioretention* (BMP Fact Sheet T-3) of this manual for additional information.
- The sand filter should not be put into operation while construction or major landscaping activities are taking place in the watershed.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for a sand filter.

1. **Basin Storage Volume**: Provide a storage volume above the sand bed of the basin equal to the WQCV based on a 12-hour drain time.
   - Determine the imperviousness of the tributary area (or effective imperviousness where LID techniques are implemented). Determine the required WQCV (watershed inches of runoff) using Figure 3-2 in Chapter 3 of this manual. The volume should be based on a drain time of 12 hours.
   - Calculate the design volume as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation SF-1}$$

   Where:

   V = design volume (ft^3)

   A = watershed area tributary to the sand filter (ft^2)

2. **Basin Geometry:** Use equation SF-2 to calculate the minimum filter area, which is the flat surface of the sand filter. Sediment will reside on the filter area of the sand filter. Therefore, if the filter area is too small, the filter may clog prematurely. If this is of particular concern, increasing the filter area will decrease the frequency of maintenance. The following equation provides the minimum filter area allowing for some of the volume to be stored beyond the area of the filter. **Note that the total**

volume must also equal or exceed the design volume.

The side slopes of the basin should be stable and maintainable. For vegetated side slopes, a 4:1 (horizontal: vertical) minimum slope is recommended. Use vertical walls where side slopes are steeper than 3:1

$$A_F = 0.0125AI \qquad \text{Equation SF-2}$$

Where:

A_F = minimum filter area (flat surface area) (ft^2)

A = area tributary to the sand filter (ft^2)

I = imperviousness of area tributary to the sand filter (percent expressed as a decimal)

Filter Material: Provide, at a minimum, an 18-inch layer of CDOT Class B or C filter material (see Table SF-1). Maintain a flat surface on the top of the sand bed.

Table SF-1. Gradation specifications for CDOT Class B or C filter material
(Source: CDOT Table 703-7)

	CDOT Class B filter material	CDOT Class C filter material
Sieve Size	Mass Percent Passing Square Mesh Sieves	
37.5 mm (1.5")	100	
19.0 mm (0.75")		100
4.75 mm (No.4)	20-60	60-100
1.18 um (No. 16)	10-30	
300 um (No. 50)	0-10	10-30
150 um (No. 100)		0-10
75 um (No. 200)	0-3	0-3

4. **Underdrain System**: Underdrains are typically required for sand filters and should be provided if infiltration tests show rates slower than 2 times that required to drain the WQCV over 12 hours, or where required to divert water away from structures as determined by a professional engineer. Infiltration tests should be performed or supervised by a licensed professional engineer and conducted at a minimum depth equal to the bottom of the sand filter. Additionally, underdrains are required where impermeable membranes are used. There are three basic types of sand filters:

   - **No-Infiltration Section**: This section includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils. Consider using this section when any of the following conditions exist:
     - The site is a stormwater hotspot and infiltration could result in contamination of groundwater.
     - The site is located over contaminated soils and infiltration could mobilize these contaminants.
     - The facility is located over potentially expansive soils or bedrock that could swell due to infiltration and potentially damage adjacent structures (e.g., building foundation or pavement).
   - **Partial Infiltration Section**: This section does not include an impermeable liner, and allows some infiltration. Stormwater that does not infiltrate is collected and removed by an underdrain system.
   - **Full Infiltration Section**: This section is designed to infiltrate the water stored in the basin into the subgrade below. UDFCD recommends a minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours. A conservative design could utilize the partial infiltration section with the addition of a valve at the underdrain outlet. In the event that infiltration does not remain adequate following construction, the valve could be opened and allow this section to operate as a partial infiltration section. It is rare that sand filters are designed to fully infiltrate.

   When using an underdrain system, provide a control orifice sized to drain the design volume in approximately 12 hours or more (see Equation SF-3). Use a minimum orifice size of 3/8 inch to avoid clogging. This will provide detention and slow release of the WQCV to offset hydromodification. Provide cleanouts to allow inspection of the drainpipe system during and after construction to ensure that the pipe was not crushed or disconnected during construction and to allow for maintenance of the underdrain. Space underdrain pipes a maximum of 20 feet on-center.

$$D_{12\text{ hour drain time}} = \sqrt{\frac{V}{1414\ y^{0.41}}} \qquad \text{Equation SF-3}$$

Where:

D = orifice diameter (in)

y = distance from the lowest elevation of the storage volume (ft) (i.e., surface of the filter) to the center of the orifice

V = volume to drain in 12 hours (WQCV) (ft^3)

In previous versions of this manual, UDFCD recommended that the underdrain be placed in an aggregate layer and that a geotextile (separator fabric) be placed between this aggregate and the growing medium. This version of the manual replaces that section with materials that, when used

together, eliminate the need for a separator fabric.

The underdrain system should be placed below the 18-inch (minimum) filter layer. The underdrain system should be placed within an 5-inch-thick section of CDOT Class C filter material meeting the gradation in Table SF-1. Areas of the underdrain layer may be deeper due to the slope of the underdrain. If no underdrain is required, the minimum section can be reduced to the 18-inch filter layer. Use slotted pipe that meets the slot dimensions provided in Table SF-2.

Table SF-2. Dimensions for Slotted Pipe[1]

Pipe Size	Slot Length	Maximum Slot Width	Slot Centers	Open Area (per foot)
4"	1-1/16"	0.032"	0.413"	1.90 in^2
6"	1-3/8"	0.032"	0.516"	1.98 in^2

[1] Pipe must conform to requirements of ASTM designation F949. There shall be no evidence of splitting, cracking, or breaking when the pipe is tested per ASTM test method D2412 in accordance with F949 section 7.5 and ASTM F794 section 8.5. Contech A-2000 slotted pipe (or equal).

Table SF-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction
[2] As measured in accordance with ASTM D 4632

5. **Impermeable Geomembrane Liner and Geotextile Separator Fabric:** For no-infiltration sections, install a minimum 30-mil thick PVC geomembrane liner, per Table SF-4, on the bottom and sides of the basin, extending up at least to the top of the underdrain layer. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration. The geomembrane should be field-seamed using a dual track welder, which allows for non-destructive testing of almost all field seams. A small amount of single track and/or adhesive seaming should be allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs. The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. Place CDOT Class B geotextile separator fabric above the geomembrane to protect it from being punctured during the placement of the filter material above the liner. If the subgrade contains angular rocks or other material that could puncture the geomembrane, smooth-roll the surface to create a suitable surface. If smooth-rolling the surface does not provide a suitable surface, also place the separator fabric between the geomembrane and the underlying subgrade. This should only be done when necessary because fabric placed under the geomembrane can increase seepage losses through pinholes or other geomembrane defects. Connect the geomembrane to perimeter concrete walls around the basin perimeter, creating a watertight seal between the geomembrane and the walls using a continuous batten bar and anchor connection (see Figure SF-3). Where the need for the impermeable membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Use watertight PVC boots for underdrain pipe penetrations through the liner (see Figure SF-2).

Table SF-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m^2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

6. **Inlet Works**: Provide energy dissipation and a forebay at all locations where concentrated flows enter the basin. Use an impact basin for pipes and a baffle chute or grouted sloping boulder drop if a channel or swale is used, or install a Type VL or L riprap basin underlain with geotextile fabric at the inlet (see Figure SF-1). Fill all rock voids with the filter material specified in Table SF-1.

7. **Outlet Works**: Slope the underdrain into a larger outlet structure. As discussed in Step 4, use an orifice plate to drain the WQCV over approximately 12 hours. Flows exceeding the WQCV should also drain into the outlet structure. Additional flow restrictions may be incorporated to provide full spectrum detention, as discussed in the *Storage* chapter of Volume 2, or peak reduction for other specific storm events.

   For full spectrum detention, perform reservoir routing calculations to design the outlet structure. The *UD-Detention* workbook, available at www.udfcd.org, can be used for this purpose. The design could include a second orifice located at the WQCV elevation or could include a downstream point of control designed to drain the full excess urban runoff volume (EURV).

Construction Considerations

Proper construction of sand filters involves careful attention to material specifications and construction details. For a successful project, do the following:

- Protect area from excessive sediment loading during construction. The portion of the site draining to the sand filter must be stabilized before allowing flow into the sand filter.
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner.

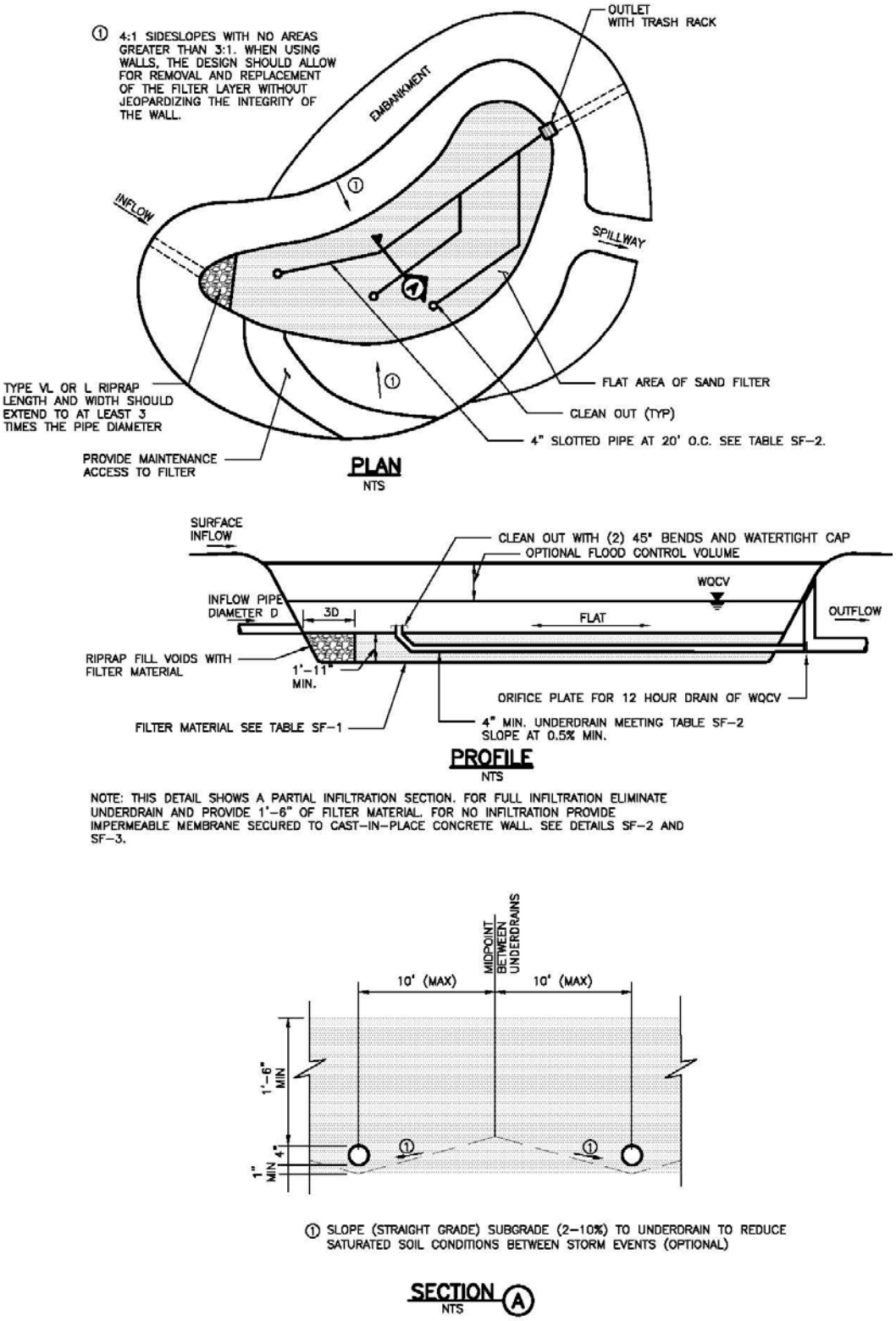


Figure SF-1. Sand Filter Plan and Sections

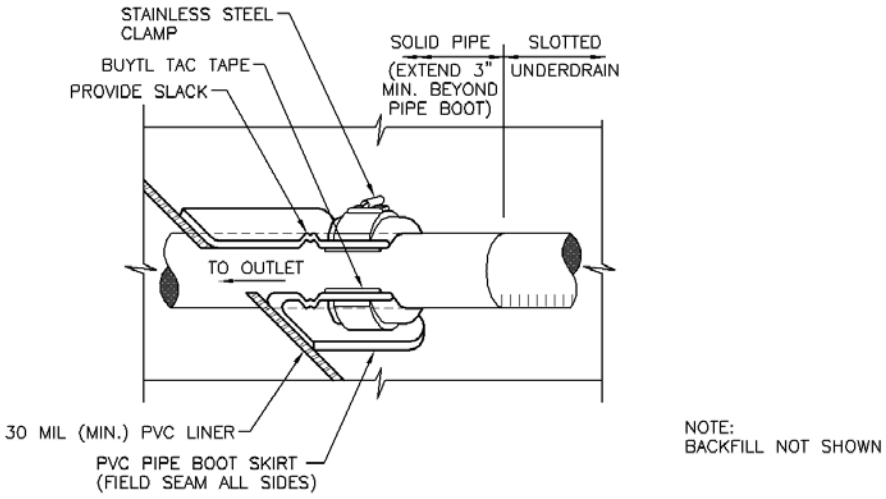


Figure SF-2. Geomembrane Liner/Underdrain Penetration Detail

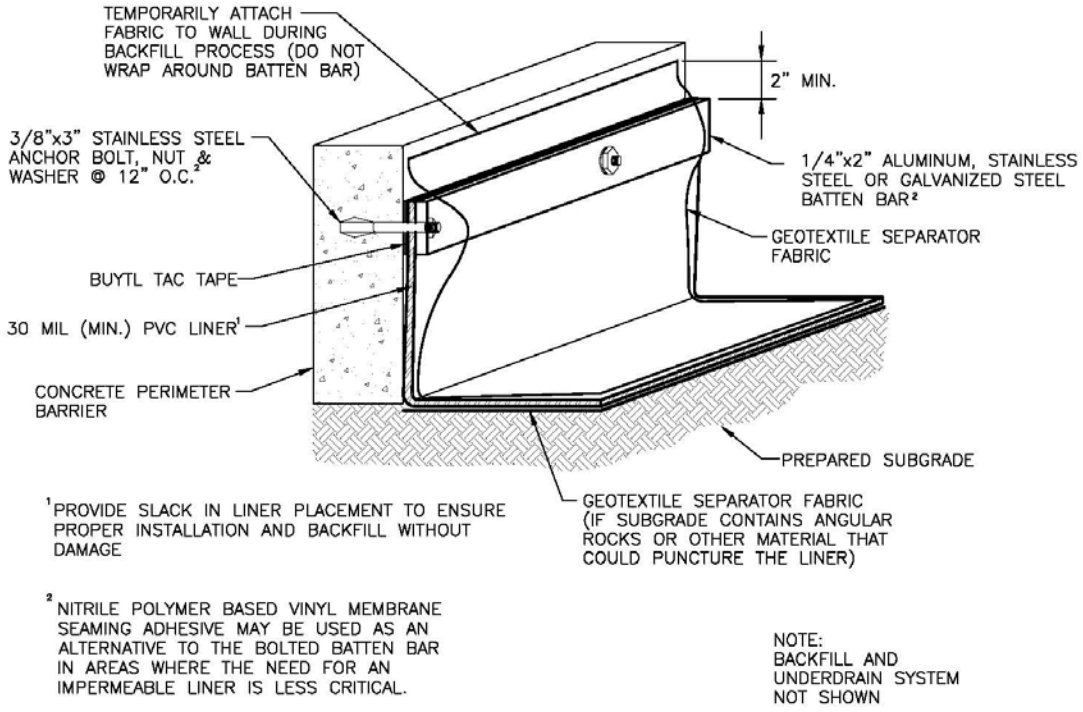


Figure SF-3. Geomembrane Liner/Concrete Connection Detail

Retention Pond T-7

Description

Photograph RP-1. Retention ponds treat stormwater though sedimentation and biological processes including uptake.

A retention pond, sometimes called a "wet pond," has a permanent pool of water with capacity above the permanent pool designed to capture and slowly release the water quality capture volume (WQCV) over 12 hours. The permanent pool is replaced, in part, with stormwater during each runoff event so stormwater runoff mixes with the permanent pool water. This allows for a reduced residence time compared to that of the extended detention basin (EDB). The 12-hour drain time helps to both better replicate pre-development flows for frequent events and reduce the potential for short circuiting treatment in smaller ponds. Retention ponds can be very effective in removing suspended solids, organic matter and metals through sedimentation, as well as removing soluble pollutants like dissolved metals and nutrients through biological processes.

Site Selection

Retention ponds require groundwater or a dry-weather base flow if the permanent pool elevation is to be maintained year-round. They also require legal and physical use of water. In Colorado, the availability of this BMP can be limited due to water rights issues.

The designer should consider the overall water budget to ensure that the baseflow will exceed evaporation, evapotranspiration, and seepage losses (unless the pond is lined). High exfiltration rates can initially make it difficult to maintain a permanent pool in a new pond, but the bottom can eventually seal with fine sediment and become relatively impermeable over time. However, it is best to seal the bottom and the sides of a permanent pool if the pool is located on permeable soils and to leave the areas above the permanent pool unsealed to promote infiltration of the stormwater detained in the surcharge WQCV.

Retention	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Moderate
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis is based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Studies show that retention ponds can cause an increase in temperature from influent to effluent. Retention ponds are discouraged upstream of receiving waters that are sensitive to increases in temperature (e.g., fish spawning or hatchery areas).

Use caution when placing this BMP in a basin where development will not be completed for an extended period, or where the potential for a chemical spill is higher than typical. When these conditions exists, it is critical to provide adequate containment and/or pretreatment of flows. In developing watersheds, frequent maintenance of the forebay may be necessary.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term.

- Provide pretreatment upstream of the permanent pool.
- Provide maintenance access to the outlet structure as well as the forebay.
- Exceed the minimum criterion for the permanent pool volume. Greater depth will help deter algae growth by reducing temperature and the area of the pond bottom that receives sunlight.

Benefits

- Creates wildlife and aquatic habitat.
- Provides recreation, aesthetics, and open space opportunities.
- Can increase adjacent property values.
- Cost-effective BMP for larger tributary watersheds.

Limitations

- Safety concerns associated with open water.
- Requires both physical supply of water and a legal availability (in Colorado) to impound water.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.
- Ponds can attract water fowl which can add to the nutrients and bacteria leaving the pond.
- Ponds increase water temperature.

Design Procedure and Criteria

The following steps outline the retention pond design procedure and criteria and Figure RP-1 shows a typical configuration. UD-BMP, available at www.udfcd.org, is an Excel based workbook that can be used to perform some of the below calculations and ensure conformance to these criteria. UD-Detention, another workbook developed by UDFCD can be used to develop and route a storm hydrograph through a retention pond and design the outlet structure.

1. **Baseflow**: Unless the permanent pool is establish by groundwater, a perennial baseflow that exceeds losses must be physically and legally available. Net influx calculations should be conservative to account for significant annual variations in hydrologic conditions. Low inflow in relation to the pond volume can result in poor water quality. Losses include evaporation, evapotranspiration, and seepage. Evaporation can be estimated from existing local studies or from the National Weather Service (NWS) Climate Prediction website. Data collected from Chatfield Reservoir from 1990 to 1997 show an average annual evaporation of 37 inches, while the NWS shows approximately 40 inches of evaporation per year in the Denver metropolitan area. Potential evapotranspiration (which occurs

when water supply to both plant and soil surface is unlimited) is approximately equal to the evaporation from a large, free-water surface such as a lake (Bedient and Huber, 1992). When retention ponds are placed above the groundwater elevation, a pond liner is recommended unless evaluation by a geotechnical engineer determines this to be unnecessary.

2. **Surcharge Volume**: Provide a surcharge volume based on a 12-hour drain time.

   - Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).
   - Find the required storage volume. Determine the required WQCV or EURV (watershed inches of runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 (for EURV).
   - Calculate the design volume (surcharge volume above the permanent pool) as follows:

     For WQCV:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation RP-1}$$

     For EURV:

$$V = \left[\frac{\text{EURV}}{12}\right] A \qquad \text{Equation RP-2}$$

     Where:

     V = design volume (acre ft)

     A = tributary catchment drainage area (acres)

3. **Basin Shape:** Always maximize the distance between the inlet and the outlet. A basin length to width ratio between 2:1 and 3:1 is recommended to avoid short-circuiting. It may be necessary to modify the inlet and outlet locations through the use of pipes, swales, or channels to accomplish this.

4. **Permanent Pool**: The permanent pool provides stormwater quality enhancement between storm runoff events through biochemical processes and continuing sedimentation.

   - Volume of the permanent pool:

$$V_p \geq 1.2\left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation RP-3}$$

     Where:

     V_p = permanent pool volume (acre ft)

     A = tributary catchment drainage area (acres)

- Depth Zones: The permanent pool should have two zones:

  - Safety Wetland Bench: This area should be located along the perimeter of the pond, 6 to 12 inches deep and a minimum of 4 feet wide. Aquatic plant growth along the perimeter of the permanent pool can help strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake. The safety wetland bench is also constructed as a safety precaution. It provides a shallow area that allows people or animals who inadvertently enter the open water to gain footing to get out of the pond.

  - Open Water Zone: The remaining pond area should be open, providing a volume to promote sedimentation and nutrient uptake by phytoplankton. To avoid anoxic conditions, the maximum depth in the pool should not exceed 12 feet.

5. **Side Slopes**: Side slopes should be stable and sufficiently gentle to limit rill erosion and to facilitate maintenance. Side slopes above the safety wetland bench should be no steeper than 4:1, preferably flatter. The safety wetland bench should be relatively flat with the depth between 6 to 12 inches. The side slope below this bench should be 3:1 (or flatter when access is required or when the surface could be slippery). The steeper 3:1 slope below the safety wetland bench can be beneficial to deterring algae growth as it will reduce the shallow area of the pond, thus reducing the amount of sunlight that penetrates the pond bottom.

6. **Inlet**: Dissipate energy at the inlet to limit erosion and to diffuse the inflow plume. Inlets should be designed in accordance with the *Hydraulic Structures* chapter of Volume 2. This chapter includes design of impact basins and drop structures.

7. **Forebay**: Forebays provide an opportunity for larger particles to settle out, which will reduce the required frequency of sediment removal in the permanent pool. Install a solid driving surface on the bottom and sides below the permanent water line to facilitate sediment removal. A soil riprap berm should be constructed to contain the forebay opposite of the inlet. This should have a minimum top width of 8 feet and side slopes no steeper than 4:1. The forebay volume within the permanent pool should be sized for anticipated sediment loads from the watershed and should be at least 3% of the WQCV. If the contributing basin is not fully developed, additional measures should be taken to maintain a relatively clean forebay. This includes more frequent maintenance of the forebay and/or providing and maintaining temporary erosion control.

8. **Outlet:** The outlet should be designed to release the WQCV over a 12-hour period. This can be done through an orifice plate as detailed in BMP Fact Sheet T-12. Use reservoir routing calculations as discussed in the *Storage* Chapter of Volume 2 to properly design the outlet. The UD-Detention tool, available at www.udfcd.org, can be used for this purpose.

   Refer to BMP Fact Sheet T-12 for schematics pertaining to structure geometry, grates, trash racks, orifice plate, and all other necessary components.

9. **Trash Rack**: Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Similar to the trash rack design for the extended detention basin, extend the water quality trash rack into the permanent pool a minimum of 28 inches. The benefit of this is documented in Fact Sheet T-5. BMP Fact Sheet T-12 provides additional guidance on trash rack design including sizing based on the smallest dimension of the orifice.

10. **Overflow Embankment**: Design the embankment not to fail during the 100-year storm. If the embankment falls under the jurisdiction of the State Engineer's Office, it should be designed to meet the requirements of the State Engineer's Office. Embankment slopes should be no steeper than 4:1, preferably flatter, and planted with turf grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to 95% of maximum dry density for ASTM D698 (Standard Proctor) or 90% for ASTM D1557 (Modified Proctor). Spillway structures and overflows should be designed in accordance with local drainage criteria and should consider the use of stabilizing materials such as buried soil riprap or reinforced turf mats installed per manufacturer's recommendations.

11. **Maintenance Considerations:** The design should include a means of draining the pond to permit drying out of the pond when it has to be "mucked out" to restore volume lost due to sediment deposition. A means to drain the pond or a portion of the pond by gravity is preferred but not always practicable. Some level of pumping is typically required. Past versions of this manual included an underdrain at the perimeter of the pond with a valved connection to the outlet structure for this purpose. This remains an acceptable method for draining the pond. Additional alternatives include providing a drywell with a piped connection to the outlet structure or to a downstream conveyance element or connecting a valved pipe directly to the outlet structure. The pipe should include a valve that will only be opened for maintenance.

Providing a buffer of tall native grasses around a retention pond provides treatment through filtering (straining) and helps discourage frequent use of the pond by geese.

12. **Vegetation:** Vegetation provides erosion control and enhances site stability. Berms and side-sloping areas should be planted with native grasses or irrigated turf, depending on the local setting and proposed uses for the pond area. The safety wetland bench should be vegetated with aquatic species. This vegetation around the perimeter of an open water body can discourage frequent use of the pond by geese.

13. **Access:** All weather stable access to the bottom, forebay, and outlet works area should be provided for maintenance vehicles. Grades should not exceed 10% for haul road surfaces and should not exceed 20% for skid-loader and backhoe access. Provide a solid driving surface such as gravel, concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement. The recommended cross slope is 2%.

Photograph RP-2. This retention pond outlet structure is both accessible and functional while not interfering with the natural aesthetic.

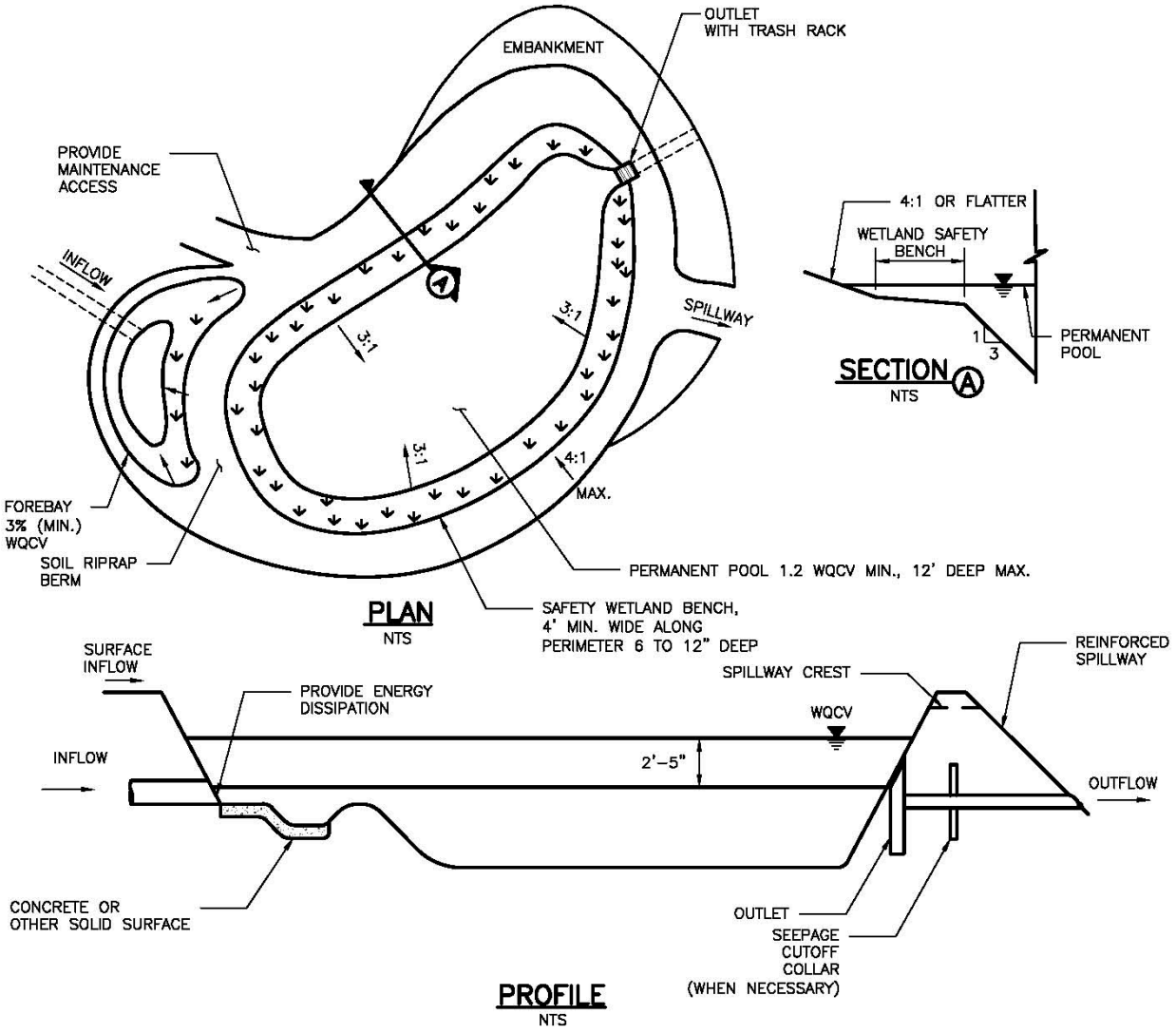


Figure RP-1. Retention Pond Plan and Sections

Aesthetic Design

Since all land owners and managers wish to use land in the most efficient manner possible, it is important that retention basins become part of a multi-use system. This encourages the design of retention ponds as an aesthetic part of a naturalized environment or to be expanded to include passive and/or active open space. Within each scenario, the retention basin can begin to define itself as more than just a drainage facility. When this happens, the basin becomes a public amenity. This combination of public amenity and drainage facility is of much greater value to a landowner. Softened and varied slopes, interspersed irrigated fields, planting areas and wetlands can all be part of a retention pond.

The design should be aesthetic whether it is considered to be an architectural or naturalized basin. Architectural basins incorporate design borrowed or reflective of the surrounding architecture or urban forms. An architectural basin is intended to appear as part of the built environment, rather than hiding the cues that identify it as a stormwater structure. A naturalized basin is designed to appear as though it is a natural part of the landscape. This section provides suggestions for designing a naturalized basin. The built environment, in contrast to the natural environment, does not typically contain the randomness of form inherent in nature. Constructed slopes typically remain consistent, as do slope transitions. Even dissipation structures are usually a hard form and have edges seldom seen in nature. If the retention pond is to appear as though it is a natural part of the landscape, it is important to minimize shapes that provide visual cues indicating the presence of a drainage structure. For example, the pond sides in the area of the surcharge volume should be shaped more naturally and with varying slopes for a naturalized pond. See Figure RP-2 for an example.

Suggested Methods for Creating the Look of a Naturalized Pond:

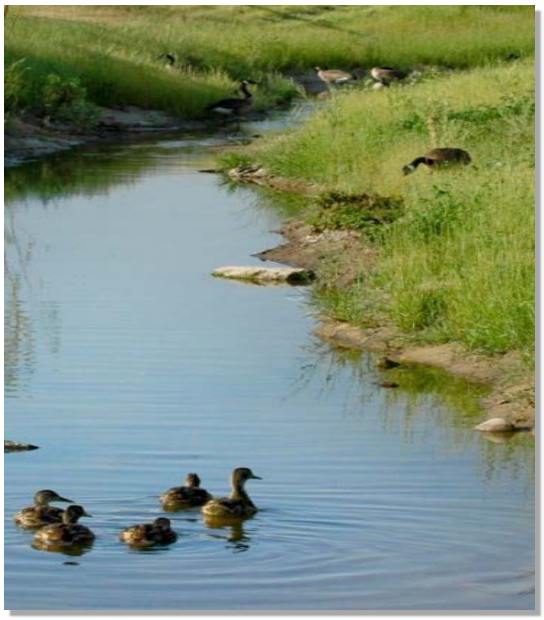
- Create a flowing overall form that looks like it was shaped by water. This includes the banks of the retention pond, which should have an undulating outline rather than a straight line.
- One side of the pond can be higher than the other side. This may require a berm.
- The shape of the permanent pool should vary from the shape of the surcharge volume.
- The slopes on at least three sides of the pond (above the permanent pool) should be varied and gentle. To achieve this, one or more sides of the basin may have to be stabilized by a retaining structure, i.e., stacked boulders and walls.
- Vary slope transitions.

Photograph RP-3. (altered photo) When incorporating rock into a structure, use other matching, functional rock to prevent the structure from looking out of context. Photo courtesy of Design Concepts.

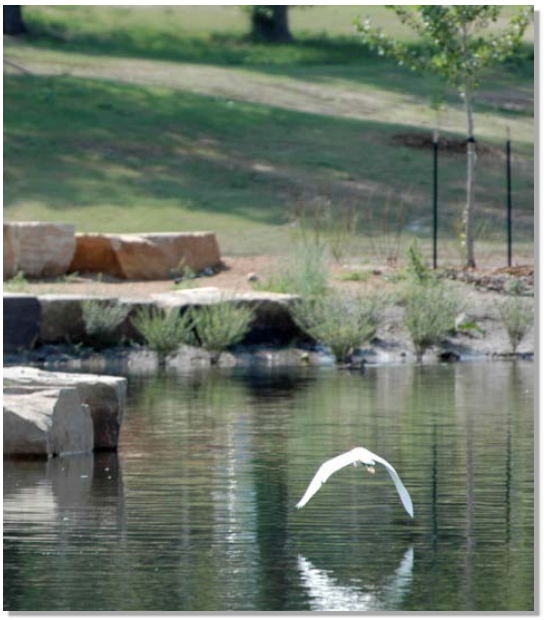
- Any use of rock for energy dissipation or for erosion control should graduate away from the area of hard edge into the surrounding landscape. Other functional matching rock should occur in other areas of the pond to prevent the energy dissipation structure from appearing out of context. Photo RP-3 serves as an example of this.
- If concrete is required in the basin, colored concrete matching the rocks or other site features of the surrounding landscape can be used to prevent the structure from appearing out of context. Colored concrete, form liners and veneers for construction walls are preferred for outlet structures.

Photograph RP-4. (altered photo) Variations in slope and texture around the pond are brought together by mass groupings of local stone boulders. The boulders are placed intermittently around the pond in groups and interspersed with plantings. Photo courtesy of Design Concepts. Note: A minimum 4-foot vegetated buffer (littoral zone) is recommended to strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake.

- Adjust the vegetation to the different uses of the pond surrounding.
- Ground cover should reflect the type of water regime expected for the location within the basin. For example, riparian plants would be placed around the edge of the retention pond, groups of trees and shrubs would be placed in more manicured areas that have no retention or detention function.



Photograph RP-5. A curving stream with vegetated edges provides habitat for wildlife. Photo courtesy of Design Concepts.



Photograph RP-6. Landscape elements such as vegetation and stone highlight the irregularly-shaped pond edge, making it appear more natural. Photo courtesy of Design Concepts.

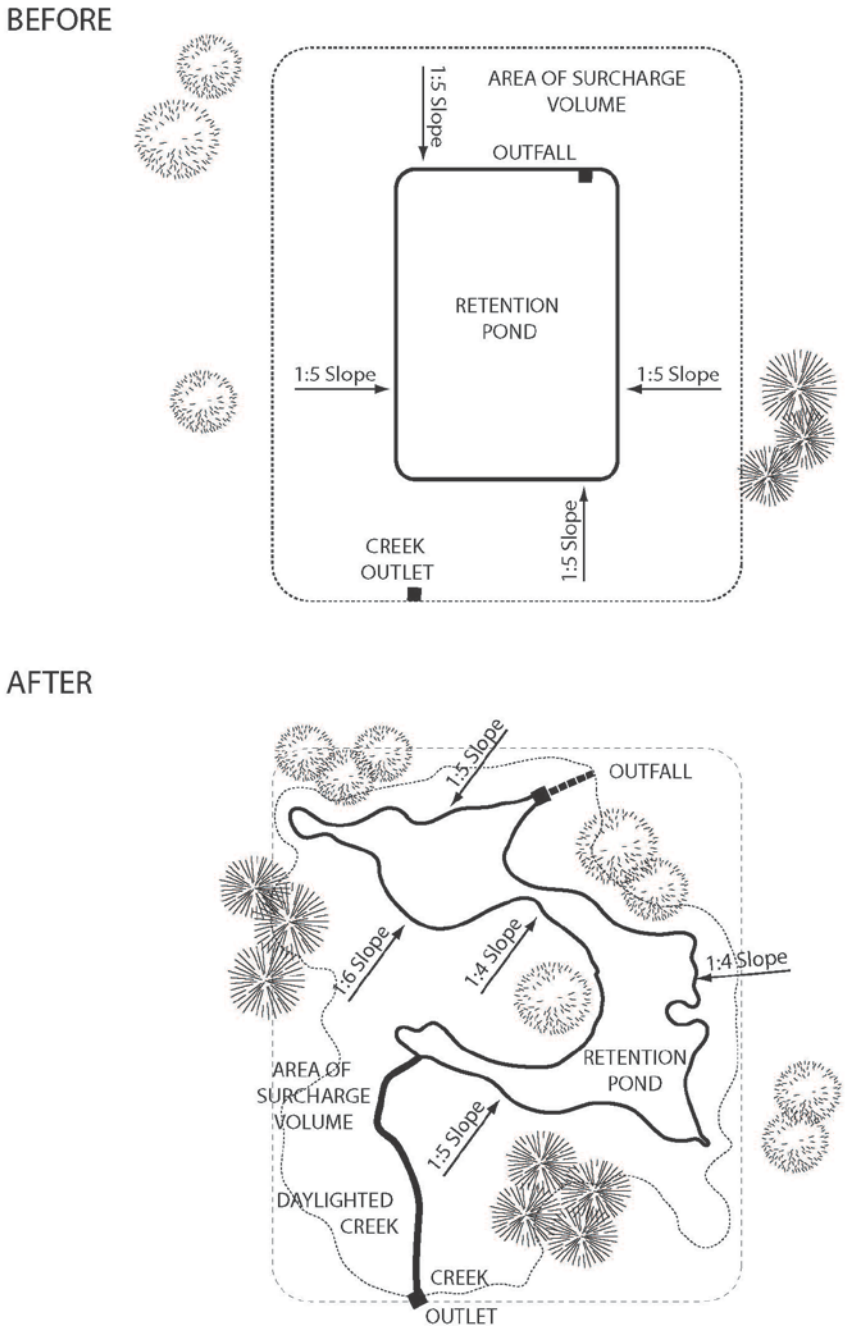


Figure RP-2. Example of a Naturalized Retention Pond

References

Bedient, Philip B. and Wayne C. Huber. 1992. *Hydrology and Floodplain Analysis (Second Edition).* Addison-Wesley Publishing Company.

United States Environmental Protection Agency (EPA). 1999. *Storm Water Technology Fact Sheet: Wet Detention Ponds.*

Constructed Wetland Pond T-8

Description

A constructed wetlands pond is a shallow retention pond designed to permit the growth of wetland plants such as rushes, willows, and cattails. Constructed wetlands slow runoff and allow time for sedimentation, filtering, and biological uptake.

Photograph CWP-1. This constructed wetland pond, located downstream of an extended detention basin, is part of a BMP "treatment train."

Constructed wetlands ponds differ from "natural" wetlands, as they are artificial and are built to enhance stormwater quality. Do not use existing or natural wetlands to treat stormwater runoff. Stormwater should be treated prior to entering natural or existing wetlands and other environmentally sensitive areas. Allowing untreated stormwater to flow into existing wetlands will overload and degrade the quality of the wetland. Sometimes, small wetlands that exist along ephemeral streams on Colorado's high plains can be enlarged and incorporated into the constructed wetland system. Such actions, however, require the approval of federal and state regulators.

Regulations intended to protect natural wetlands recognize a separate classification of wetlands, constructed for water quality treatment. Such wetlands generally are not allowed to be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality enhancement is separate from the disturbance of a natural wetland. Nevertheless, any activity that disturbs a constructed wetland should be cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

Constructed Wetland Basin	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis is based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

A constructed wetland pond requires a positive net influx of water to maintain vegetation and microorganisms. This can be supplied by groundwater or a perennial stream. An ephemeral stream will not provide adequate water to support this BMP.

A constructed wetland pond is best used as a follow-up BMP in a watershed, although it can serve as a stand-alone facility. Algae blooms may be reduced when BMPs that are effective in removing nutrients are placed upstream. Constructed wetland ponds can also be designed for flood control in addition to capture and treatment of

the water quality capture volume (WQCV).

Although this BMP can provide an aesthetic onsite amenity, constructed wetland ponds designed to treat stormwater can also become large algae producers. The owner should maintain realistic expectations.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design consider the sediment removal process, including access and equipment for the pond. As sedimentation occurs and depth becomes limited, removal of sediment from the pond bottom will be required to support beneficial habitat.

Be aware, nutrient rich inflow will produce algae blooms in this BMP. Source control BMPs, such as reduced fertilizer use, should be implemented to reduce regular maintenance.

Design Procedure and Criteria

The following steps outline the design procedure for a constructed wetland pond and Figure CWP-1 shows a typical configuration. UD-BMP, available at www.udfcd.org, is an Excel based workbook that can be used to perform some of the below calculations and ensure conformance to these criteria. UD-Detention, also available for download website can be used to develop and route a storm hydrograph through a constructed wetland pond and design the outlet structure.

Benefits

- Creates wildlife and aquatic habitat.
- Provides open space opportunities.
- Cost effective BMP for larger tributary watersheds.

Limitations

- Requires both physical supply of water and a legal availability (in Colorado) to impound water.
- Ponding depth can pose safety concerns requiring additional considerations for public safety during design and construction.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.
- Ponds can attract water fowl which can add to the nutrients leaving the pond.

1. **Baseflow**: Unless the permanent pool is establish by groundwater, a perennial baseflow that exceeds losses must be physically and legally available. Net influx calculations should be conservative to account for significant annual variations in hydrologic conditions. Low inflow in relation to the pond volume can result in poor water quality. Losses include evaporation, evapotranspiration, and seepage. Evaporation can be estimated from existing local studies or from the National Weather Service (NWS) Climate Prediction website. Data collected from Chatfield Reservoir from 1990 to 1997 show an average annual evaporation of 37 inches, while the NWS shows approximately 40 inches of evaporation per year in the Denver metropolitan area. Potential evapotranspiration (which occurs when water supply to both plant and soil surface is unlimited) is approximately equal to the evaporation from a large, free-water surface such as a lake (Bedient and Huber, 1992). When constructed wetland ponds are placed above the groundwater elevation, a pond liner is recommended unless evaluation by a geotechnical engineer determines this to be unnecessary.

2. **Surcharge Volume**: Provide a surcharge storage volume based on a 24-hour drain time.

   - Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).
   - Find the required storage volume: Determine the required WQCV/EURV (watershed inches of

runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 of the USDCM (for EURV).

- Calculate the design volume (surcharge volume above the permanent pool) as follows:

  For WQCV:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation CWP-1}$$

  For EURV:

$$V = \left[\frac{\text{EURV}}{12}\right] A \qquad \text{Equation CWP-2}$$

  Where:

  V = design volume (acre ft)

  A = watershed tributary to the constructed wetland pond (acre)

3. **Depth of Surcharge WQCV***:* In order to maintain healthy wetland growth, the surcharge depth for WQCV above the permanent water surface should not exceed 2 feet.

4. **Basin Shape**: Always maximize the distance between the inlet and the outlet. Shape the pond with a gradual expansion from the inlet and a gradual contraction to the outlet to limit short-circuiting. Try to achieve a basin length to width ratio between 2:1 to 4:1. It may be necessary to modify the inlet and outlet point through the use of pipes, swales, or channels to accomplish this.

5. **Permanent Pool**: The permanent pool provides stormwater quality enhancement between storm runoff events through biochemical processes and sedimentation. This requires a minimum volume as provided in Equation CWP-3.

$$V_p \geq 0.75 \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation CWP-3}$$

   Where:

   V_p = permanent pool volume (acre ft)

   A = watershed tributary to the constructed wetland pond (acre)

   Proper distribution of wetland habitat within and surrounding the permanent pool is needed to establish a diverse ecology. Distribute pond area in accordance with Table CWP-1.

Table CWP-1.

Pond Components	Permanent Pool Surface Area	Water Design Depth
Forebay, outlet and open water surface areas	30% to 50%	2 to 4 feet deep
Wetland zones with emergent vegetation	50% to 70%	6 to 12 inches deep[1]
[1] One-third to one-half of this zone should be 6 inches deep.		

6. **Side slopes:** Side slopes should be stable and sufficiently gentle to limit rill erosion and to facilitate maintenance. They should provide a safety wetland bench along the perimeter of the pond. This area should be 6 to 12 inches deep and a minimum of 4 feet wide. Aquatic plant growth along the perimeter of the permanent pool can help strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake. The safety wetland bench is also constructed as a safety precaution. It provides a shallow area that allows people or animals who inadvertently enter the open water to gain footing to get out of the pond. Side slopes above the safety wetland bench should be no steeper than 4:1, preferably flatter. The safety wetland bench surrounding the perimeter of the pond should be relatively flat with the depth between 6 to 12 inches.

7. **Inlet**: Provide energy dissipation for flows entering the basin to limit sediment resuspension. Inlet designs should correspond to UDFCD drop-structure criteria, impact basin pipe outlet structure standards, or other energy dissipating and flow diffusing structure designs.

8. **Forebay**: Forebays provide an opportunity for larger particles to settle out, which will reduce the required frequency of sediment removal in the permanent pool. Install a solid driving surface on the bottom and sides below the permanent water line to facilitate sediment removal. A soil riprap berm should be constructed to contain the forebay opposite of the inlet. This should have a minimum top width of 8 feet and side slopes no steeper than 4:1. The forebay volume within the permanent pool should be sized for anticipated sediment loads from the watershed and should be at least 3% of the WQCV. If the contributing basin is not fully developed, additional measures should be taken to maintain a relatively clean forebay. This includes more frequent maintenance of the forebay and/or providing and maintaining temporary erosion control.

2. **Outlet**: The outlet should be designed to release the WQCV over a 24-hour period. This can be done through an orifice plate as detailed in BMP Fact Sheet T-12. Use reservoir routing calculations as discussed in the *Storage* Chapter of Volume 2. UD-Detention, available at www.udfcd.org, can be used for this purpose.

   Refer to BMP Fact Sheet T-12 for schematics pertaining to structure geometry, grates, trash racks, orifice plate, and all other necessary components.

9. **Trash Rack**: Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Similar to the trash rack design for the extended detention basin, extend the water quality trash rack into the permanent pool a minimum of 28 inches. The benefit of this is documented in Fact Sheet T-5. BMP Fact Sheet T-12 provides additional guidance on trash rack design including sizing based on the smallest dimension of the orifice.

10. **Overflow Embankment**: Design the embankment not to fail during the 100-year storm. If the embankment falls under the jurisdiction of the State Engineer's Office, it should be designed to meet the requirements of the State Engineer's Office. Embankment slopes should be no steeper than 4:1, preferably flatter, and planted with turf grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to 95 percent of maximum dry density for ASTM D698 (Standard Proctor) or 90 percent for ASTM D1557 (Modified Proctor). Spillway structures and overflows should be designed in accordance with local drainage criteria and should consider the use of stabilizing materials such as buried soil riprap or reinforced turf mats installed per manufacturer's recommendations.

11. **Maintenance Considerations:** The design should include a means of draining the pond to facilitate drying out of the pond when it has to be "mucked out" to restore volume lost due to sediment deposition. Past versions of this manual included an underdrain at the perimeter of the pond with a valved connection to the outlet structure for this purpose. This remains an acceptable method for draining the pond. Additional alternatives include providing a drywell with a piped connection to the outlet structure or a downstream conveyance element, or connecting a valved pipe directly to the outlet structure. The pipe should include a valve that will only be opened for maintenance.

12. **Vegetation**: Vegetation provides erosion control and enhances site stability. Berms and side-sloping areas should be planted with native bunch or turf-forming grasses. The safety wetland bench at the perimeter of the pond should be vegetated with aquatic species. Aquatic species should be planted in the wetland bottom. Initial establishment of the wetlands requires control of the water depth. After planting wetland species, the permanent pool should be kept at 3 to 4 inches deep at the plant zones to allow growth and to help establish the plants, after which the pool should be raised to its final operating level.

Diverse wetlands make healthy wetlands. Create zones with different depths and plant a variety of vegetation.

13. **Access:** All-weather stable access to the bottom, forebay, and outlet works area should be provided for maintenance vehicles. Grades should not exceed 10% for haul road surfaces and should not exceed 20% for skid-loader and backhoe access. Provide a solid driving surface such as gravel, concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement. The recommended cross slope is 2%.

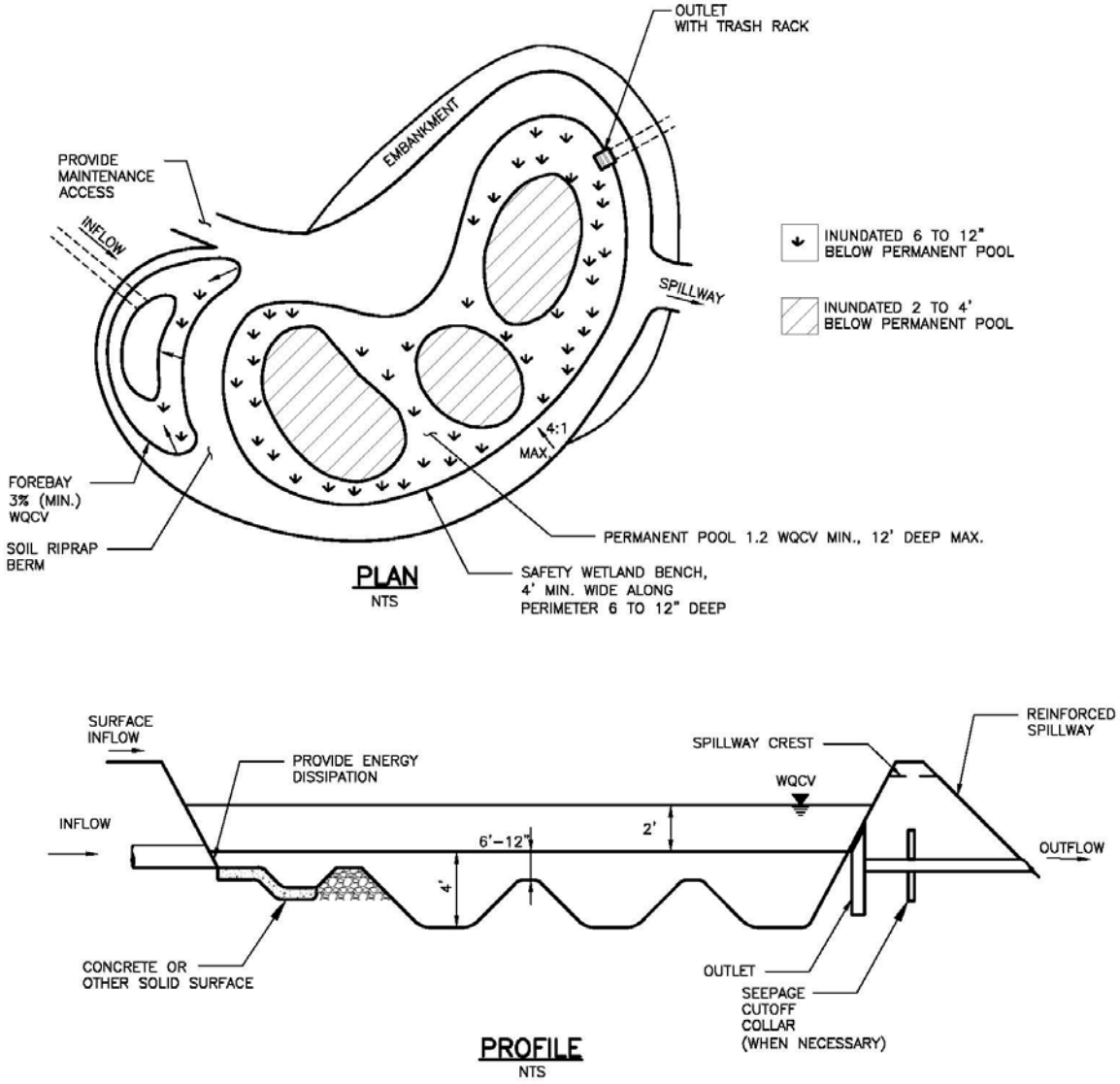


Figure CWP-1 – Constructed Wetland Pond – Plan and Cross-Section

References

Bedient, Philip B. and Wayne C. Huber. 1992. *Hydrology and Floodplain Analysis (Second Edition).* Addison-Wesley Publishing Company.

Constructed Wetland Channel T-9

Description

A constructed wetland channel is a conveyance BMP that is built, in part, to enhance stormwater quality. Constructed wetland channels use dense vegetation to slow down runoff and allow time for both biological uptake and settling of sediment.

Photograph CWC-1: Constructed wetland channels treat stormwater through straining, settling, and biological processes.

Constructed wetlands differ from natural wetlands, as they are artificial and are built to enhance stormwater quality. Do not use existing or natural wetlands to treat stormwater runoff. Stormwater should be treated prior to entering natural or existing wetlands and other environmentally sensitive areas. Allowing untreated stormwater to flow into existing wetlands will overload and degrade the quality of the wetland. Sometimes, small wetlands that exist along ephemeral drainageways on Colorado's high plains may be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

Regulations intended to protect natural wetlands recognize a separate classification of wetlands constructed for water quality treatment. Such wetlands generally are not allowed to be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality enhancement is separate from the disturbance of a natural wetland. Nevertheless, any activity that disturbs a constructed wetland should be first cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

Constructed Wetland Channel	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	Unknown
Nutrients	Unknown
Total Metals	Unknown
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

Constructed wetland channels provide conveyance of stormwater similar to a grass swale; however, this BMP is appropriate when a baseflow can be anticipated. A constructed wetland channel requires a net influx of water to maintain vegetation and microorganisms. This can be supplied by groundwater or a perennial stream. An ephemeral stream may not provide adequate water. In addition to water supply, loamy soils are needed in the wetland bottom to permit plants to take root. Wetland channels also require a near-zero longitudinal slope; drop structures can be used to create and maintain a flat grade.

T-9 Constructed Wetland Channel

A constructed wetland channel can be used in the following two ways:

- It can be established in a completely man-made channel providing conveyance and water quality enhancement.
- It can be located in a treatment train configuration, downstream of a stormwater detention facility (water quality and/or flood control) where a large portion of the sediment load has been removed upstream. This allows the wetland channel to benefit from the long duration of outlet flow and reduced maintenance requirements associated with pretreatment.

Benefits

- Wetland channels provide natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal.
- Provides effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles

Limitations

- Requires a continuous baseflow.
- Without proper design, salts and scum can accumulate and be flushed out during larger storms.
- Safety concerns associated with open water.

Designing for Maintenance

Recommended maintenance practices for all BMPs are provided in the BMP Maintenance chapter of this manual. As with many BMPs, poor maintenance of this BMP can result in reduced effectiveness (see inset). During design, the following should be considered to ensure ease of maintenance over the long-term:

- Ensure a continuous dry-weather baseflow. Without adequate water supply, salts and algae can concentrate in the water column and can be released into the receiving water in higher levels.
- Provide pretreatment when appropriate. If the influent concentrations are high, this BMP should be used in a treatment train approach. High levels of nutrients will overload the BMP causing algae growth. High solids will reduce capacity and increase maintenance requirements.

Design Procedure and Criteria

The criteria for a wetland channel presented in the following section differ somewhat from the criteria presented in the *Major Drainage* chapter of Volume 1. This is because of the water quality focus of this BMP. Before selecting this BMP, assess the water budget required so that the inflow of water throughout the year is sufficient to meet all the projected losses (such as evaporation, evapotranspiration, and seepage). An insufficient baseflow could cause the wetland vegetation to dry out and die.

The following steps outline the constructed wetland channel design procedure. Refer to Figure CWC-1 for its design components.

1. **Design Discharge**: Calculate the 2-year peak flow rate in the wetland channel using methods discussed in the *Runoff* chapter of Volume 1. Unless higher flows are diverted from the wetland channel, also calculate the 100-year peak flow rate.

2. **Channel Geometry**: Design the mature channel geometry to pass the design 2-year flow rate at 2.0 feet per second or less with a channel depth between 1.5 to 3.0 feet. The channel cross-section should be trapezoidal with stabilized side slopes of 2.5:1 (Horizontal:Vertical) or flatter. The bottom width should be no less than 3.0 feet. Unless higher flows are diverted from the wetland channel, ensure the

100-year peak flow rate can also be safely conveyed in the channel. See the *Major Drainage* chapter in Volume 1.

3. **Longitudinal Slope**: Set the longitudinal slope to meet channel geometry criteria using Manning's equation and a Manning's roughness coefficient of n=0.035 for the 2-year flow. If necessary due to the existing terrain, include grade control checks or small drop structures. Tie grade control structures into the bank a minimum of 0.50 feet above the 2-year water surface elevation. Design drop structures to satisfy the drop structure criteria of the *Major Drainage* chapter in Volume *1*.

4. **Channel Capacity**: Calculate the mature channel capacity during a 2-year event using a Manning's roughness coefficient based on the method for composite channels presented in the *Major Drainage* chapter of Volume 1. The channel should also provide enough capacity to contain the flow during a 100-year event while maintaining one foot of free-board. Increase the bottom width of the channel when additional capacity is needed.

5. **Grade Control Structures:** Grade control structures are frequently required to meet longitudinal slope and velocity recommendations. The structures should extend into the bank and at least 0.5 feet above the 2-year water surface elevation.

6. **Toe Protection**: Provide bank toe protection using type VL soil riprap or other stabilization methods as discussed in the *Major Drainage* chapter of Volume 1. Channel stabilization should include protection of the side slopes extending up to the 2-year water surface elevation. Carry this protection down 3 feet below the channel invert or place soil riprap in channel invert.

7. **Vegetation**: Vegetate the channel bottom and side slopes to provide solids entrapment and biological nutrient uptake. Cover the channel bottom with loamy soils to enable establishment of sedges and reeds. Side slopes should be planted with grasses.

8. **Maintenance Access**: Provide access for maintenance along the channel length. Maximum grades for maintenance vehicles should be 10% and provide a solid driving surface.

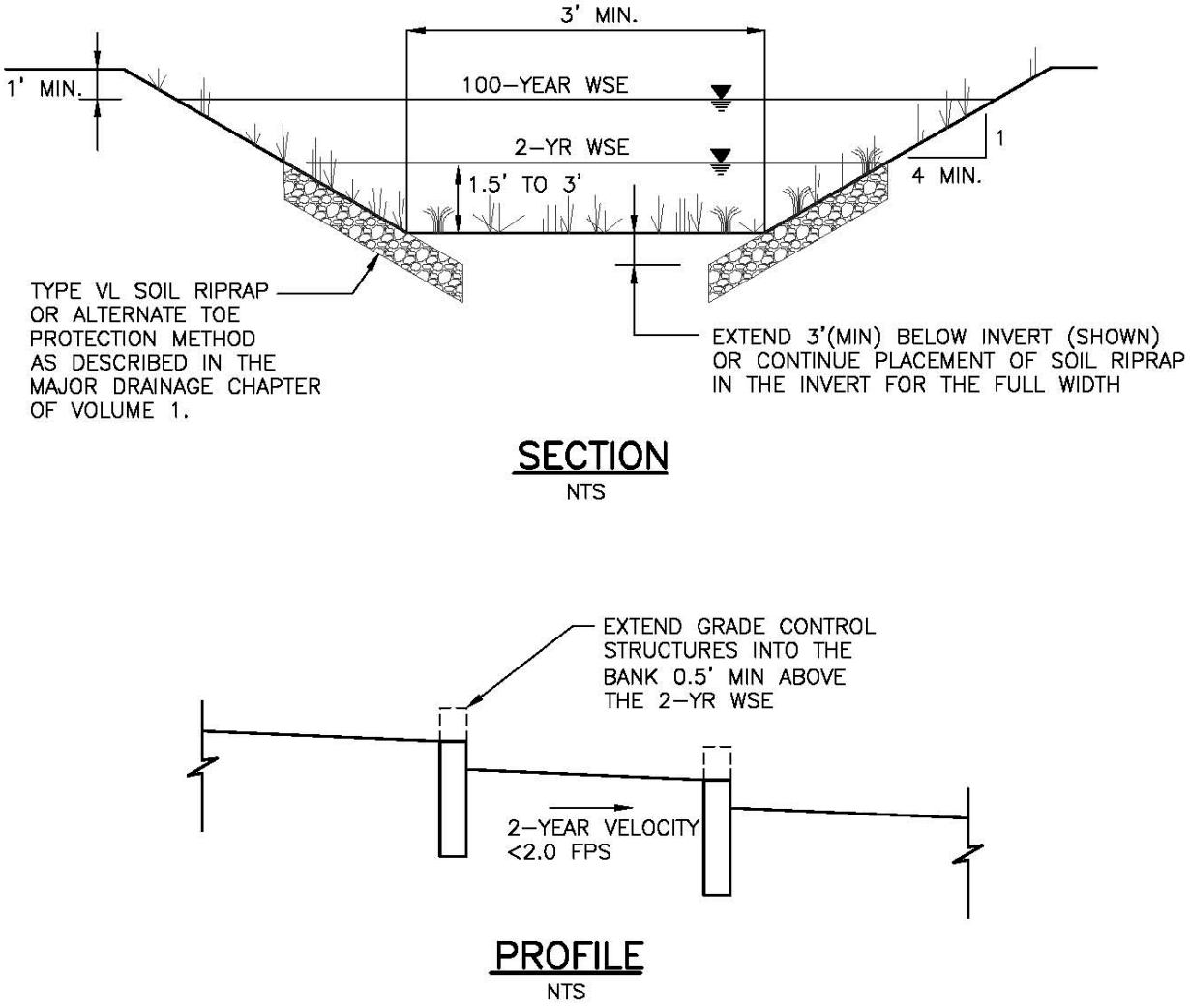


Figure CWC-1. Constructed Wetland Channel Plan and Section

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Constructed Wetland Channel T-9

Design Procedure Form: Constructed Wetland Channel (CWC)

Designer: G. Damato
Company: BMP, Inc.
Date: November 29, 2010
Project: Subdivison F
Location: NW corner of 90th Ave. and 57th St.

1. Design Discharge

   A) 2-Year Design Discharge — Q_2 = 15.00 cfs

   B) 100-Year Design Discharge — Q_{100} = 48.00 cfs

2. Channel Geometry (New Channel - No Wetland Veg. in Bottom)
   Channel Side Slopes (Z = 2.5 min., horiz. distance per unit vertical) — Z = 2.50 (H:V)

3. Longitudinal Slope (Based on Manning's *n* for the mature channel so as not to exceed the maximum given velocity) — S = 0.005 feet/feet

4. Channel Capacity
   (Based on Manning's n = 0.0018 * D2 ^ 2 - 0.0206 * D2 + 0.099 for D ≤ 5, and Manning's n = 0.0001 * Y ^ 2 - 0.0025 * Y + 0.05 for D > 5)

   A) Calculated channel geometry required to maintain the design discharge during a 2-year event with newly established and mature vegetation. Calculated resulting flow velocities for mature condition should be kept to 2 fps or less for the 2-year flow.

   B) Geometry and velocity to use for the 100-year discharge:
   Suggest the design for a 100-year capacity channel follow the guidance contained in the Major Drainage Chapter of Volume One. of the USDCM, or through the use of the UD-CHANNELS workbook.

   100-Year depth with 1-foot freeboard is 3.4 feet.
   100-Year top width with 1-foot freeboard is 20.1 feet.

	New 2-Yr. Channel		Mature 2-Yr. Channel	
D_2 =	1.10	feet	1.55	feet
B_2 =	3.0	feet	3.0	feet
T_2 =	8.5	feet	10.7	feet
V_2 =	2.39	fps	1.42	fps
n_2 =	0.035		0.071	
$Froude_2$ =	0.35		0.25	

	New 100-Yr. Channel		Mature 100-Yr. Channel	
D_{100} =	1.91	feet	2.43	feet
B_{100} =	3.0	feet	3.0	feet
T_{100} =	12.5	feet	15.1	feet
V_{100} =	3.24	fps	2.18	fps
n_{100} =	0.035		0.060	
$Froude_{100}$ =	0.47		0.32	

5. Grade Control Structures: Number required — 5 number

6. Toe Protection
   Due to narrow channel bottom, provide soil riprap across width. — 1.75 soil riprap thickness (feet)

7. Vegetation

- [x] Wetland Seeding
- [ ] Wetland Plugs
- [x] Willow Stakes
- [ ] Other (Describe):

8. Maintenance Access: Describe access along channel. — reinforced grass maintenance trail parallel to channel

Notes:

Permeable Pavement Systems T-10

Description

The term *Permeable Pavement System*, as used in this manual, is a general term to describe any one of several pavements that allow movement of water into the layers below the pavement surface. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the water quality capture volume (WQCV), and reduce effective imperviousness. Use of permeable pavements is a common Low Impact Development (LID) practice and is often used in combination with other BMPs to provide full treatment and slow release of the WQCV. A number of installations within the UDFCD boundary have also been designed with an increased depth of aggregate material in order to provide storage for storm events in excess of the water quality (80th percentile) storm event. This requires some additional design considerations, which are discussed within this BMP Fact Sheet.

Photograph PPS-1. The reservoir layer of a permeable pavement provides storage volume for the WQCV. Photo courtesy of Muller Engineering and Jefferson County Open Space.

Permeable Pavement	
Functions	
LID/Volume Red.	Yes
WQCV	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Good
Total Metals	Good
Bacteria	Unknown
Other Considerations	
Life-cycle Costs[4]	High[2]

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

[2] Does not consider the life cycle cost of the conventional pavement that it replaces.

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

This infiltrating BMP requires consultation with a geotechnical engineer when proposed near a structure. In addition to providing the pavement design, a geotechnical engineer can assist with evaluating the suitability of soils, identifying potential impacts, and establishing minimum distances between the BMP and structures.

Permeable pavement systems provide an alternative to conventional pavement in pedestrian areas and lower-speed vehicle areas. They are not appropriate where sediment-laden runoff could clog the system (e.g., near loose material storage areas).

This BMP is not appropriate when erosive conditions such as steep slopes and/or sparse vegetation drain to the permeable pavement. The sequence of construction is also important to preserve pavement infiltration. Construction of the pavement should take place only after construction in the watershed is complete.

For sites where land uses or activities can cause infiltrating stormwater to contaminate groundwater, special design requirements are required to ensure no-infiltration from the pavement section.

Permeable pavements and other BMPs used for infiltration that are located adjacent to buildings, hardscape or conventional pavement areas can adversely impact those structures if protection measures are not provided. Wetting of subgrade soil underlying those structures can cause the structures to settle or result in other moisture-related problems. Wetting of potentially expansive soils or bedrock can cause those materials to swell, resulting in structure movements. In general, a geotechnical engineer should evaluate the potential impact of the BMP on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. In addition, the following minimum requirements should be met:

- In locations where subgrade soils do not allow infiltration, the pavement section should include an underdrain system.
- Where infiltration can adversely impact adjacent structures, the filter layer should be underlain by an underdrain system designed to divert water away from the structure.
- In locations where potentially expansive soils or bedrock exist, placement of permeable pavement adjacent to structures and conventional pavement should only be considered if the BMP includes an underdrain designed to divert water away from the structure and is lined with an essentially impermeable geomembrane liner designed to restrict seepage.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in the BMP Maintenance chapter of this manual. During design and construction, the following should be considered to ensure ease of maintenance over the long-term:

- Hold a pre-construction meeting to ensure that the contactor has an understanding of how the pavement is intended to function. Discuss the contractor's proposed sequence of construction and look for activities that may require protection of the permeable pavement system.
- Ensure that the permeable pavement is protected from construction activities following pavement construction (e.g., landscaping operations). This could include covering areas of the pavement, providing alternative construction vehicle access, and providing education to all parties working on-site.
- Include an observation well to monitor the drain time of the pavement system over time. This will assist with determining the required maintenance needs. See Figure PPS-8.

Benefits

- Permeable pavement systems provide water quality treatment in an area that serves more than one purpose. The depth of the pavement system can also be increased to provide flood control.
- Permeable pavements can be used to reduce effective imperviousness or alleviate nuisance drainage problems.
- Permeable pavements benefit tree health by providing additional air and water to nearby roots.
- Permeable pavements are less likely to form ice on the surface than conventional pavements.
- Some permeable pavements can be used to achieve LEED credits.

Limitations

- Additional design and construction steps are required for placement of any ponding or infiltration area near or upgradient from a building foundation, particularly when potentially expansive soils exist. This is discussed in the design procedure section.
- In developing or otherwise erosive watersheds, high sediment loads can clog the facility.

- Call for construction fence on the plans around pervious areas where infiltration rates need to be preserved and could be reduced by compaction from construction traffic or storage of materials.

Example Construction Drawing Notes

- Excavation of subgrade shall not commence until after the pre-construction meeting.
- Subgrade shall be excavated using low ground pressure (LGP) track equipment to minimize over compaction of the subgrade. [1]
- Grading and compaction equipment used in the area of the permeable pavement should be approved by the engineer prior to use.
- Loose materials shall not be stored on the permeable pavement area.
- The contractor shall, at all times during and after system installation, prevent sediment, debris, and dirt from any source from entering the permeable pavement system.
- Placement of the wearing course shall be performed after fine grading and landscaping in adjacent areas is complete. If the wearing course becomes clogged due to construction activities, clean the surface with a vacuum machine to restore the infiltration rate after construction is complete.

[1] For partial and full infiltration sections only.

Design Procedure and Criteria

Note: This manual includes a variety of specific pavements, which are discussed and distinguished in supplemental BMP Fact Sheets T-10.1, T-10.2, etc. This BMP Fact Sheet outlines the design procedure and other design components and considerations that are common to all of the systems. Review of the supplemental Fact Sheets is recommended to determine the appropriate pavement for a specific site or use.

1. **Subsurface Exploration and Determination of a No-Infiltration, Partial Infiltration, or Full Infiltration Section**: Permeable pavements can be designed with three basic types of sections. The appropriate section will depend on land use and activities, proximity to adjacent structures and soil characteristics. Sections of each installation type are shown in Figure PPS-1.

    - **No-Infiltration Section**: This section includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils. Consider using this section when any of the following conditions exist:

        - Land use or activities could contaminate groundwater if stormwater is allowed to infiltrate.
        - Permeable pavement is located over potentially expansive soils or bedrock that could swell due to infiltration and potentially damage the permeable pavement system or adjacent structures (e.g., building foundation or conventional pavement).

- **Partial Infiltration Section**: This section does not include an impermeable liner, and allows some infiltration. Stormwater that does not infiltrate is collected and removed by an underdrain system.

- **Full Infiltration Section**: This section is designed to infiltrate the water stored in the voids of the pavement into the subgrade below. UDFCD recommends a minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours.

Subsurface Exploration and Testing for all Sections: A geotechnical engineer should scope and perform a subsurface study. Typical geotechnical investigation needed to select and design the pavement system for handling anticipated traffic loads includes:

- Prior to exploration review geologic and geotechnical information to assess near-surface soil, bedrock and groundwater conditions that may be encountered and anticipated ranges of infiltration rate for those materials. For example, if the site is located in a general area of known shallow, potentially expansive bedrock, a no-infiltration section will likely be required. It is also possible that this BMP may be infeasible, even with a liner, if there is a significant potential for damage to the pavement system or adjacent structures (e.g., areas of dipping bedrock).

- Drill exploratory borings or exploratory pits to characterize subsurface conditions beneath the subgrade and develop requirements for subgrade preparation. Drill at least one boring or pit for every 40,000 ft^2, and at least two borings or pits for sites between 10,000 ft^2 and 40,000 ft^2. The boring or pit should extend at least 5 feet below the bottom of the base, and at least 20 feet in areas where there is a potential of encountering potentially expansive soils or bedrock. More borings or pits at various depths may be required by the geotechnical engineer in areas where soil types may change, in low-lying areas where subsurface drainage may collect, or where the water table is likely within 8 feet below the planned bottom of the base or top of subgrade. Installation of temporary monitoring wells in selected borings or pits for monitoring groundwater levels over time should be considered where shallow groundwater that could impact the pavement system area is encountered.

- Perform laboratory tests on samples obtained from the borings or pits to initially characterize the subgrade, evaluate the possible section type, and to assess subgrade conditions for supporting traffic loads. Consider the following tests: moisture content (ASTM D 2216); dry density (ASTM D 2936); Atterberg limits (ASTM D 4318); gradation (ASTM D 6913); swell-consolidation (ASTM D 4546); subgrade support testing (R-value, CBR or unconfined compressive strength); and hydraulic conductivity. A geotechnical engineer should determine the appropriate test method based on the soil type.

- For sites where a full infiltration section may be feasible, perform on-site infiltration tests using a double-ring infiltrometer (ASTM D 3385). Perform at least one test for every 160,000 ft^2 and at least two tests for sites between 40,000 ft^2 and 160,000 ft^2. The tests should be located near completed borings or pits so the test results and subsurface conditions encountered in the borings can be compared, and at least one test should be located near the boring or pit showing the most unfavorable infiltration condition. The test should be performed at the planned top of subgrade underlying the permeable pavement system, and that subgrade should be prepared similar to that required for support of the permeable pavement system.

- Be aware that actual infiltration rates are highly variable dependent on soil type, density and moisture content and degree of compaction as well as other environmental and construction influences. Actual rates can differ an order of magnitude or more from those indicated by

infiltration or permeability testing. Selection of the section type should be based on careful assessment of the subsurface exploration and testing data.

2. **Required Storage Volume**: Provide the WQCV based on a 12-hour drain time.

   - Find the required WQCV (watershed inches of runoff). Using the effective impervious area of the watershed area, use Figure 3-2 located in Chapter 3 to determine the WQCV based on a 12-hour drain time. The maximum recommended ratio for tributary impervious area to permeable pavement area is 2.0. Higher loading is not recommended, as it may increase the required maintenance interval.

   - Calculate the design volume as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation PPS-1}$$

     Where:

     A = watershed area tributary to the permeable pavement (ft^2)

     V = design volume (ft^3)

   - Add flood control volume if desired. When designing for flood control volumes, provide an overflow that will convey runoff in excess of the WQCV directly into the reservoir. A gravel strip or inlet that is connected to the reservoir can provide this overflow.

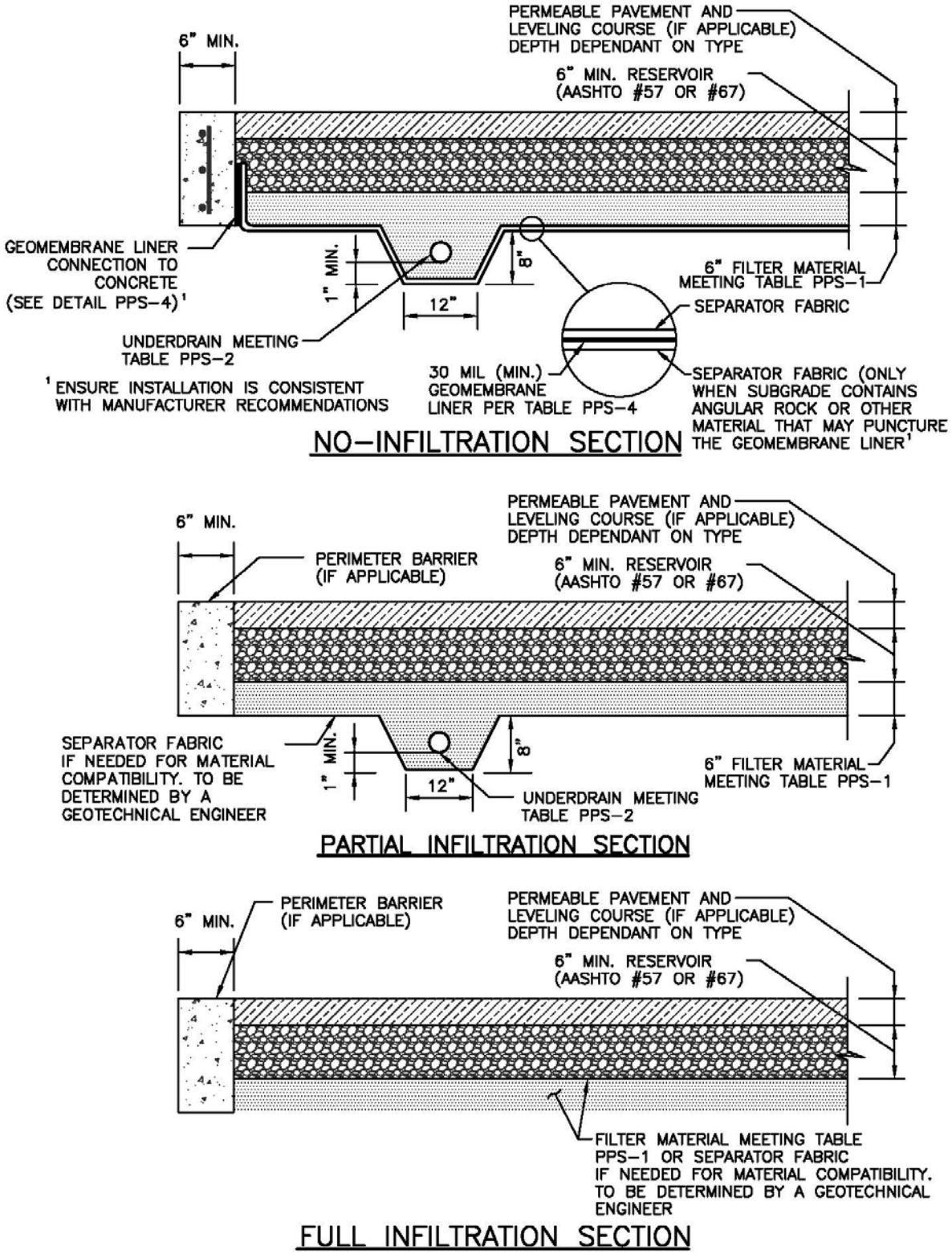


Figure PPS-1. Permeable Pavement Sections

3. **Depth of Reservoir**: The minimum recommended depth of AASHTO No. 57 or No. 67 coarse aggregate is 6 inches. Additional depth may be required to support anticipated loads or to provide additional storage, (i.e., for flood control). This material should have all fractured faces. UDFCD recommends that void storage be calculated only for the reservoir, assuming the aggregate filter layer is saturated. With the exception of porous gravel pavement, use a porosity of 40% or less for both No. 57 and No. 67 coarse aggregate. For porous gravel pavement use a porosity of 30% or less to account for reduced volume due to sediment. Porous gravel pavements typically allow greater sediment volumes to enter the pavement. See Figures PPS-2 and PPS-3 for alternative pavement profiles. Calculate available storage using equation PPS-2 for a flat subgrade installation, and PPS-3 for a sloped subgrade installation. These equations allow for one inch of freeboard. Flat installations are preferred as the design spreads infiltration evenly over the subgrade. For sloped subgrade installations, the increased storage depth located upstream of the lateral barrier (see step 7) can increase lateral movement (parallel to the flow barrier) of water into areas adjacent to the pavement section.

   When used for vehicular traffic, a pavement design should be performed by a qualified engineer experienced in the design of permeable pavements and conventional asphalt and concrete pavements. The permeable pavement should be adequately supported by a properly prepared subgrade, properly compacted filter material and reservoir material.

   Reservoir aggregate should have all fractured faces. Place the aggregate in 6-inch (maximum) lifts, compacting each lift by using a 10-ton, or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.

   - For flat or stepped installations (0% slope at the reservoir/subgrade interface):

$$V = P\left[\frac{D-1}{12}\right]A \qquad \text{Equation PPS-2}$$

   Where:

   V = volume available in the reservoir (ft^3)

   P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

   D = depth of reservoir (in)

   A = area of the permeable pavement (ft^2)

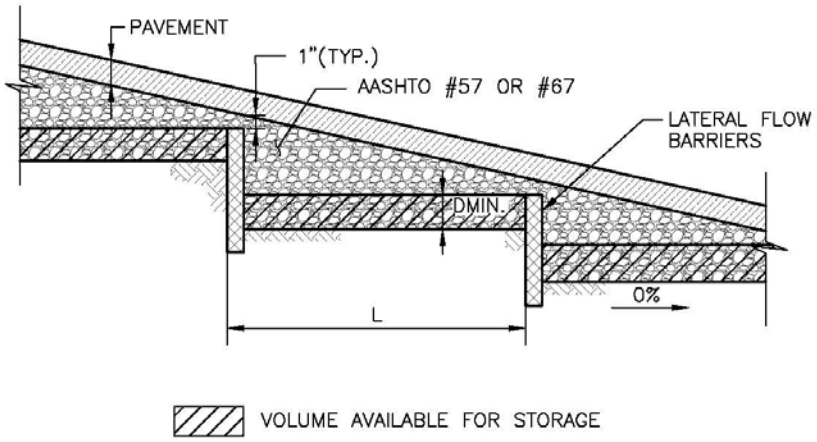


Figure PPS-2. Permeable Pavement Profile, Stepped Installation

- For sloped installations (slope of the reservoir/subgrade interface > 0%):

$$V = P\left[\frac{D - 6sL - 1}{12}\right]A \qquad \text{Equation PPS-3a}$$

While:

$$L < \frac{2\,\text{WQCV}}{sAP} \qquad \text{Equation PPS-3b}$$

Where:

V = volume available in the reservoir (ft^3)

P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

s = slope of the reservoir/subgrade interface (ft/ft)

D = depth of the reservoir (in)

L = length between lateral flow barriers (see step 4) (ft)

A = area of the permeable pavement (ft^2)

WQCV = water quality capture volume (ft^3)

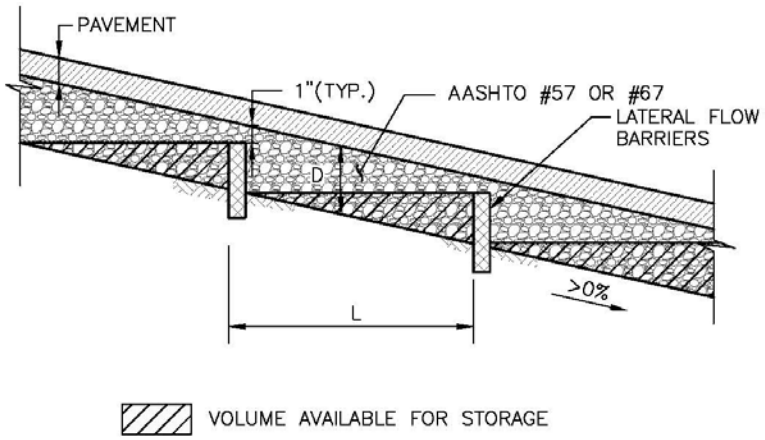


Figure PPS-3. Permeable Pavement Profile, Sloped Installation.

4. **Lateral Flow Barriers:** Construct lateral flow cutoff barriers using concrete walls or a 30 mil (minimum) PVC geomembrane. Lateral flow barriers should be placed parallel to contours (normal to flow). This will preserve the volume available for storage and ensure that stormwater will not resurface, washing out infill material. See Figure PPS-6 and Table PPS-4 when using a PVC geomembrane for this purpose. Also include a separator fabric, per Table PPS-3, between the geomembrane and all aggregate materials. Lateral flow barriers should be installed in all permeable pavement installations that have a reservoir/subgrade interface greater than zero percent. Lateral flow barriers should be spaced, as necessary, to satisfy equations PPS-3a and PPS-3b. One exception is reinforced grass pavement. Infill washout is not a concern with reinforced grass pavement.

5. **Perimeter Barrier:** For all no-infiltration sections, provide a reinforced concrete barrier on all sides of the pavement system. Perimeter barriers may also be recommended for other permeable pavement installations depending on the type or use of the pavement. For PICP and concrete grid pavement, a barrier is required to restrain movement of the pavers or grids. Precast, cast-in-place concrete or cut stone barriers are required for commercial vehicular areas. For residential use and commercial pedestrian use, a metal or plastic edge spiked with 3/8-inch-diameter, 10-inch-long nails provides a less expensive alternative for edge restraint.

   For all pavements, consider the section beyond the permeable pavement when evaluating the perimeter design. The perimeter barrier helps force water into the underdrain and reduces lateral flow of water. Lateral flow can negatively impact the adjacent conventional pavement section, structure, or embankment (especially when the subgrade is sloped). Also consider material separation. Consider construction of the interface between the permeable pavement and the adjacent materials and how the design will prevent adjacent materials from entering the permeable pavement section. Depending on the soils, depth of pavement, and other factors, this may be achieved with fabric or may require a more formalized barrier.

   When a permeable pavement section is adjacent to conventional pavement, a vertical liner may be required to separate the reservoir of the permeable pavement system from dense-graded aggregates and soils within the conventional pavement. An impermeable linear can be used to provide this vertical barrier and separate these two pavement systems.

   No-Infiltration Section: For this type of section, the perimeter barrier also serves to attach the impermeable membrane. The membrane should extend up to the top of the filter layer and be firmly

attached to the concrete perimeter barrier using batten bars to provide a leak-proof seal. A nitrile-based vinyl adhesive can be used when the need for an impermeable liner is less critical. See Figures PPS-4 and PPS-5 for installation details. For ease of construction, including the placement of geotextiles, it is suggested that the barrier extend to the bottom of the filter layer.

Partial and Full Infiltration Section: The perimeter barrier for these sections also restricts lateral flow to adjacent areas of conventional pavement or other structures where excessive moisture and/or hydrostatic pressure can cause damage. When this is of particular concern, the perimeter barrier should be extended to a depth 12 inches or more below the underdrain. Otherwise, extend the barrier to the bottom of the filter layer.

6. **Filter Material and Underdrain System**: An aggregate filter layer and underdrain are required for all partial and no-infiltration sections. Without this filter layer, the section will not provide adequate pollutant removal. This is based on research performed by UDFCD monitoring sites with and without this component. A filter or separator fabric may also be necessary under the reservoir in a full infiltration section if the subgrade is not filter compatible with the reservoir material such that finer subgrade soils could enter into the voids of the reservoir.

   In previous versions of the USDCM, UDFCD recommended that the underdrain be placed in an aggregate drainage layer and that a geotextile separator fabric be placed between this drainage and the filter layer. This version of the USDCM replaces that fabric, which could more easily plug or be damaged during construction, with aggregate filter material that is filter-compatible with the reservoir, and a drainpipe with perforations that are filter-compatible with the filter material. This eliminates the need for a separator fabric between the reservoir and the underdrain layer. The filter material provided below should only be used with the underdrain pipe specified within this section.

   The underdrain should be placed below a 6-inch-thick layer of CDOT Class B or C filter material meeting the gradation in Table PPS-1. Extend the filter material around and below the underdrain as shown in Figure PPS-1.

   Provide clean-outs to allow inspection (by camera) of the drainpipe system during and after construction to ensure that the pipe was not crushed or disconnected during construction and to allow for maintenance of the underdrain.

   Use of Class B or C Filter material with a slotted PVC pipe that meets the slot dimensions provided in Table PPS-2 will eliminate the need for an aggregate layer wrapped geotextile fabric.

Design Opportunity

Pollutant removal occurs in the filter material layer of the section. The basic permeable pavement section may be considered with other wearing courses to provide water quality as long as:

- the filter layer is included in the section,
- the wearing course provides adequate permeability, and
- the new section does not introduce new pollutants to the runoff.

Table PPS-1. Gradation Specifications for Class B and C Filter Material (Source: CDOT Table 703-7)

Sieve Size	Class B Mass Percent Passing Square Mesh Sieves	Class C Mass Percent Passing Square Mesh Sieves
37.5mm (1.5")	100	
19.0 mm (3/4")		100
4.75 mm (No. 4)	20-60	60 – 100
1.18 µm (No. 16)	10-30	
300 µm (No. 50)	0-10	10 – 30
150 µm (No. 100)		0 – 10
75 µm (No. 200)	0-3	0 - 3

Table PPS-2. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4"	1-1/16"	0.032"	0.413"	1.90 in^2
6"	1-3/8"	0.032"	0.516"	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

Compact the filter layer using a vibratory drum roller or plate. The top of each layer below the leveling course must be uniform and should not deviate more than a ½ inch when a 10-foot straight edge is laid on its surface. The top of the leveling course should not deviate more than 3/8 inch in 10 feet.

7. **Impermeable Geomembrane Liner and Geotextile Separator Fabric:** For no-infiltration sections, install a 30 mil (minimum) PVC geomembrane liner, per Table PPS-4, on the bottom and sides of the basin, extending up at least to the top of the filter layer. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration. The geomembrane should be field-seamed using a dual track welder, which allows for non-destructive testing of almost all field seams. A small amount of single track and/or adhesive seaming should be allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs. The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. Place CDOT Class B geotextile separator fabric, per Table PPS-3, above the geomembrane to protect it from being punctured during the placement of the filter material above the liner. If the subgrade contains angular rocks or other material that could puncture the geomembrane, smooth-roll the surface to create a suitable surface. If smooth-rolling the surface does not provide a suitable surface, also place the separator fabric between

the geomembrane and the underlying subgrade. This should only be done when necessary because fabric placed under the geomembrane can increases seepage losses through pinholes or other geomembrane defects. Connect the geomembrane to perimeter concrete walls around the basin perimeter, creating a watertight seal between the geomembrane and the walls using a continuous batten bar and anchor connection (see Figure PPS-5). Where the need for the impermeable membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Use watertight PVC boots for underdrain pipe penetrations through the liner (see Figure PPS-4).

Table PPS-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction
[2] As measured in accordance with ASTM D 4632

Table PPS-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m^2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

8. **Outlet**: The portion of the WQCV in each cell should be slowly released to drain in approximately 12 hours. An orifice at the outlet of the underdrain can be used for each cell to provide detention and slow release of the WQCV to offset hydromodification. Use a minimum orifice size of 3/8 inch to avoid clogging. If lateral walls are required, each cell should be considered a separate system and be controlled independently. See Figure PPS-6 for underdrain system layout and outlet details showing a multi-cell configuration. Equations PPS-4 and PPS-5 can be used to determine the depth of the WQCV within the pavement section (based either on the stepped/flat installation shown in Figure PPS-2 or the sloped installation shown in Figure PPS-3) and Equation PPS-6 can be used to size the WQCV orifice. If the design includes multiple cells, these calculations should be performed for each cell substituting WQCV and V_{Total} with the volumes provided in each cell. The UD-BMP workbook available at www.udfcd.org can be used when multiple cells are similar in area. The workbook assumes that the WQCV is distributed evenly between each cell.

   For calculating depth of the WQCV using a flat/stepped installation, see Figure PPS-2:

$$d = \frac{12\ \mathrm{WQCV}}{PA}$$ Equation PPS-4

   Where:

   d = depth of WQCV storage in the reservoir (in)

   P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

   A = area of permeable pavement system (ft^2)

   WQCV = water quality capture volume (ft^3)

   For calculating depth of the WQCV using a sloped installation, see Figure PPS-3:

$$d = 6\left[\frac{2\ \mathrm{WQCV}}{PA}\right] + \mathrm{sL}$$ Equation PPS-5

   Where:

   d = depth of WQCV storage in the reservoir (in)

   A = area of permeable pavement system (ft^2)

   s = slope of the reservoir/subgrade interface (ft/ft)

   L = length between lateral flow barriers (see step 4) (ft)

For calculating the diameter of the orifice for a 12-hour drain time (Use a minimum orifice size of 3/8 inch to avoid clogging.):

$$D_{12\text{ hour drain time}} = \sqrt{\frac{V}{1414\ y^{0.41}}} \qquad \text{Equation PPS-6}$$

Where:

D = diameter of the orifice to drain a volume in 12 hours (in)

Y = distance from the lowest elevation of the storage volume (i.e. the bottom of the reservoir) to the center of the orifice (ft)

V = volume (WQCV or the portion of the WQCV in the cell) to drain in 12 hours (ft^3)

Additional Design Considerations

Subgrade Preparation

Partial Infiltration and Full Infiltration Installations: The subgrade should be stripped of topsoil or other organics and either excavated or filled to the final subgrade level. Unnecessary compaction or over-compaction will reduce the subgrade infiltration rate. However, a soft or loosely compacted subgrade will settle, adversely impacting the performance of the entire permeable pavement system. The following recommendations for subgrade preparation are intended to strike a balance between those competing objectives:

- For sites, or portions thereof, requiring excavation to the final subgrade level, compaction of the subgrade may not be needed, provided that loose materials are removed from the excavation, and a firm subgrade is provided for the support of the pavement system. A geotechnical engineer should observe the prepared subgrade. Local soft areas should be excavated and replaced with properly compacted fill. As an alternative to excavating and replacing material, stabilization consisting of geogrid and compacted granular fill material can be used to bridge over the soft area. Fill material should be free draining and have a hydraulic conductivity significantly higher than the subgrade soil. Fill is typically compacted to a level equivalent to 95% Standard Proctor compaction (ASTM D 698). The designer should specify the level of compaction required to support the pavement system.

- For sites (or portions thereof), requiring placement of fill above the existing subgrade to reach the final subgrade level, the fill should be properly compacted. Specify the hydraulic conductivity for the material that is to be placed. This should be at least one order of magnitude higher than the native material. If the type or level of compaction of fill material available for construction is different than that considered in design, additional testing should be performed to substantiate that the design infiltration rate can be met. However, additional infiltrometer testing may not be necessary, provided that it can be demonstrated by other means that the compacted fill material is more permeable than that considered for design.

- Low ground pressure (LGP) track equipment should be used within the pavement area to limit over-compacting the subgrade. Wheel loads should not be allowed.

No-Infiltration Sections: Unless otherwise indicated by the geotechnical engineer, the subgrade for this section should be scarified and properly compacted to support the liner and pavement system. A level of compaction equivalent to 95% of the Standard Proctor density (ASTM D 698) is typically used. The designer should specify the level of compaction. No-infiltration sections should be smooth rolled with a roller compactor, and the prepared subgrade surface should be free of sharp objects that could puncture the liner. Both the designer and the liner installer should inspect the subgrade for acceptance prior to liner placement.

Filter and Reservoir Layer Compaction

Filter material placed above the prepared subgrade should be compacted to a relative density between 70% and 75% (ASTM D4253 and ASTM D4254) using a walk-behind vibratory roller, vibratory plate compactor or other light compaction equipment. Do not over-compact; this will limit unnecessary infiltration into the underlying subgrade. The reservoir layer may not be testable for compaction using a method based on specified density (e.g., nuclear density testing). The designer should consider a method specification (e.g., number of passes of a specified vibratory compactor) for those materials. The number of passes appropriate is dependent on the type of equipment and depth of the layer.

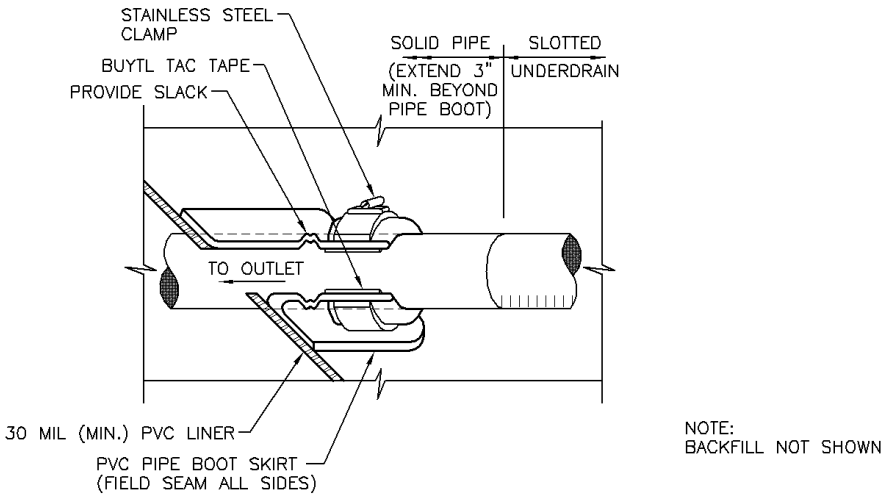


Figure PPS-4. Geomembrane Liner/Underdrain Penetration Detail

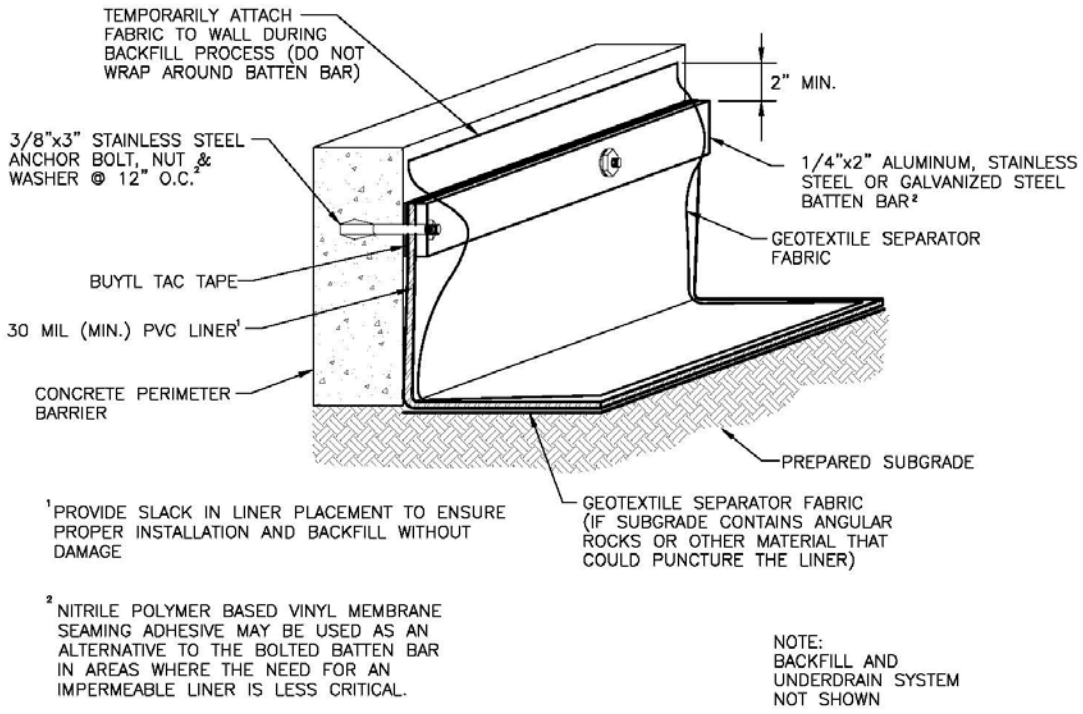


Figure PPS-5. Geomembrane Liner/Concrete Connection Detail

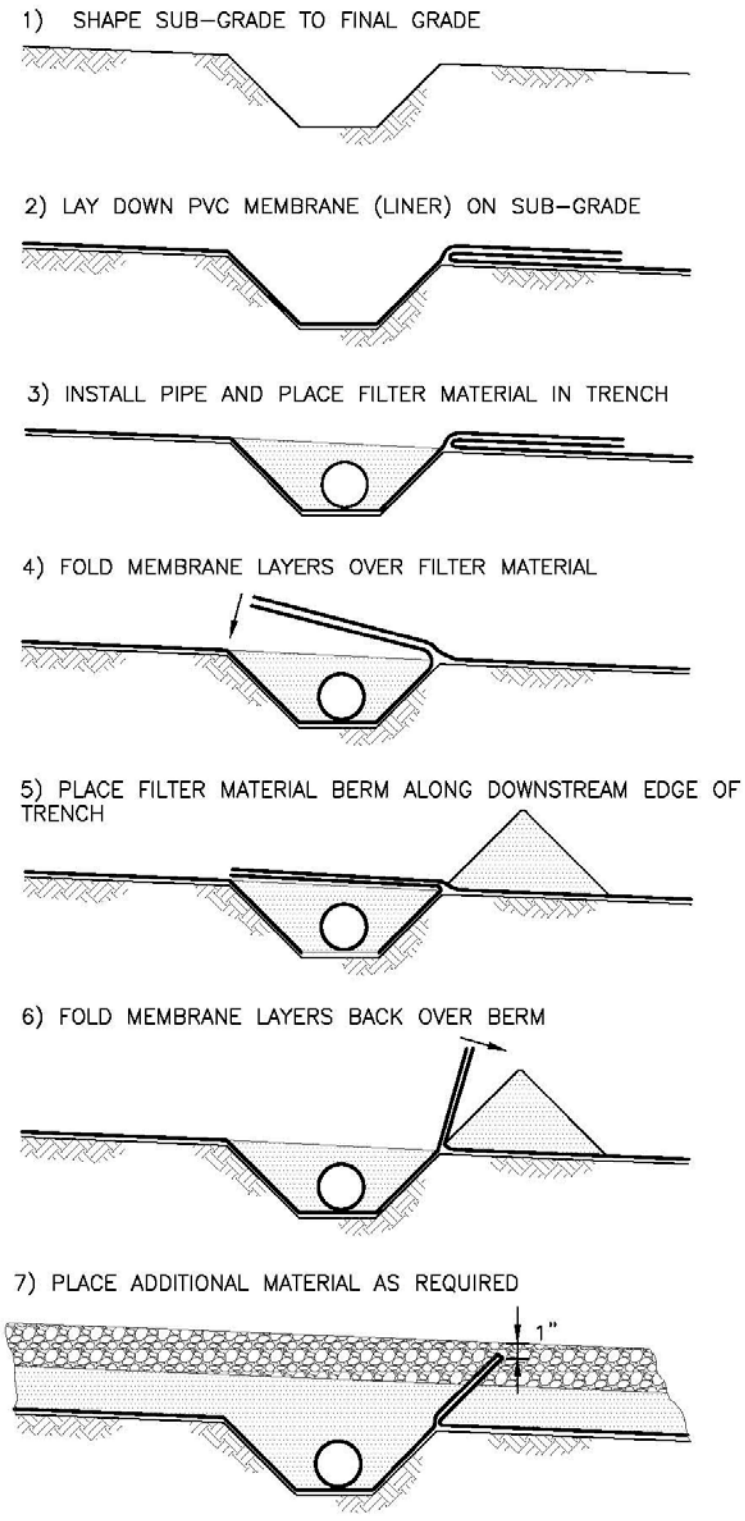


Figure PPS-6. Lateral Barrier Installation

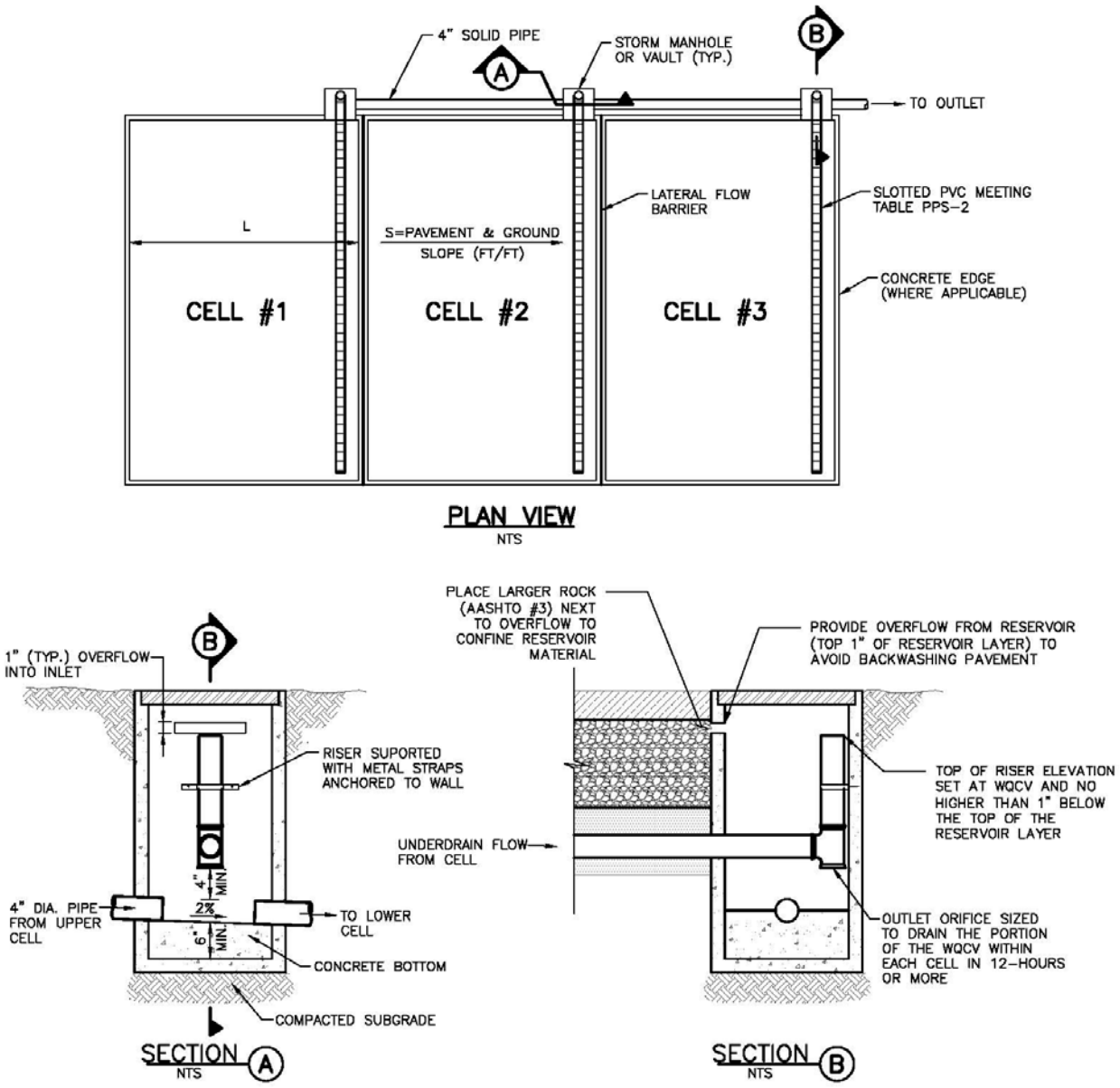


Figure PPS-7. Underdrain System Layout and Outlet Details

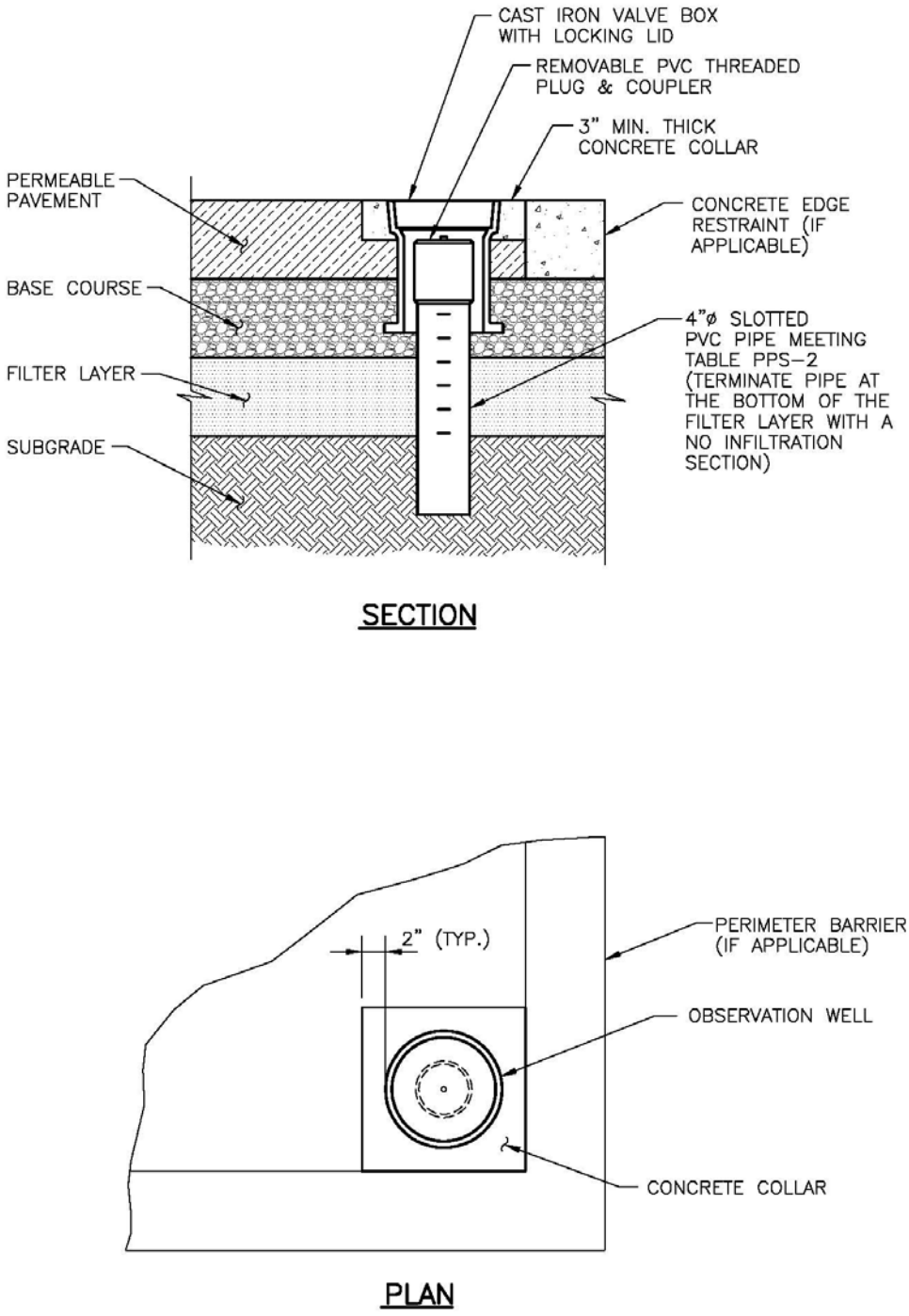


Figure PPS-8. Observation Well

Construction Considerations

Proper construction of permeable pavement systems requires measures to preserve natural infiltration rates (for full and partial infiltration sections) prior to placement of the pavement, as well as measures to protect the system from the time that pavement construction is complete to the end of site construction. Supplemental Fact Sheets on the specific pavements provide additional construction considerations. The following recommendations apply to all permeable pavement systems:

- Specify all aggregate, outside of the filter layer, be dry screened and the mass percent passing the No. 200 sieve be no more than one percent. This reduces sediment within the section. Observe aggregate on-site prior to placement to ensure it is free of excess sediment.
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner.
- Provide necessary quality assurance and quality control (QA/QC) when constructing an impermeable geomembrane liner system, including, but not limited to fabrication testing, destructive and non-destructive testing of field seams, observation of geomembrane material for tears or other defects, and air lace testing for leaks in all field seams and penetrations. QA/QC should be overseen by a professional engineer. Consider requiring field reports or other documentation from the engineer.
- Keep mud and sediment-laden runoff away from the pavement area.
- Temporarily divert runoff or install sediment control measures as necessary to reduce the amount of sediment run-on to the pavement.
- Cover surfaces with a heavy impermeable membrane when construction activities threaten to deposit sediment onto the pavement area.

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Permeable Pavement Systems (PPS)

Designer:	**G. Frazer**
Company:	**BMP Inc.**
Date:	**November 29, 2010**
Project:	**Shops at 56th Ave.**
Location:	**SE corner of 56th Ave. and 83rd St.**

1. Type of Permeable Pavement Section

A) What type of section of permeable pavement is used? (Based on the land use and activities, proximity to adjacent structures and soil characteristics.)

Choose One
- ○ No Infiltration
- ◉ Partial Infiltration Section
- ○ Full Infiltration Section

B) What type of wearing course?

Choose One
- ◉ PICP
- ○ Concrete Grid Pavement
- ○ Pervious Concrete
- ○ Porous Gravel

2. Required Storage Volume

A) Effective Imperviousness of Area Tributary to Permeable Pavement, I_a — I_a = 65.0 %

B) Tributary Area's Imperviousness Ratio ($I = I_a / 100$) — i = 0.650

C) Tributary Watershed Area (including area of permeable pavement system) — A_{Total} = 55,000 sq ft

D) Area of Permeable Pavement System (Minimum recommended permeable pavement area = 13491 sq ft) — A_{PPS} = 15,000 sq ft

E) Impervious Tributary Ratio (Contributing Imperviuos Area / Permeable Pavement Ratio) — R_T = 1.7

F) Water Quality Capture Volume (WQCV) Based on 12-hour Drain Time ($WOCV = (0.8 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i) / 12) * Area$) — WQCV = 932 cu ft

G) Is flood control volume being added?

Choose One
- ◉ YES
- ○ NO

Provide overflow to carry runoff directly into the reservoir layer to ensure use of flood control volume regardless of infiltration rates.

H) Total Volume Needed — V_{Total} = 6,340 cu ft

3. Depth of Reservoir

A) Minimum Depth of Reservoir (Minimum recommended depth is 6 inches) — D_{min} = 18.0 inches

B) Is the slope of the reservoir/subgrade interface equal to 0%?

Choose One
- ◉ YES- Flat or Stepped Installation
- ○ NO- Sloped Installation

C) Porosity (Porous Gravel Pavement ≤ 0.3, Others ≤ 0.40) — P = 0.40

D) Slope of the Base Course/Subgrade Interface — S = _____ ft / ft

E) Length Between Lateral Flow Barriers — L = _____ ft

F) Volume Provided Based on Depth of Base Course
Flat or Stepped: $V = P * ((D_{min-1})/12) * Area$
Sloped: $V = P * [(D_{min} - (D_{min} - 6*SL-1)) / 12] * Area$ — V = 8,500 cu ft

4. Lateral Flow Barriers

A) Type of Lateral Flow Barriers

Choose One
- ○ Concrete Walls
- ○ PVC geomembrane installed normal to flow
- ◉ N/A- Flat installation
- ○ Other (Describe):

B) Number of Permeable Pavement Cells — Cells = 1

5. Perimeter Barrier

A) Is a perimeter barrier provided on all sides of the pavement system? (Recommeded for PICP, concrete grid pavement, or for any no-infiltration section.)

Choose One
- ◉ YES
- ○ NO

Design Procedure Form: Permeable Pavement Systems (PPS)

Sheet 2 of 2

Designer: G. Frazer
Company: BMP Inc.
Date: November 29, 2010
Project: Shops at 56th Ave.
Location: SE corner of 56th Ave. and 83rd St.

6. Filter Material and Underdrain System	
A) Is the underdrain placed below a 6-inch thick layer of CDOT Class C filter material?	Choose One: (●) YES ( ) NO ( ) N/A
B) Diameter of Slotted Pipe (slot dimensions per Table PPs-2)	Choose One: (●) 4-inch ( ) 6-inch
C) Distance from the Lowest Elevation of the Storage Volume (i.e. the bottom of the base course to the center of the orifice)	y = 3.8 ft
7. Impermeable Geomembrane Liner and Geotextile Separator Fabric	
A) Is there a minimum 30 mil thick impermeable PVC geomembrane liner on the bottom and sides of the basin, extending up to the top of the base course?	Choose One: ( ) YES (●) NO
B) CDOT Class B Separator Fabric	Choose One: ( ) Placed above the liner ( ) Placed above and below the liner
8. Outlet (Assumes each cell has similar area, subgrade slope, and length between lateral barriers (unless subgrade is flat). Calculate cells individually where this varies.)	
A) Depth of WQCV in the Reservoir (Elevation of the Flood Control Outlet)	D_{WQCV} = 1.86 inches
B) Diameter of Orifice for 12-hour Drain Time (Use a minimum orifice diameter of 3/8-inches)	$D_{Orifice}$ = 0.62 inches

Notes:

Permeable Interlocking Concrete Pavement T-10.1

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Permeable Interlocking Concrete Pavement (PICP) is one of several different types of permeable pavement systems contained within Volume 3. In previous versions of this manual, PICP was referred to as *cobblestone block pavement*. The PICP wearing course consists of concrete blocks that, when placed together, create spaces between the blocks where runoff can enter the pavement. Typically, the blocks contain ridges along the sides that both create these spaces and help ensure that the blocks are installed correctly. The spaces between the blocks are filled with aggregate. Depending on the manufacturer, these spaces should provide an open surface that is between 5 and 15% of the pavement surface. Figure PICP-1 provides a pavement section.

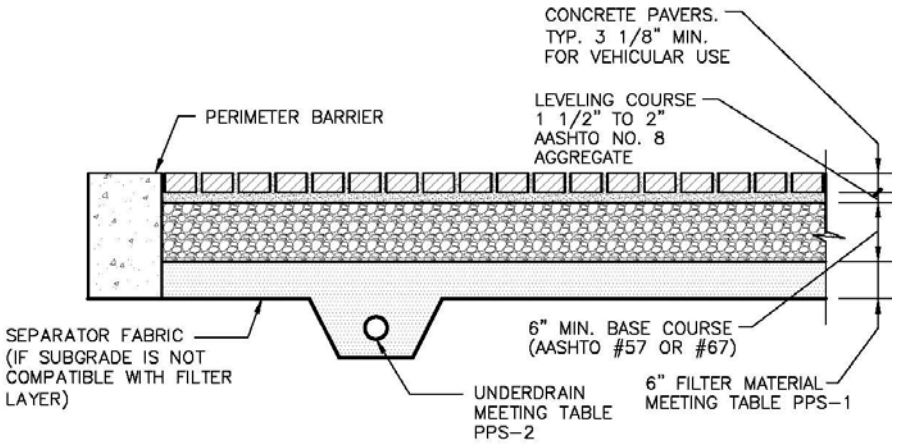
Photograph PICP-1. PICP in downtown Ft. Morgan, CO. Photo courtesy of SEH and the City of Ft. Morgan.

Site Selection

PICP is appropriate for areas with low to high traffic volume and lower vehicle speeds. Applications include:

- Intersections,
- Parking lots,
- Residential streets,
- Sidewalks/pedestrian areas,
- Emergency vehicle and fire access lanes, and
- Equipment storage areas.

See additional details on Fact Sheet T-10.



NOTES:

1. THIS SECTION IS DESIGNED FOR PARTIAL INFILTRATION AS DESCRIBED IN BMP FACT SHEET T-10. SEE FIGURE PPS-1 FOR MODIFICATIONS FOR USE WITH NO INFILTRATION OR FULL INFILTRATION SECTIONS.
2. A PAVEMENT DESIGN SHOULD BE PERFORMED IN AREAS OF VEHICULAR USE.

Figure PICP-1. PICP Pavement Section

T-10.1 Permeable Interlocking Concrete Pavement

Use the herring bone pattern shown in Photo PICP-1 and units with an overall length to thickness (aspect) ratio of three or less for vehicular applications. When ADA accessibility is needed, select units with a maximum opening of 0.5 inches.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- The outer edge of any vehicular PICP area should be bordered by concrete. This can be a concrete ribbon or curb and gutter. Additionally, provide a line of uncut blocks adjacent to the concrete border. This will ensure that cut edges are not placed directly against the concrete border, which could cause damage to the paver at the interface with the concrete. This is often accomplished by specifying a sailor course (see photo PICP-1) or soldier course (see photo PICP-2) adjacent to the concrete edge.

Benefits

- Provides traffic calming benefits.
- Can be placed back if utility cuts or other patches are required.
- Maintains infiltration rates well.
- Provides flexibility in design options such as color and patterns.
- Can be ADA compliant.

Limitations

- Capital costs are generally more expensive than some other permeable pavement systems.

- Specify that all cut pavers used must be at least 40% of its full, uncut size when subject to vehicular use. This criterion can be easily met, although it occasionally requires a slight modification to the paver pattern in construction. See photo PICP-2.
- Use units with an overall length to thickness (aspect) ratio of three or less for vehicular applications. Units with aspect ratios between three and four may be used in pedestrian areas or in areas with limited automobile use (e.g., residential driveways) (ICPI Tech Spec No. 10).
- Specify a herringbone pattern for areas intended for vehicular traffic. This provides greater structural support.

Photograph PICP-2. The very small cut paver shown in this photo could have been eliminated by rotating the paver above it 90 degrees

Paver Placement

Where cutting pavers can be avoided, there is often a savings of time and cost. Additionally, the integrity of the paver is preserved. Photos PICP-3, 4, and 5 show good examples for incorporating markings into the pavement with and without cutting paver blocks.

Photograph PICP-3. Parking spaces can be clearly delineated without cutting the pavers. Photo courtesy of Bill Wenk.

Photograph PICP-4. The pattern used allows both parking spaces and the crosswalk to be delineated with minimal cutting of pavers. Photo courtesy SEH and the City of Ft. Morgan.

Photograph PICP-5. Pavers can also be painted just like conventional pavement. Photo courtesy of SEH and the City of Ft. Morgan.

Photograph PICP-6. Mechanical placement in larger areas can reduce the unit cost of the pavement. Photo courtesy of Muller Engineering and Jefferson County Open Space**.**

Local Installation

The City of Greenwood Village decided to replace their concrete patio at the employee entrance of City Hall with PICP citing the following issues with the former concrete patio:

- The patio had little positive drainage.
- Roof drains discharged directly onto the patio.
- Snowmelt caused icing and a safety issue.
- Freeze/thaw cycles were rapidly deteriorating the existing concrete creating tripping hazards.

The patio has been in place since November 2008. To date, the City lists the following benefits:

- The patio dries quickly with no ponding or refreezing.
- Water moves quickly through the pavement rather than sheet flowing over the entire length of the walkway.
- City staff describe maintenance of the patio as "minimal." Discussions with building maintenance staff were held to get assistance with debris removal and to ensure that sanding for ice control was eliminated.

Photograph PICP-7. City staff demonstrate the infiltration capacity of PICP at the Greenwood Village City Hall.

Photograph PICP-8. The limits of wetting remain the same after multiple demonstrations.

T-10.1 Permeable Interlocking Concrete Pavement

References

Interlocking Concrete Pavement Institute (ICPI), Contractor Focus PICP Construction Tips. *Interlocking Concrete Pavement Magazine* vol. 17, no. 2, pp. 16-22, May 2010.

Interlocking Concrete Pavement Institute (ICPI). 2008. *Permeable Interlocking Concrete Pavement: A Comparison Guide to Porous Asphalt and Pervious Concrete.* www.icpi.org

Interlocking Concrete Pavement Institute (ICPI). 2007. *Permeable Interlocking Concrete Pavements: Selection, Design, Construction, Maintenance*. www.icpi.org

Interlocking Concrete Pavement Institute (ICPI). 2004. *ICPI Tech Spec No. 10.* www.icpi.org

Concrete Grid Pavement T-10.2

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Concrete grid pavement is one of several different types of permeable pavement systems described in Volume 3. Previous versions of the manual referred to this pavement as *modular block pavement*. This pavement consists of concrete block units with large openings (at least 20% of the total surface area) that are filled with free draining material. Figure CGP-1 provides a pavement section.

Photograph CGP-1. Concrete grid pavement installation in a parking area. The concrete segments along the perimeter of this installation showed wear that could have been mitigated with a concrete perimeter barrier.

Site Selection

Concrete grid pavement is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Overflow parking areas,
- Access/maintenance roads,
- Emergency vehicle and fire access lanes, and
- Equipment storage areas.

See additional details on Fact Sheet T-10.

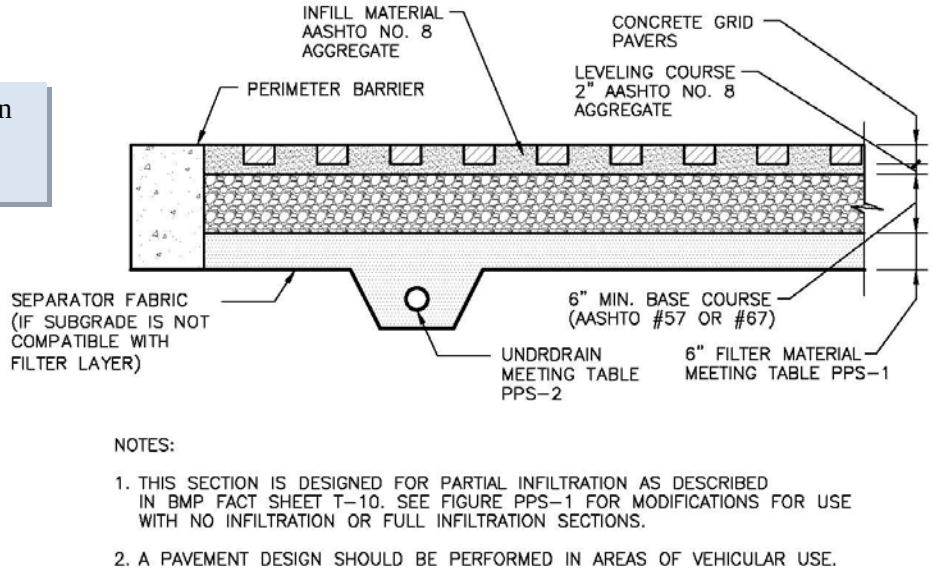


Figure CGP-1. Concrete Grid Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- A concrete perimeter is recommended for this pavement. This will reduce movement and grinding between blocks.

Local Installation

The concrete grid pavement parking site was one of UDFCD's first stormwater monitoring sites. This site was constructed in 1994 and monitored with and without a layer of ASTM C-33 sand to provide filtration. Through our work at this site and the data collected, UDFCD learned the following:

Benefits

- Concrete blocks can be removed and replaced back if utility cuts or other patches are required.
- Concrete grid pavement maintains infiltration rates well.

Limitations

- Concrete Grid Pavement does not meet ADA requirements for accessible paths.

- A filter layer (such as ASTM C-33 sand or CDOT Class C filter material) is required to achieve adequate pollutant removal.
- A concrete perimeter barrier will increase the lifespan of the concrete blocks.
- Concrete blocks can be removed and reused.

Photograph CGP-2. The Lakewood concrete grid pavement installation was one the first permeable pavement stormwater monitoring sites constructed by UDFCD. This photo was taken following construction in 1994.

Pervious Concrete T-10.3

This BMP Fact Sheet was removed in January 2013. UDFCD does not recommend pervious concrete at this time. Additional information is provided in a memorandum available at www.udfcd.org (Ken MacKenzie, January 2013)

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Porous gravel is one of several different types of permeable pavement systems contained within Volume 3. This BMP can be used in place of conventional gravel paving and is well suited for industrial applications that do not pose contamination risks to groundwater. Figure PG-1 provides a typical pavement section of porous gravel.

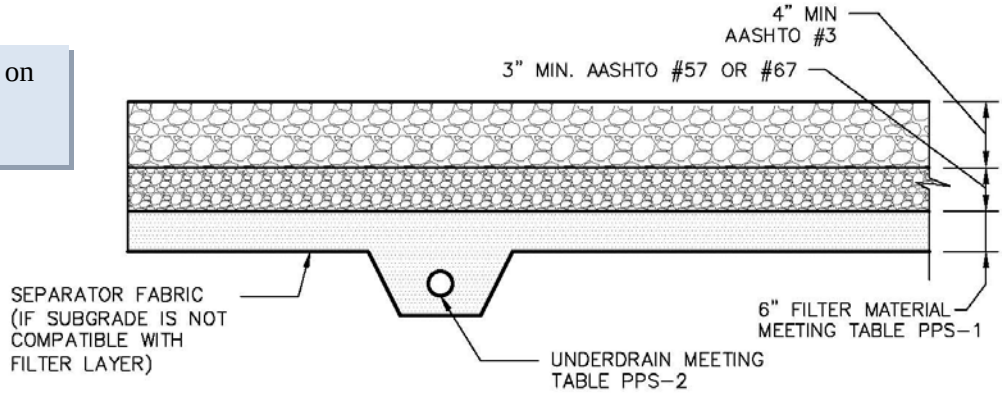
Photograph PG-1. This Denver installation of porous gravel provides volumetric treatment of the WQCV as well as a material storage area.

Site Selection

Porous gravel is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Parking lots,
- Driveways,
- Storage yards, and
- Maintenance roads.

See additional details on Fact Sheet T-10.



NOTES:

1. THIS SECTION IS DESIGNED FOR PARTIAL INFILTRATION AS DESCRIBED IN BMP FACT SHEET T-10. SEE FIGURE PPS-1 FOR MODIFICATIONS FOR USE WITH NO INFILTRATION OR FULL INFILTRATION SECTIONS.
2. A PAVEMENT DESIGN SHOULD BE PERFORMED IN AREAS OF VEHICULAR USE.

Figure PG-1. Porous Gravel Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, consider the items provided on BMP Fact Sheet T-10 as well as the following:

- The surface of porous gravel pavement may rut more than desired. If this is a concern, consider an interlocking plastic cellular paving product (or similar product) to better stabilize the wearing course. Discussion on this product is provided in BMP Fact Sheet T-10.5 (Reinforced Grass).

Benefits

- Low cost compared to other permeable pavements.

Limitations

- Not ADA compliant.
- Ruts without stabilization.

Note: This permeable pavement system differs from others discussed in this manual. Rather than a pavement system designed to capture the WQCV, it is offered for the uses discribed within this Fact Sheet. Unlike Fact Sheets T-10.1 through T-10.4, this document is intended as a standalone document.

Description

Reinforced grass is one of several different types of permeable pavement systems contained within Volume 3. Reinforced grass is designed to have the appearance of grass turf while providing the stability of pavement. There are a number of reinforced grass products available. Different products provide varied levels of turf protection as well as pavement stability and can vary significantly in price. This BMP is frequently used to provide emergency vehicle access. It can also be used to stabilize an area adjacent to a roadway. Figure RG-1 provides a non-proprietary section for reinforced grass pavement.

Site Selection

Reinforced grass is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Roadway shoulder,
- Maintenance roads including BMP access ramps,
- Emergency vehicle access roads, and
- Infrequently used parking areas.

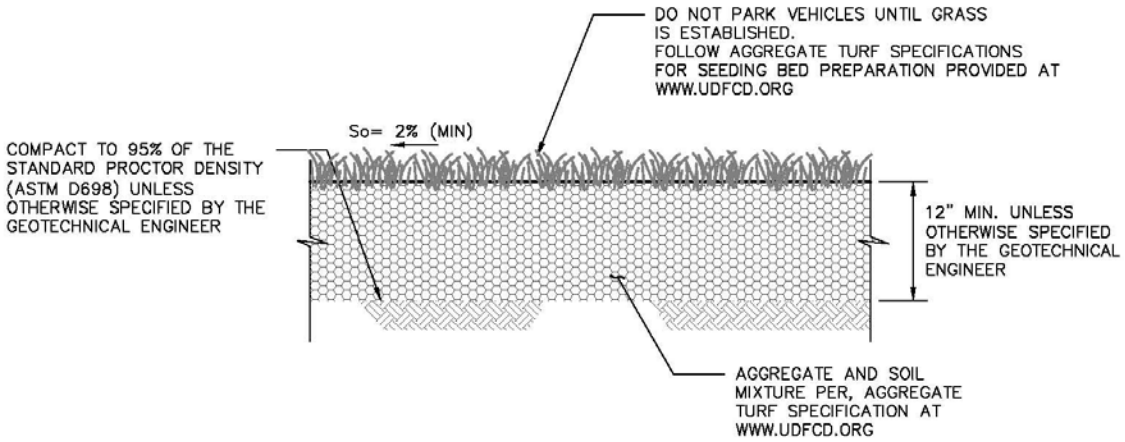


Figure RG-1. Aggregate Turf Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- For parking lot installations, consider a conventional pavement section in the drive aisles. These areas experience a higher volume of traffic.
- Irrigation requirements increase with frequency of use.

Benefits

- Reduces the heat island effect.

Limitations

- Requires irrigation.
- Not recommended when frequency of use exceeds two to three uses per space (for parking stalls) per week.

Selection Considerations

Figure RG-1 is adapted from the Federal Aviation Administration (FAA) section for *aggregate turf pavement*. In addition to this non-proprietary section, there are a number of products available under the name of *reinforced grass* or *turf pavement systems*. The most commonly used systems include:

- **Plastic Cellular Paving**: This category includes interlocking plastic pavers typically designed to be filled with turf or aggregate. This system allows for a high percentage of grass surface within the pavement area.
- **Concrete Cellular Paving**: This type of pavement consists either of interlocking pavers that have openings for the placement of grass or a similar cast-in-place system. Some systems include a reinforcement system that ties the pavers together providing greater protection from over-compaction and greater resistance to differential movement. Although some systems confine the grass area to the opening in the concrete, others are designed to provide the appearance of a fully vegetated landscape.

Consider the following variables when selecting a reinforced grass system:

- **Frequency of Use**: For more frequently used areas, it is important to select a system that protects the root system of the turf from compaction.
- **Appearance**: Concrete systems look different than plastic systems.
- **Vehicle Loading**: Emergency vehicle access roads may need to be designed for high loads but will be used infrequently.
- **Irrigation Expectations**: Some pavements rely, in part, on the turf for stability.
- **Optimum Drainage Capability**: Where soils allow for infiltration, select a product that will bridge the subgrade providing better protection from over-compaction.

Permeable Interlocking Concrete Pavement T-10.1

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Permeable Interlocking Concrete Pavement (PICP) is one of several different types of permeable pavement systems contained within Volume 3. In previous versions of this manual, PICP was referred to as *cobblestone block pavement*. The PICP wearing course consists of concrete blocks that, when placed together, create spaces between the blocks where runoff can enter the pavement. Typically, the blocks contain ridges along the sides that both create these spaces and help ensure that the blocks are installed correctly. The spaces between the blocks are filled with aggregate. Depending on the manufacturer, these spaces should provide an open surface that is between 5 and 15% of the pavement surface. Figure PICP-1 provides a pavement section.

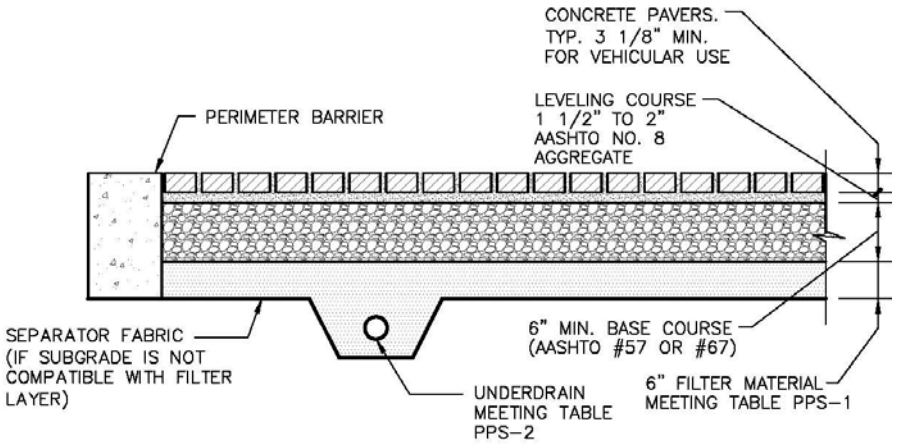
Photograph PICP-1. PICP in downtown Ft. Morgan, CO. Photo courtesy of SEH and the City of Ft. Morgan.

Site Selection

PICP is appropriate for areas with low to high traffic volume and lower vehicle speeds. Applications include:

- Intersections,
- Parking lots,
- Residential streets,
- Sidewalks/pedestrian areas,
- Emergency vehicle and fire access lanes, and
- Equipment storage areas.

See additional details on Fact Sheet T-10.



NOTES:

1. THIS SECTION IS DESIGNED FOR PARTIAL INFILTRATION AS DESCRIBED IN BMP FACT SHEET T-10. SEE FIGURE PPS-1 FOR MODIFICATIONS FOR USE WITH NO INFILTRATION OR FULL INFILTRATION SECTIONS.
2. A PAVEMENT DESIGN SHOULD BE PERFORMED IN AREAS OF VEHICULAR USE.

Figure PICP-1. PICP Pavement Section

T-10.1 Permeable Interlocking Concrete Pavement

Use the herring bone pattern shown in Photo PICP-1 and units with an overall length to thickness (aspect) ratio of three or less for vehicular applications. When ADA accessibility is needed, select units with a maximum opening of 0.5 inches.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- The outer edge of any vehicular PICP area should be bordered by concrete. This can be a concrete ribbon or curb and gutter. Additionally, provide a line of uncut blocks adjacent to the concrete border. This will ensure that cut edges are not placed directly against the concrete border, which could cause damage to the paver at the interface with the concrete. This is often accomplished by specifying a sailor course (see photo PICP-1) or soldier course (see photo PICP-2) adjacent to the concrete edge.

Benefits

- Provides traffic calming benefits.
- Can be placed back if utility cuts or other patches are required.
- Maintains infiltration rates well.
- Provides flexibility in design options such as color and patterns.
- Can be ADA compliant.

Limitations

- Capital costs are generally more expensive than some other permeable pavement systems.

- Specify that all cut pavers used must be at least 40% of its full, uncut size when subject to vehicular use. This criterion can be easily met, although it occasionally requires a slight modification to the paver pattern in construction. See photo PICP-2.
- Use units with an overall length to thickness (aspect) ratio of three or less for vehicular applications. Units with aspect ratios between three and four may be used in pedestrian areas or in areas with limited automobile use (e.g., residential driveways) (ICPI Tech Spec No. 10).
- Specify a herringbone pattern for areas intended for vehicular traffic. This provides greater structural support.

Photograph PICP-2. The very small cut paver shown in this photo could have been eliminated by rotating the paver above it 90 degrees

Paver Placement

Where cutting pavers can be avoided, there is often a savings of time and cost. Additionally, the integrity of the paver is preserved. Photos PICP-3, 4, and 5 show good examples for incorporating markings into the pavement with and without cutting paver blocks.

Photograph PICP-3. Parking spaces can be clearly delineated without cutting the pavers. Photo courtesy of Bill Wenk.

Photograph PICP-4. The pattern used allows both parking spaces and the crosswalk to be delineated with minimal cutting of pavers. Photo courtesy SEH and the City of Ft. Morgan.

Photograph PICP-5. Pavers can also be painted just like conventional pavement. Photo courtesy of SEH and the City of Ft. Morgan.

Photograph PICP-6. Mechanical placement in larger areas can reduce the unit cost of the pavement. Photo courtesy of Muller Engineering and Jefferson County Open Space**.**

Local Installation

The City of Greenwood Village decided to replace their concrete patio at the employee entrance of City Hall with PICP citing the following issues with the former concrete patio:

- The patio had little positive drainage.
- Roof drains discharged directly onto the patio.
- Snowmelt caused icing and a safety issue.
- Freeze/thaw cycles were rapidly deteriorating the existing concrete creating tripping hazards.

The patio has been in place since November 2008. To date, the City lists the following benefits:

- The patio dries quickly with no ponding or refreezing.
- Water moves quickly through the pavement rather than sheet flowing over the entire length of the walkway.
- City staff describe maintenance of the patio as "minimal." Discussions with building maintenance staff were held to get assistance with debris removal and to ensure that sanding for ice control was eliminated.

Photograph PICP-7. City staff demonstrate the infiltration capacity of PICP at the Greenwood Village City Hall.

Photograph PICP-8. The limits of wetting remain the same after multiple demonstrations.

T-10.1 Permeable Interlocking Concrete Pavement

References

Interlocking Concrete Pavement Institute (ICPI), Contractor Focus PICP Construction Tips. *Interlocking Concrete Pavement Magazine* vol. 17, no. 2, pp. 16-22, May 2010.

Interlocking Concrete Pavement Institute (ICPI). 2008. *Permeable Interlocking Concrete Pavement: A Comparison Guide to Porous Asphalt and Pervious Concrete.* www.icpi.org

Interlocking Concrete Pavement Institute (ICPI). 2007. *Permeable Interlocking Concrete Pavements: Selection, Design, Construction, Maintenance*. www.icpi.org

Interlocking Concrete Pavement Institute (ICPI). 2004. *ICPI Tech Spec No. 10.* www.icpi.org

Concrete Grid Pavement T-10.2

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Concrete grid pavement is one of several different types of permeable pavement systems described in Volume 3. Previous versions of the manual referred to this pavement as *modular block pavement*. This pavement consists of concrete block units with large openings (at least 20% of the total surface area) that are filled with free draining material. Figure CGP-1 provides a pavement section.

Photograph CGP-1. Concrete grid pavement installation in a parking area. The concrete segments along the perimeter of this installation showed wear that could have been mitigated with a concrete perimeter barrier.

Site Selection

Concrete grid pavement is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Overflow parking areas,
- Access/maintenance roads,
- Emergency vehicle and fire access lanes, and
- Equipment storage areas.

See additional details on Fact Sheet T-10.

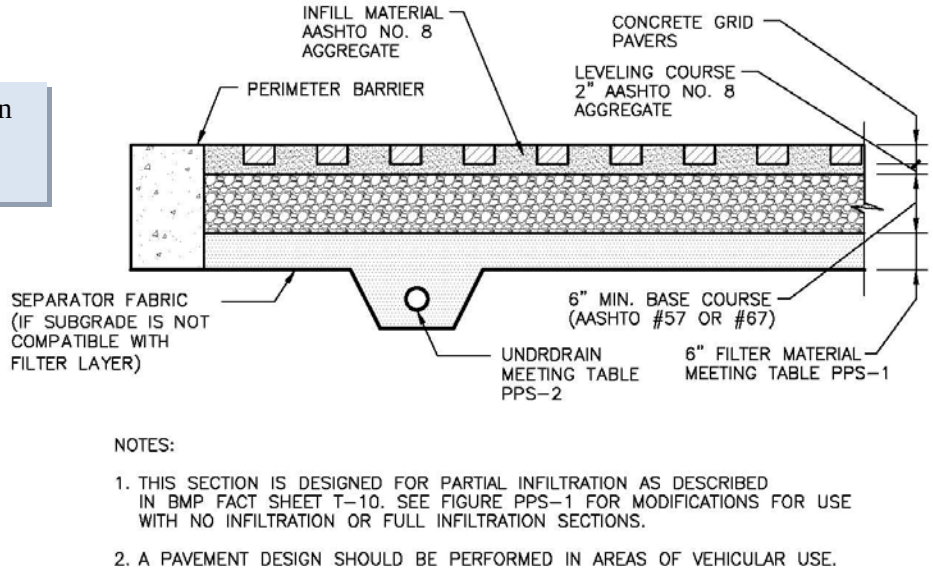


Figure CGP-1. Concrete Grid Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- A concrete perimeter is recommended for this pavement. This will reduce movement and grinding between blocks.

Local Installation

The concrete grid pavement parking site was one of UDFCD's first stormwater monitoring sites. This site was constructed in 1994 and monitored with and without a layer of ASTM C-33 sand to provide filtration. Through our work at this site and the data collected, UDFCD learned the following:

Benefits

- Concrete blocks can be removed and replaced back if utility cuts or other patches are required.
- Concrete grid pavement maintains infiltration rates well.

Limitations

- Concrete Grid Pavement does not meet ADA requirements for accessible paths.

- A filter layer (such as ASTM C-33 sand or CDOT Class C filter material) is required to achieve adequate pollutant removal.
- A concrete perimeter barrier will increase the lifespan of the concrete blocks.
- Concrete blocks can be removed and reused.

Photograph CGP-2. The Lakewood concrete grid pavement installation was one the first permeable pavement stormwater monitoring sites constructed by UDFCD. This photo was taken following construction in 1994.

Pervious Concrete T-10.3

This BMP Fact Sheet was removed in January 2013. UDFCD does not recommend pervious concrete at this time. Additional information is provided in a memorandum available at www.udfcd.org (Ken MacKenzie, January 2013)

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Porous gravel is one of several different types of permeable pavement systems contained within Volume 3. This BMP can be used in place of conventional gravel paving and is well suited for industrial applications that do not pose contamination risks to groundwater. Figure PG-1 provides a typical pavement section of porous gravel.

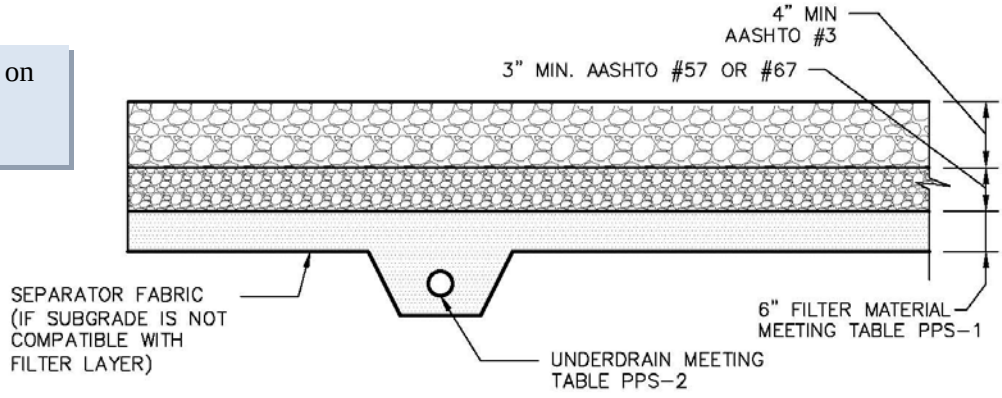
Photograph PG-1. This Denver installation of porous gravel provides volumetric treatment of the WQCV as well as a material storage area.

Site Selection

Porous gravel is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Parking lots,
- Driveways,
- Storage yards, and
- Maintenance roads.

See additional details on Fact Sheet T-10.



NOTES:

1. THIS SECTION IS DESIGNED FOR PARTIAL INFILTRATION AS DESCRIBED IN BMP FACT SHEET T-10. SEE FIGURE PPS-1 FOR MODIFICATIONS FOR USE WITH NO INFILTRATION OR FULL INFILTRATION SECTIONS.
2. A PAVEMENT DESIGN SHOULD BE PERFORMED IN AREAS OF VEHICULAR USE.

Figure PG-1. Porous Gravel Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, consider the items provided on BMP Fact Sheet T-10 as well as the following:

- The surface of porous gravel pavement may rut more than desired. If this is a concern, consider an interlocking plastic cellular paving product (or similar product) to better stabilize the wearing course. Discussion on this product is provided in BMP Fact Sheet T-10.5 (Reinforced Grass).

Benefits

- Low cost compared to other permeable pavements.

Limitations

- Not ADA compliant.
- Ruts without stabilization.

Note: This permeable pavement system differs from others discussed in this manual. Rather than a pavement system designed to capture the WQCV, it is offered for the uses discribed within this Fact Sheet. Unlike Fact Sheets T-10.1 through T-10.4, this document is intended as a standalone document.

Description

Reinforced grass is one of several different types of permeable pavement systems contained within Volume 3. Reinforced grass is designed to have the appearance of grass turf while providing the stability of pavement. There are a number of reinforced grass products available. Different products provide varied levels of turf protection as well as pavement stability and can vary significantly in price. This BMP is frequently used to provide emergency vehicle access. It can also be used to stabilize an area adjacent to a roadway. Figure RG-1 provides a non-proprietary section for reinforced grass pavement.

Site Selection

Reinforced grass is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Roadway shoulder,
- Maintenance roads including BMP access ramps,
- Emergency vehicle access roads, and
- Infrequently used parking areas.

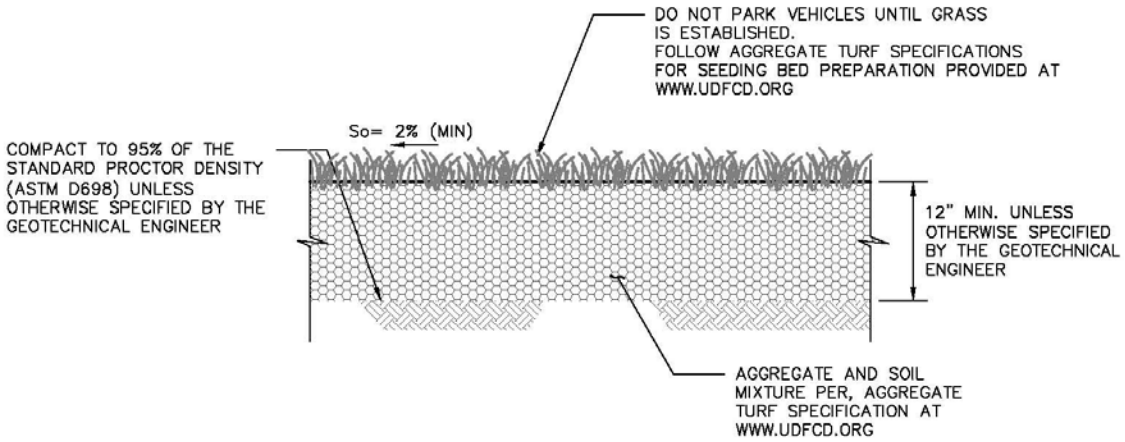


Figure RG-1. Aggregate Turf Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- For parking lot installations, consider a conventional pavement section in the drive aisles. These areas experience a higher volume of traffic.
- Irrigation requirements increase with frequency of use.

Benefits

- Reduces the heat island effect.

Limitations

- Requires irrigation.
- Not recommended when frequency of use exceeds two to three uses per space (for parking stalls) per week.

Selection Considerations

Figure RG-1 is adapted from the Federal Aviation Administration (FAA) section for *aggregate turf pavement*. In addition to this non-proprietary section, there are a number of products available under the name of *reinforced grass* or *turf pavement systems*. The most commonly used systems include:

- **Plastic Cellular Paving**: This category includes interlocking plastic pavers typically designed to be filled with turf or aggregate. This system allows for a high percentage of grass surface within the pavement area.
- **Concrete Cellular Paving**: This type of pavement consists either of interlocking pavers that have openings for the placement of grass or a similar cast-in-place system. Some systems include a reinforcement system that ties the pavers together providing greater protection from over-compaction and greater resistance to differential movement. Although some systems confine the grass area to the opening in the concrete, others are designed to provide the appearance of a fully vegetated landscape.

Consider the following variables when selecting a reinforced grass system:

- **Frequency of Use**: For more frequently used areas, it is important to select a system that protects the root system of the turf from compaction.
- **Appearance**: Concrete systems look different than plastic systems.
- **Vehicle Loading**: Emergency vehicle access roads may need to be designed for high loads but will be used infrequently.
- **Irrigation Expectations**: Some pavements rely, in part, on the turf for stability.
- **Optimum Drainage Capability**: Where soils allow for infiltration, select a product that will bridge the subgrade providing better protection from over-compaction.

Underground BMPs T-11

Description

Underground stormwater BMPs include proprietary and non-proprietary devices installed below ground that provide stormwater quality treatment via sedimentation, screening, filtration, hydrodynamic separation, and other physical and chemical processes. Conceptually, underground BMPs can be categorized based on their fundamental treatment approach and dominant unit processes as shown in Figure UG-1. Some underground BMPs combine multiple unit processes to act as a treatment train.

Photograph UG-1. Installation of an underground BMP (Photo courtesy of Robert Pitt).

Historically, underground stormwater quality treatment devices have not been recommended based on UDFCD policies and criteria. This is due to several factors including problems with unmaintained or poorly maintained devices, remobilization by wash-out (scour) of accumulated pollutants during larger events, lack of performance data for underground devices in the region, and other issues discussed in this Fact Sheet. While underground flood-control detention is still discouraged, UDFCD has added this Fact Sheet to Volume 3 to provide criteria for determining when the use of underground BMPs may be considered for water quality. When surface BMPs are found to be infeasible, underground BMPs may be the only available strategy for satisfying regulatory water quality requirements, especially in highly built-up urban areas where water quality measures must be implemented as a part of a retrofit to meet regulatory requirements.

Underground BMPs should not be considered for standalone treatment when surface-based BMPs are practicable. For most areas of new urban development or significant redevelopment, it is feasible and desirable to provide the required WQCV on the surface. It is incumbent on the design engineer to demonstrate that surface-based BMPs such as permeable pavements, rain gardens, extended detention basins and others have been thoroughly evaluated and found to be infeasible before an underground system is proposed. Surface-based BMPs provide numerous environmental benefits including infiltration, evapotranspiration, groundwater recharge, aquatic habitat, mitigation of "heat island effect", and other benefits associated with vegetation for those that are planted. Be aware that some local governments prohibit the use of underground BMPs or impose requirements that go beyond this Fact Sheet.

Underground BMPs	
Functions	
LID/Volume Red.	Variable
WQCV Capture	Variable
WQCV+Flood Control	Variable
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Variable
Nutrients	Variable
Total Metals	Variable
Bacteria	Variable
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

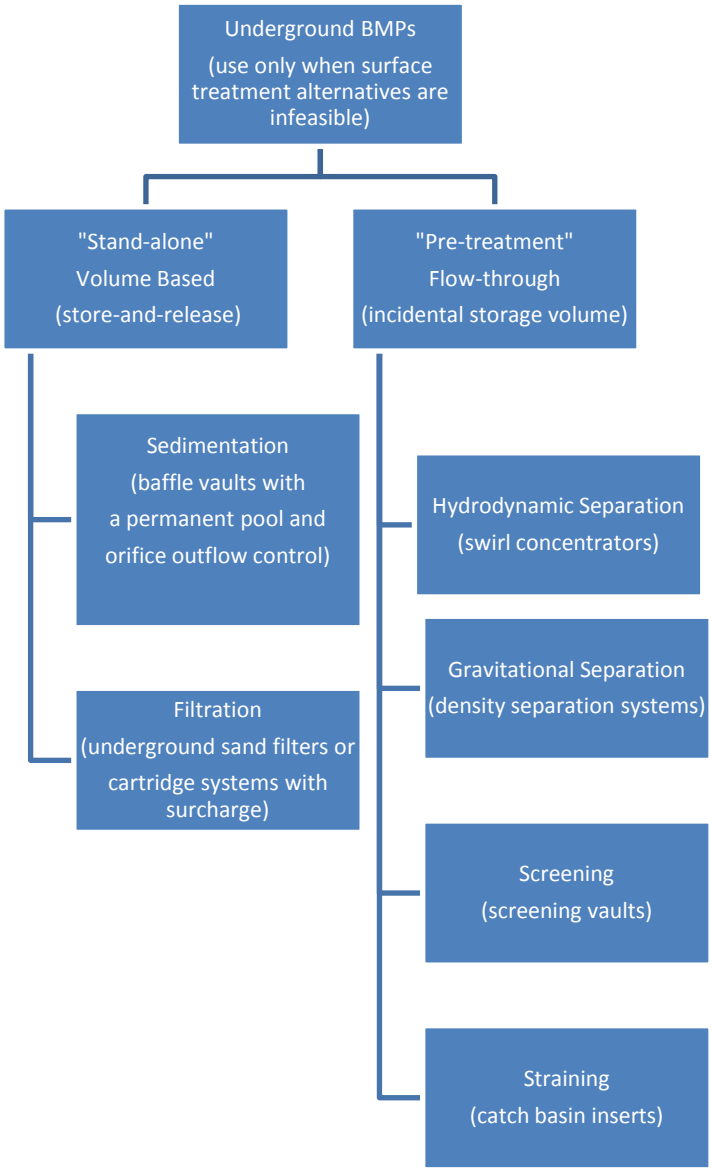


Figure UG-1. Classification of Underground BMPs

Site Selection

The most common sites for underground BMPs are "ultra urban" environments with significant space constraints. These could include downtown lot-line-to-lot-line development projects, transportation corridors, or small (less than 0.5 acre) redevelopment sites in urban areas. Important site features that must be considered include the following:

- **Depth to Groundwater**: Due to the potentially large displacement caused by an underground vault, if there is seasonally high groundwater, buoyancy can be a problem. Vaults can be sealed to prevent infiltration of groundwater into the underground system and these systems can be anchored to resist uplift. If seasonally high groundwater is expected near the bottom of an underground system, the engineer should evaluate the potential for infiltration of groundwater and uplift forces and adjust the design accordingly.
- **Proximity to Public Spaces**: As material accumulates in an underground system, there is potential for anoxic conditions and associated odor problems.
- **Gravity versus Pumped Discharge**: The ability to drain to the receiving storm sewer system via gravity is an important consideration. In some cases it may be necessary to pump discharge from an underground system; however, a gravity outfall is always reccomended if possible and some communities may not allow pumped systems. If a pumped system must be used, there should be redundancy in pumps, as well as a contingency plan in the event that a power outage disables pumps. Additionally, maintenance of the pump system should be identified as part of the water quality BMP in the maintenance plan. When BMP maintenance records are required by the MS4 permit holder, pump system maintenance records should also be included.
- **Access**: Equipment must be able to access all portions of the underground BMP, typically at multiple locations, to perform maintenance. As the size of the underground system increases, so must the number of access points.

Benefits

- Underground BMPs may be designed to provide pre-treatment and/or WQCV in space-constrained situations.
- There are many alternative configurations for proprietary and non-proprietary devices.
- Treatment train applications can be designed using different unit processes in series.
- Some underground BMPs, designed specifically for certain target pollutants, can be used to address a TMDL.
- Many underground devices can be effective for settling of particulates in stormwater runoff and gross solids removal.

Limitations

- Performance data for underground BMPs in the Denver area are limited.
- Maintenance is essential and must be performed frequently.
- Inspection and maintenance can require traffic control, confined space entry, and specialized equipment.
- Devices that do not provide WQCV do not qualify for standalone treatment.
- Gravity outfall may not be feasible in some situations.
- Many do not provide volume reduction benefits.
- Potential for anoxic conditions and odor problems.
- Not recommended when surface alternatives are feasible.

- **Traffic Loading**: Due to space constraints, in some situations, underground BMPs may be located in a right-of-way or other location where there may be traffic loadings. Many underground BMPs are or can be constructed for HS-20 traffic loading. Take additional measures when necessary to ensure that the BMP is designed for the anticipated loading.

- **Potential for Flooding of Adjacent Structures or Property**: For underground BMPs, it is important that the hydraulic grade line be analyzed to evaluate the potential for backwater in the storm sewer system. In addition, some types of underground BMPs, such as catch basin inserts, have the potential to clog and cause flooding if not frequently maintained.

Designing for Maintenance

All underground BMPs must be sized so that routine maintenance is not required more than once per year. The only exception to this is inlet inserts which may need to be cleaned as frequently as following each runoff producing event. **Because underground BMPs are generally less visible and more difficult to access than surface-based BMPs, regular maintenance and early detection of performance issues can be a challenge.**

When developing a design for an underground BMP, the engineer should ensure that all portions of the underground facility can be accessed with maintenance equipment. For multi-chambered systems, access should be provided to each chamber, and openings should be of sufficient size to accommodate the equipment recommended by the manufacturer or designer for maintenance.

Photograph UG-2. Maintenance access to all chambers of an underground BMP is an important design consideration. Photo courtesy of Robert Pitt.

Underground BMPs are generally considered confined spaces and OSHA confined space training typically will be required if a person must enter the underground BMP to perform maintenance. In all cases, a maintenance plan should be developed at the time that the underground BMP is designed.

The maintenance plan should specify, at a minimum, quarterly inspections with maintenance performed as needed based on inspections. The required inspection frequency may be reduced to biannually if, after two or more years, the quarterly regimen demonstrates that this will provide adequate maintenance. Local governments may consider requiring owners of underground BMPs to provide written inspection and maintenance documentation to better assure that required inspection and maintenance activities are taking place. When the BMP includes a pump system, pump inspection and maintenance records should also be included.

Questions to Ask When Considering an Underground BMP

Feasibility
- Are surface-based BMPs truly infeasible?
- Does the device help mitigate the adverse hydrologic impact of development?
- What are the pollutants of interest and are the treatment processes associated with the BMP expected to be effective for these pollutants?
- What is the whole life cycle cost of the BMP?

Location
- If applicable, is the device equipped for HS-20 traffic loading?
- Will the device be placed so that parked vehicles have potential to block access?

Performance
- Is stormwater monitoring required to demonstrate effectiveness of the BMP?
- Where else has a similar BMP been applied in the region? How effective was the application?
- Have independent, third-party data been collected to support performance claims?

Design
- Is pretreatment required?
- Should the device serve as a step in a treatment train instead of a standalone BMP?
- Are there mechanisms to minimize mobilization of accumulated pollutants?
- Is there a maximum drainage area recommended for the device?
- Is the device sized properly for the contributing drainage area and imperviousness?
- What is the head loss through the device for the full range of flow conditions?
- What are design water quality flow rates?
- How does the bypass operate when flow rates are greater than those for the water quality event?
- Have hydraulic grade lines been prepared for the device to evaluate potential surcharging and flooding?

Installation and Maintenance
- What support does the manufacturer provide for design, installation and/or maintenance?
- Who will be on-site during and after construction to ensure that the BMP has been installed correctly?
- What are the maintenance requirements, including access? Is the overall site plan compatible with assured long-term maintenance? Will the underground BMP be located in an easement to assure long-term access?
- What is the recommended maintenance frequency, and what is the cost and method of disposal for removed material?
- What parts of the BMP will need to be maintained and/or replaced (filter media, absorbent pillows, etc.) and what are the associated costs?
- What monitoring will occur?
- Are access openings large enough to accommodate the equipment that will be used to maintain the BMP?
- Who is responsible for inspection and maintenance?
- What proof of maintenance will be required of the owner to show that inspections and routine maintenance is performed?
- What level of effort is required to determine if the BMP is being maintained? Can this be done visually?
- Is there a contingency plan for failure of essential components (pumps, screens, obstructions in flow paths, etc.)?

Design Procedure and Criteria

Two primary options are available for underground BMPs:

1. **Underground BMPs Based on a Surface BMP design**: BMPs that satisfy the requirements for capture and slow release of the WQCV and that are based on and designed in substantial conformance with the criteria for surface-based BMPs described in this manual.

2. **Underground Proprietary BMPs**: Proprietary BMPs that satisfy the requirements for capture and slow release of the WQCV and provide a level of treatment for targeted pollutants that is comparable to that of the surface-based BMPs provided in this manual.

Underground BMPs Based on a Surface BMP Design

This class of underground BMP includes sand filter basins and retention facilities designed for below grade installation. The design must provide the WQCV and empty it over a time period of 12 hours or more. Not all of the surface-based BMPs that provide the WQCV can be adapted for underground use. For example, the vegetative components of a constructed wetland pond render it inadaptable to underground use. Underground extended detention basins are also problematic due to historical problems with remobilization of collected sediment and the difficulty of creating an effective underground micropool.

The most commonly used underground BMP to date in the UDFCD area is the underground sand filter. In addition to the criteria for an above ground sand filter, underground sand filters should meet the following criteria:

1. A pretreatment chamber for removal of coarse sediments with a volume equivalent to 0.10 times the WQCV should be provided. The pretreatment chamber must be separated from the sand filter chamber by baffles, and serves as the sediment forebay to reduce the frequency of maintenance required in the sand filter. Also consider incorporating a vertical baffle to trap oil and grease. This can be easily incorporated into the forebay and should be included where oil and grease are target constituents. Absorbent mats or booms could also be used for this purpose.

2. Where discharges from the BMP will be pumped, a separate outlet chamber is required from which the water passing through the filter layer can be pumped. The outlet pump must be sized to discharge at a rate such that the WQCV is released in no less than 12 hours.

3. For flows in excess of the water quality design event, a diversion must be sized so that excess flows bypass the sand filter chamber and the underground sand filter is not surcharged (in terms of depth or hydraulic grade line) beyond the WQCV maximum elevation.

4. Maintenance access must be provided to each chamber. Access must be sufficient to allow complete removal and replacement of the filter material. Allow for at least 6 feet of headroom (from the surface of the filter) to facilitate maintenance.

Underground Proprietary BMPs

There are numerous proprietary BMPs with wide variability in performance, design flow rates, unit processes, and volume of storage provided (if any). Sizing methodologies for proprietary devices vary from device to device—some are flow based, some are volume based, some consider surface/filter hydraulic loading, etc. As a result, this manual does not seek to provide a one-size-fits-all sizing methodology for proprietary BMPs. Instead, this manual provides a performance-based set of criteria for determining whether a proprietary BMP is acceptable for use.

To evaluate performance of an underground proprietary BMP, data should be provided to the local jurisdiction to demonstrate that anticipated BMP performance will be comparable to that of surface-based BMPs such as extended detention basins, constructed wetland basins, sand filter basins, or retention ponds. Underground BMPs approved for standalone treatment should be capable, on an annual basis, of producing effluent quality with a median TSS concentration of no more than 30 mg/L. This level of treatment is comparable to the long-term effluent median concentrations from the International Stormwater BMP Database for surface-based BMPs.

Data collected to substantiate performance of proprietary BMPs should meet the following criteria:

1. Testing must consist of field data (not laboratory data) collected in compliance with the criteria in Table UG-1. Laboratory studies and/or vendor-supplied studies without third party involvement or verification should not be considered. The Technology Acceptance Reciprocity Partnership (TARP) Protocol for Stormwater Best Management Practice Demonstrations may provide additional useful information on development of a monitoring program for evaluation of underground BMPs. Information on the TARP program can be found in several locations on the internet, including http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/. Forthcoming field testing guidelines from the American Society of Civil Engineers Urban Water Resources Research Council (ASCE UWRRC) Task Committee developing Guidelines for Certification of Manufactured Stormwater BMPs (Sansalone et al. 2009) may also be applicable in the future.

2. Data collected in environments similar to the Colorado Front Range (i.e., semi-arid with freezing and thawing in the winter) are preferable. This is particularly important for flow based devices where differences in rainfall intensity and duration may affect performance.

3. Data should be collected and analyzed in accordance with the guidance provided in *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE 2009; available online at www.bmpdatabase.org). When reviewing performance data, it is important to recognize that the use of percent removal may be more reflective of how "dirty" the influent water is rather than how well the BMP is actually performing (Jones et. al. 2008). Instead, look at effluent concentrations for a range of influent concentrations. **The device should have performance data that demonstrates the ability to meet a median TSS effluent concentration of approximately 30 mg/L or lower on an annual basis**.

4. Data should be collected or verified by independent third parties in accordance with good Quality Assurance/Quality Control (QA/QC) procedures.

Many studies have been conducted over the past decade to document the performance of underground BMPs. Sources of data that may be used to support using a proprietary BMP include the following:

- New Jersey Corporation for Advanced Technology (NJCAT) Technology Verification Program. (http://www.njcat.org/verification/protocol.cfm).

- Washington State Department of Ecology (2002). Guidance for Evaluating Emerging Stormwater Treatment Technologies, Technology Assessment Protocol – Ecology (TAPE), October 2002 (Revised June 2004), Publication Number 02-10-037. (http://www.ecy.wa.gov/biblio/0210037.html).

- International Stormwater BMP Database (www.bmpdatabase.org).

- University of Massachusetts Amherst Stormwater Technologies Clearinghouse (www.mastep.net).

- Wisconsin Department of Commerce & Wisconsin Department of Natural Resources (2007). Method for Predicting the Efficiency of Proprietary Storm Water Sedimentation Devices (1006), http://www.socwisconsin.org/pdf/Broad%20Review/Proprietary%20Stormwater%20Devices%20Std.-Draft6.pdf

- U.S. Environmental Protection Agency Environmental Technology Verification (ETV) Program http://www.epa.gov/etv/

Other data sources may also be acceptable, provided they meet the documentation criteria above.

Table UG-1. Field Monitoring Criteria for Evaluation of Proprietary Underground BMPs

Monitoring Plan Element	Criteria
Number of storm events	▪ Minimum of 10 with "complete" data sets (inflow and outflow quality and quantity data).
Parameters	▪ Inflow(s), Outflow(s) (volume and rate), Precipitation, TSS, TP, COD, Particle Size Distribution (minimum of 3 out of 10 events).
Quality Assurance/Quality Control (QA/QC)—monitoring plan	▪ Monitoring plan shall be developed in accordance with guidance from TARP or *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE 2009) and shall satisfy USEPA requirements for a Quality Assurance Project Plan (QAPP).
QA/QC—laboratory analyses	▪ All analyses shall be performed by a qualified laboratory using USEPA standard analytical procedures.
Representativeness —sampling method	▪ Flow-weighted composite samples for event mean concentrations.
Representativeness—storm characteristics	▪ Aliquots from event shall bracket at least 2/3 of the volume of runoff and the peak of the hydrograph for each monitoring station.
Representativeness—precipitation depth	▪ All events monitored shall have a depth of at least 0.2 inches. ▪ At least 6 of the 10 events shall have total depths between 0.2 and 0.6 inches (targeted water quality storms). ▪ At least 2 of the 10 events shall have total depths > 0.6 inches—bypass quantity and quality shall be quantified and reported.
Representativeness—antecedent dry period	▪ For a storm to qualify as one of the 10 required events, the storm should be preceded by an antecedent dry period of at least 72 hours.
Data Analysis	▪ Data analysis shall follow procedures in *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE 2009) or other established protocols such as TARP or the ASCE UWRRC Task Committee Guidelines for Certification of Manufactured Stormwater BMPs (Sansalone et al. 2009).

Depending on long-term median effluent concentrations from monitoring and whether or not the BMP provides the WQCV, a proprietary underground BMP will fall into one of three categories:

1. **Not recommended:** This category is for underground BMPs that have not demonstrated the ability to achieve an effluent median concentration for TSS of 30 mg/L or less over the long term. This category also may apply to BMPs that have a limited number of data points or studies that were not conducted in accordance with the criteria described above. Even if performance data are favorable, an underground BMP may be deemed unacceptable if a community determines that it is more difficult and/or expensive to maintain compared to a surface BMP alternative.

Stand-alone Treatment

Underground BMPs should meet three basic criteria when considered for stand-alone treatment:

- Capture and treat the WQCV.
- Drain the WQCV over approximately 12 hours.
- Demonstrate performance capable of meeting a median effluent concentration for TSS of 30 mg/L or less.

2. **Pretreatment:** This category is for underground BMPs that are constructed in series with other BMPs, the sum of which meet both the recommendation for capture and treatment of the WQCV over 12 hours or longer and also demonstrate performance capable of meeting a median effluent concentration for TSS of 30 mg/L or less. When the underground BMP does not meet the TSS effluent criterion it should be placed upstream of a BMP capable of meeting this criterion. Alternatively, this category also includes underground BMPs that are capable of meeting the 30 mg/L TSS median effluent benchmark but provide little, if any, surcharge storage/WQCV. BMPs in this category may be useful as an initial step in a treatment train approach to water quality.

3. **Standalone:** This category is for underground BMPs that demonstrate the ability to produce effluent with a median concentration of 30 mg/L TSS or less over the long term and provide the WQCV in accordance with UDFCD criteria. "Standalone" devices should be designed to provide release of the WQCV in no less than 12 hours. Furthermore, this category of BMP should only be used where it is determined that surface BMPs are not feasible.

See Figure UG-1 for typical types of underground BMPs that may fall into each category. UDFCD does not maintain a list of specific devices that fall into each of these categories. It is the responsibility of the designer to present relevant data, demonstrate that the criteria for data collection above have been satisfied, and identify the appropriate category for the BMP based on those data. Local governments should reserve the right to disallow underground BMPs, proprietary or not, at their discretion. In addition, a local government may require collection of additional monitoring data to demonstrate BMP performance, especially in situations where data from other geographic regions have been presented to justify use of the underground BMP. Finally, local governments may require agreements that run in perpetuity attached to the property served by the BMP, assuring that it will be inspected and maintained by the owner as required by the local government (or recommended by manufacturer) with a provision for taking over the inspection and maintenance if needed and back charging the owner.

Construction Considerations

Improper installation will cause poor performance of proprietary underground BMPs. This problem has been noted not only by manufacturers, but also by Colorado municipalities who have observed that the "as built" BMPs often vary significantly from the design. Most underground BMPs already face hydraulic challenges due to limited vertical fall and because of head losses, so they may be sensitive to slight changes in elevation. In addition, many of the proprietary underground BMPs require assembly of special baffling or patented inserts that may not be familiar to contractors.

For these reasons, it is important to discuss the installation of the underground BMP with the manufacturer prior to selecting a contractor so that the installation requirements are clearly understood. Construction observation by the design engineer, and, if possible, a manufacturer's representative is essential for proper installation. At a minimum, the installation should be inspected by the manufacturer's representative once completed. Any deficiencies of the installation identified by the manufacturer's inspection should be corrected immediately.

Description

This section provides guidance and details for outlet structures for the use primarily with BMPs utilizing sedimentation, (i.e., extended detention basins, retention ponds and constructed wetland ponds). The information provided in this section includes guidance for different size watersheds as well as for incorporating full spectrum detention as described in the *Storage* chapter of Volume 2.

The details contained in this Fact Sheet are intended to provide a starting point for design. UDFCD recommends that design details for outlet structures be specific for each site with structural details drawn to scale. The details provided in this Fact Sheet are not intended to be used without modification or additional detail.

Photograph OS-1. Although each site is different, most sedimentation BMPs have similar outlet structures. Each structure should include a partially submerged orifice plate with a screen (or grate) protecting the orifice plate from clogging, and an overflow weir for flows exceeding the WQCV or excess urban runoff volume (EURV), when full spectrum detention is used.

Outlet Design

Large Watershed Considerations

UDFCD recommends that water quality treatment be provided close to the pollutant source. This is a fundamental concept of Low Impact Development (LID). Although flood control facilities, including full spectrum detention facilities, have been shown to be very effective for watersheds exceeding one square mile, this is not the case for water quality facilities. One reason for this is that the baseflow associated with a larger watershed will vary and can be difficult to estimate. The orifice plate should be designed to pass the baseflow while detaining the water quality capture volume (WQCV) for approximately 40 hours. When the baseflow is overestimated, the WQCV is not detained for the recommended time, passing through without treatment. When the baseflow is underestimated, the elevation of the permanent pool will be higher than designed, causing maintenance issues as well as reducing the volume available for detention of the WQCV, which also allows for a portion of this volume to pass through without treatment. For this reason, UDFCD recommends that facilities designed for both water quality and flood control be limited, where possible, to watersheds without a baseflow. The maximum recommended watershed for combined facilities is one square mile. Additional discussion on designing for baseflows is provided in the EDB BMP Fact Sheet (T-5).

Designing for Maintenance

Rather than using the minimum criteria, consider maximizing the width of the trash rack to the geometry of the outlet. This will reduce clogging and frequency of maintenance. Reduced clogging in EDB outlet structures will preserve the initial surcharge volume thus reducing frequency of inundation in the bottom of the basin. This will benefit the grasses and reduce long-term EDB maintenance requirements (including sediment removal in the grassed area) and may reduce the life-cycle cost of the BMP.

Orifice Plates, Trash Racks, and Safety Grates

An orifice plate is used to release the WQCV slowly over 40 hours. For full spectrum detention, the orifice plate is extended to drain a larger volume, the EURV, over approximately 72 hours. The figures and tables in this section provide recommendations for orifice configurations and trash rack type and size. Guidance is provided for plates using both circular and rectangular orifices.

Orifice Sizing

Follow the design steps included in the BMP Fact Sheet for the appropriate BMP. The UD-Detention workbook, available at www.udfcd.org, can be used to route flows and calculate the required orifice sizes. UDFCD recommends a total of three orifices to maximize the orifice size and avoid clogging of the orifice plate. A detail showing the recommended orifice configuration is provided in Figure OS-4.

Trash Rack Sizing

Once the size of the orifice has been determined, this information, along with the total orifice area in the water quality plate, is used to determine the total open area of the grate. See Figure OS-1 and use the dashed line to size the trash rack. Include the portion of the trash rack that is inundated by the micropool in total open area of the grate.

Be aware, Figures OS-5, OS-6, OS-7, and OS-8 dimension the minimum width clear for the trash rack frame. It is also important to provide adequate width for attachment to the outlet structure (see Photos OS-2 and OS-3). Also, consider maximizing the width of the trash rack to the geometry of the outlet. This will reduce clogging and maintenance requirements associated with cleaning the trash rack. This Fact Sheet also includes recommendations for the thickness of the steel water quality plate (see Table OS-2).

Photograph OS-2. This trash rack could not be properly

Photograph OS-3. Trash rack after repair.

Safety Grates

Safety grates are intended to keep people and animals from inadvertently entering a storm drain. They are sometimes required even when debris entering a storm drain is not a concern. The grate on top of the outlet drop box is considered a safety grate and should be designed accordingly. The danger associated with outlet structures is the potential associated with pinning a person or animal to unexposed outlet pipe or grate. See the *Culverts and Bridges* chapter of Volume 2 of this manual for design criteria related to safety grates.

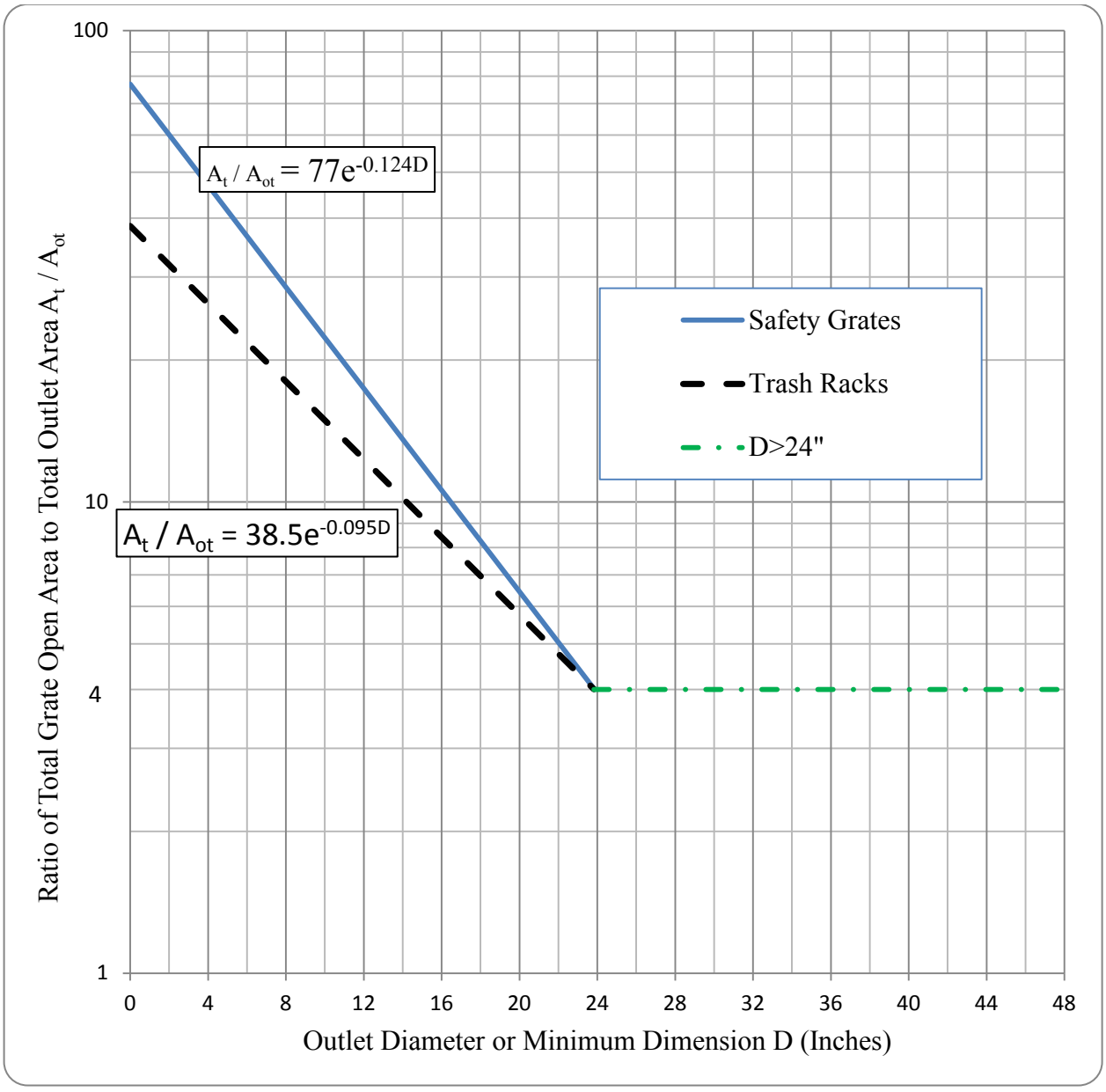


Figure OS-1. Trash Rack Sizing

Outlet Geometry

Outlets for small watersheds will typically be sized for maintenance operations while the geometry of outlets for larger watersheds may be determined based on the required size of the trash rack. For all watershed sizes, the outlet should be set back into the embankment of the pond to better allow access to the structure. This also provides a more attractive BMP. For larger watersheds, this will require wing walls. Wing walls are frequently cast-in-place concrete, although other materials, such as grouted boulders, may be used where appropriate. Consider safety, aesthetics, and maintenance when selecting materials and determining the geometry. A safety rail should be included for vertical drops of 3 feet or more. Depending on the location of the structure in relation to pedestrian trails, safety rails may also be required for lesser drops. Stepped grouted boulders can be used to reduce the height of vertical drops.

As shown in Figures EDB-1 and EDB-2 provided in BMP Fact Sheet T-5, wing walls can be flared or parallel. There are advantages to both configurations. Parallel wing walls may be more aesthetic; however, depending on the geometry of the pond, may limit accessibility to the trash rack. Flared wing walls can call attention to the structure but provide better accessibility and sometimes a vertical barrier from the micropool of an EDB, which can increase safety of the structure. Parallel walls can also be used with a second trash rack that is secured flush with the top of the wall as shown in Photo OS-4. This eliminates the need for a safety rail and may provide additional protection from clogging; however, it creates a maintenance issue by restricting access to the water quality screen. The rack shown in Photo OS-4 was modified after construction due to this problem.

Photograph OS-4. Maintenance access to the water quality trash rack was compromised by the location of a secondary trash rack on this outlet. This may have been included as a safety rack or as additional protection from clogging. The owner modified the structure for better access. A safety rail would have been a better solution.

Photograph OS-5. Interruptions in the horizontal members of this trash rack and the spacing of the vertical members allow easier access to clean the water quality grate. A raking tool can be used to scrape the water quality trash rack.

Micropools within the Outlet Structure

The micropool of an EDB may be placed inside the structure when desired. This is becoming increasingly common for smaller watersheds and near airfields where large bird populations can be problematic. When designing this type of structure, consider maintenance of the water quality trash rack. The secondary trash rack should be designed to allow maintenance of the water quality trash rack similar to that shown in Photo OS-5. This concept can easily be incorporated into smaller outlet structures (see Figures OS-7 and OS-8 for details).

Outlet Structure Details

A number of details are presented in this section to assist designers with detailing outlet structures. Table OS-1 provides a list of details available at www.udfcd.org. These details are not intended to be used in construction plans without proper modifications as indicated in this table.

Table OS-1. Summary of Outlet Structure Details and Use

Figure	Detail	Use of Detail
OS-2	Typical outlet structure for full spectrum detention	Conceptual.
OS-3	Typical outlet structure for WQCV treatment and attenuation	Conceptual.
OS-4	Orifice plate and trash rack detail and notes	Outlet section. Modify per true structure geometry and concrete reinforcement. Modify notes per actual design.
OS-5	Typical outlet structure with well screen trash rack	Outlet sections. Modify per true structure geometry and concrete reinforcement. Add additional sections and detailing as necessary. Modify notes per actual design.
OS-6	Typical outlet structure with bar grate trash rack	Outlet sections. Modify per true structure geometry and concrete reinforcement. Add additional sections and detailing as necessary. Modify notes per actual design.
OS-7	Full spectrum detention outlet structure for 5-acre impervious area or less	Outlet profile and section. Modify per true EURV elevation and concrete reinforcement. Add additional sections and detailing as necessary.
OS-8	WQCV outlet structure for 5-acre impervious area or less	Outlet sections. Modify per true WQCV elevation and concrete reinforcement. Add additional sections and detailing as necessary.

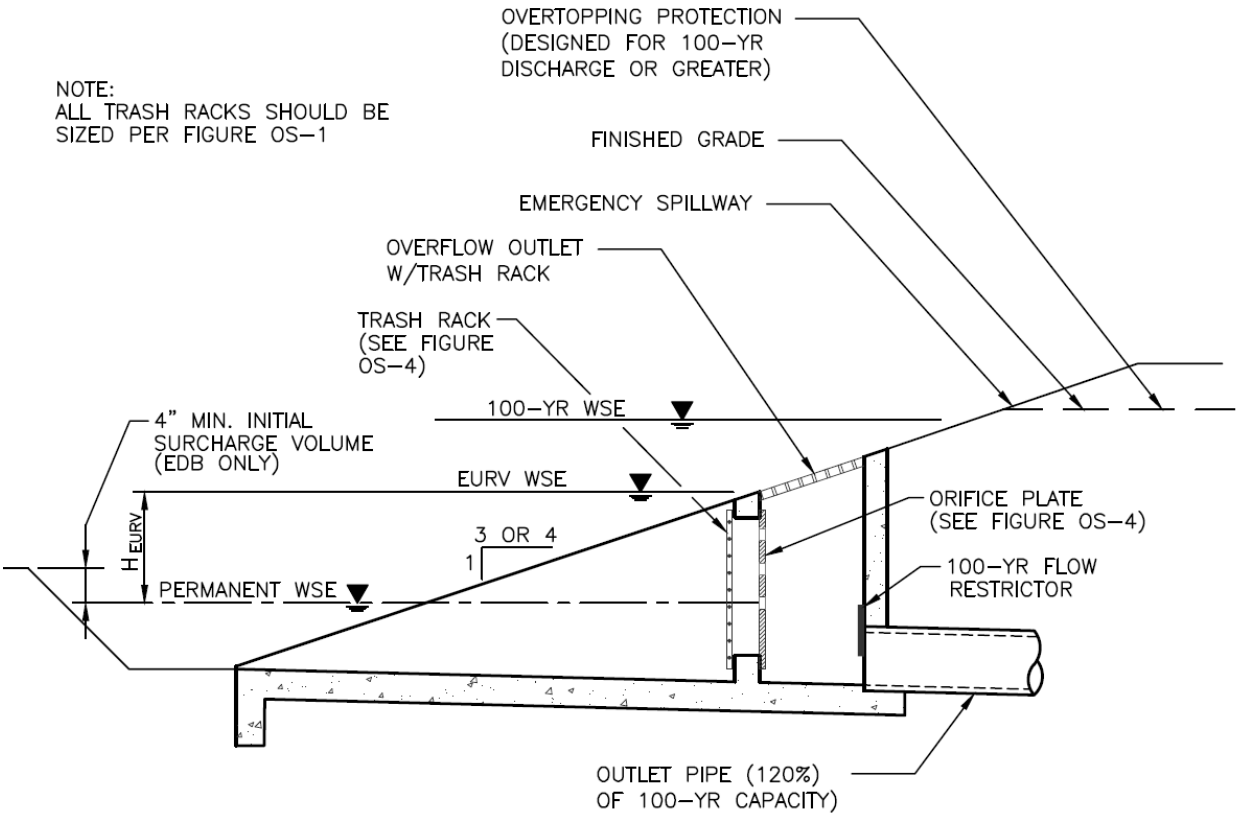


Figure OS-2. Typical outlet structure for full spectrum detention

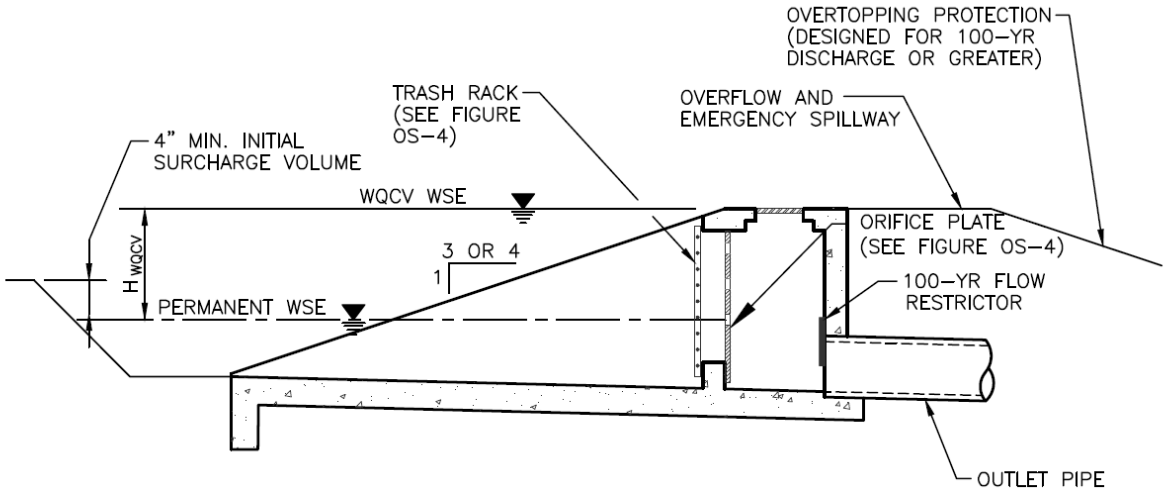
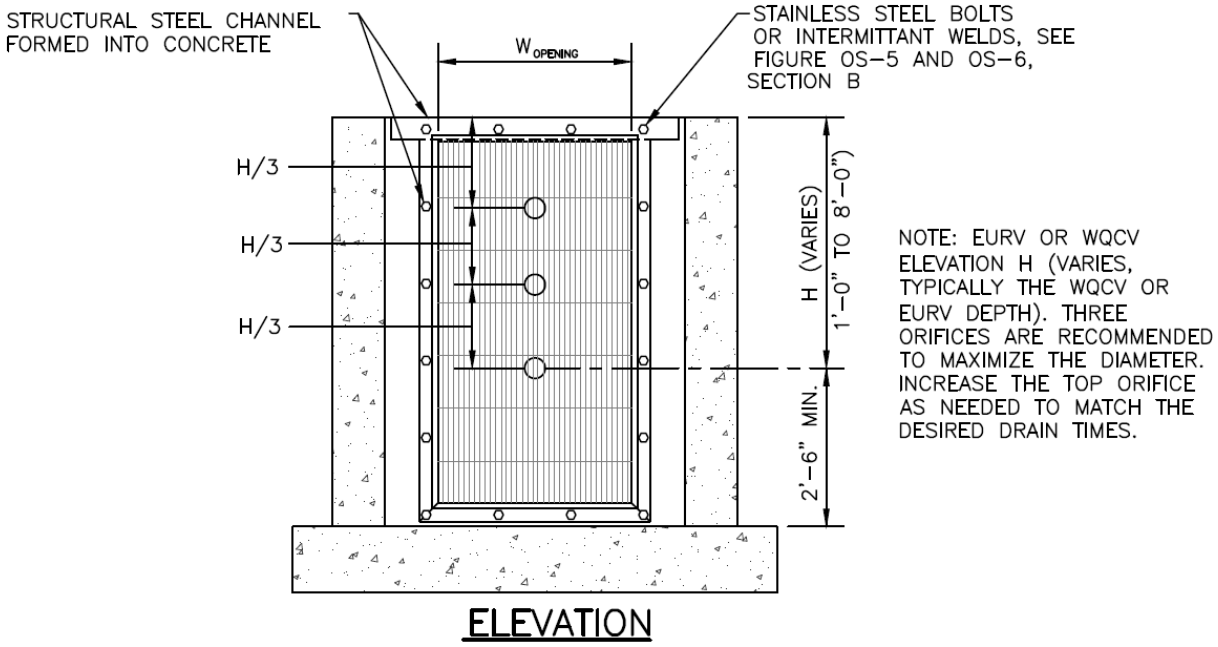


Figure OS-3. Typical outlet structure for WQCV treatment and attenuation



ORIFICE PLATE NOTES:

1. PROVIDE CONTINUOUS NEOPRENE GASKET MATERIAL BETWEEN THE ORIFICE PLATE AND CONCRETE.
2. BOLT PLATE TO CONCRETE 12" MAX. ON CENTER. SEE TABLE OS–2 FOR PLATE THICKNESS.

EURV AND WQCV TRASH RACKS:

1. WELL–SCREEN TRASH RACKS SHALL BE STAINLESS STEEL AND SHALL BE ATTACHED BY INTERMITTENT WELDS ALONG THE EDGE OF THE MOUNTING FRAME.
2. BAR GATE TRASH RACKS SHALL BE ALUMINUM AND SHALL BE BOLTED USING STAINLESS STEEL HARDWARE.
3. TRASH RACK OPEN AREAS ARE FOR SPECIFIED TRASH RACK MATERIALS. TOTAL TRASH RACK SIZE MAY NEED TO BE ADJUSTED FOR MATERIALS HAVING DIFFERENT OPEN AREA/GROSS AREA RATIO (R VALUE).
4. STRUCTURAL DESIGN OF TRASH RACKS SHALL BE BASED ON FULL HYDROSTATIC HEAD WITH ZERO HEAD DOWNSTREAM OF THE RACK.

OVERFLOW SAFETY GRATES:

1. ALL SAFETY GRATES SHALL BE MOUNTED USING STAINLESS STEEL HARDWARE AND PROVIDED WITH HINGED AND LOCKABLE OR BOLTABLE ACCESS PANELS.
2. SAFETY GRATES SHALL BE STAINLESS STEEL, ALUMINUM, OR STEEL. STEEL GRATES SHALL BE HOT DIP GALVANIZED AND MAY BE HOT POWDER COATED AFTER GALVANIZING.
3. SAFETY GRATES SHALL BE DESIGNED SUCH THAT THE DIAGONAL DIMENSION OF EACH OPENING IS SMALLER THAN THE DIAMETER OF THE OUTLET PIPE.
4. STRUCTURAL DESIGN OF SAFETY GRATES SHALL BE BASED ON FULL HYDROSTATIC HEAD WITH ZERO HEAD DOWNSTREAM OF THE RACK.

Figure OS-4. Orifice plate and trash rack detail and notes

Table OS-2. Thickness of steel water quality plate

Steel plate thickness (in inches) based on design depth and span of plate											
		Head (feet)									
		3	4	5	6	7	8	9	10	11	12
Span (feet)	1	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875
	2	0.1875	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
	3	0.2500	0.2500	0.3750	0.3750	0.3750	0.3750	0.3750	0.3750	0.3750	0.5000
	4	0.2500	0.3750	0.3750	0.3750	0.3750	0.5000	0.5000	0.5000	0.5000	0.5000

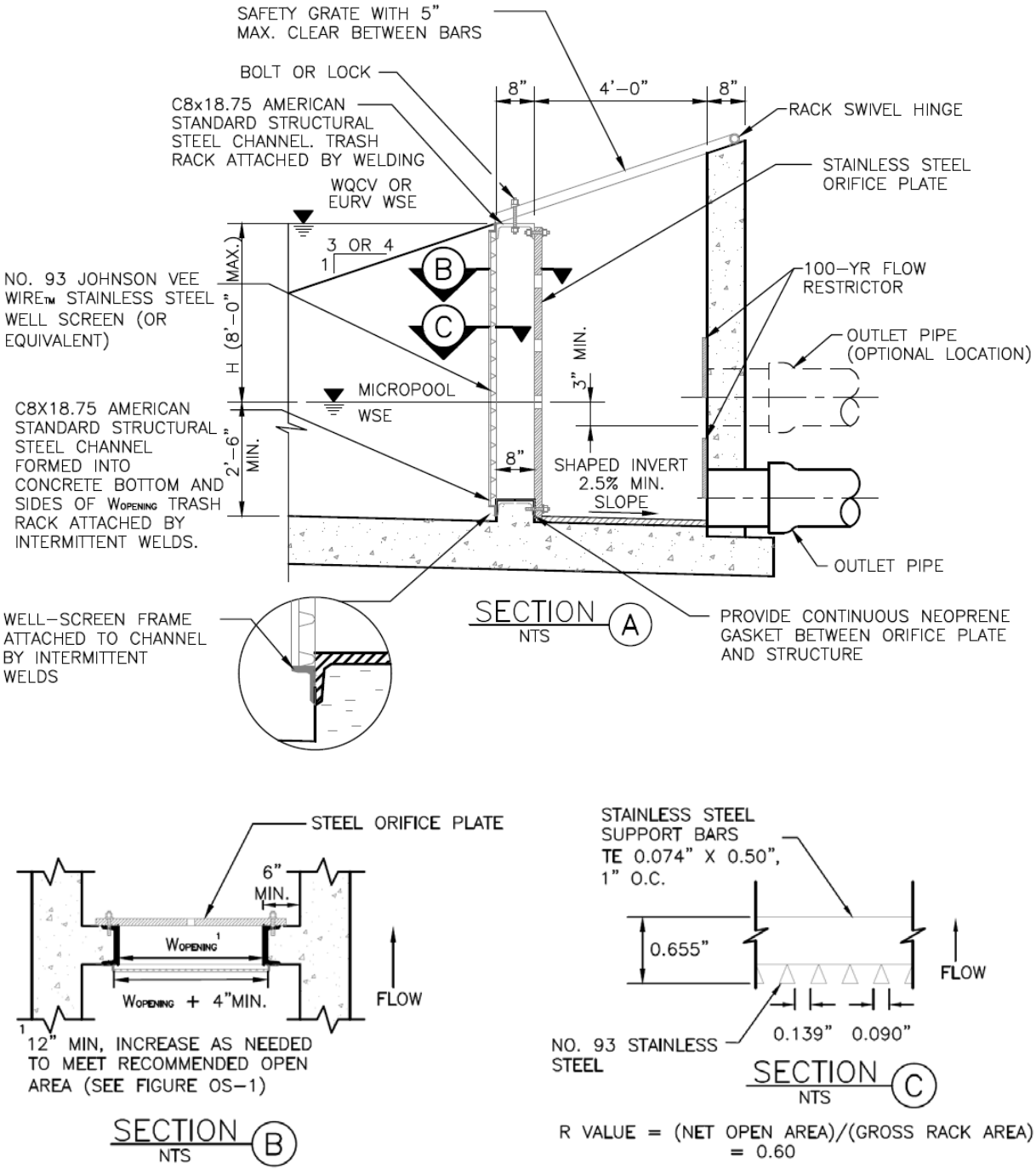
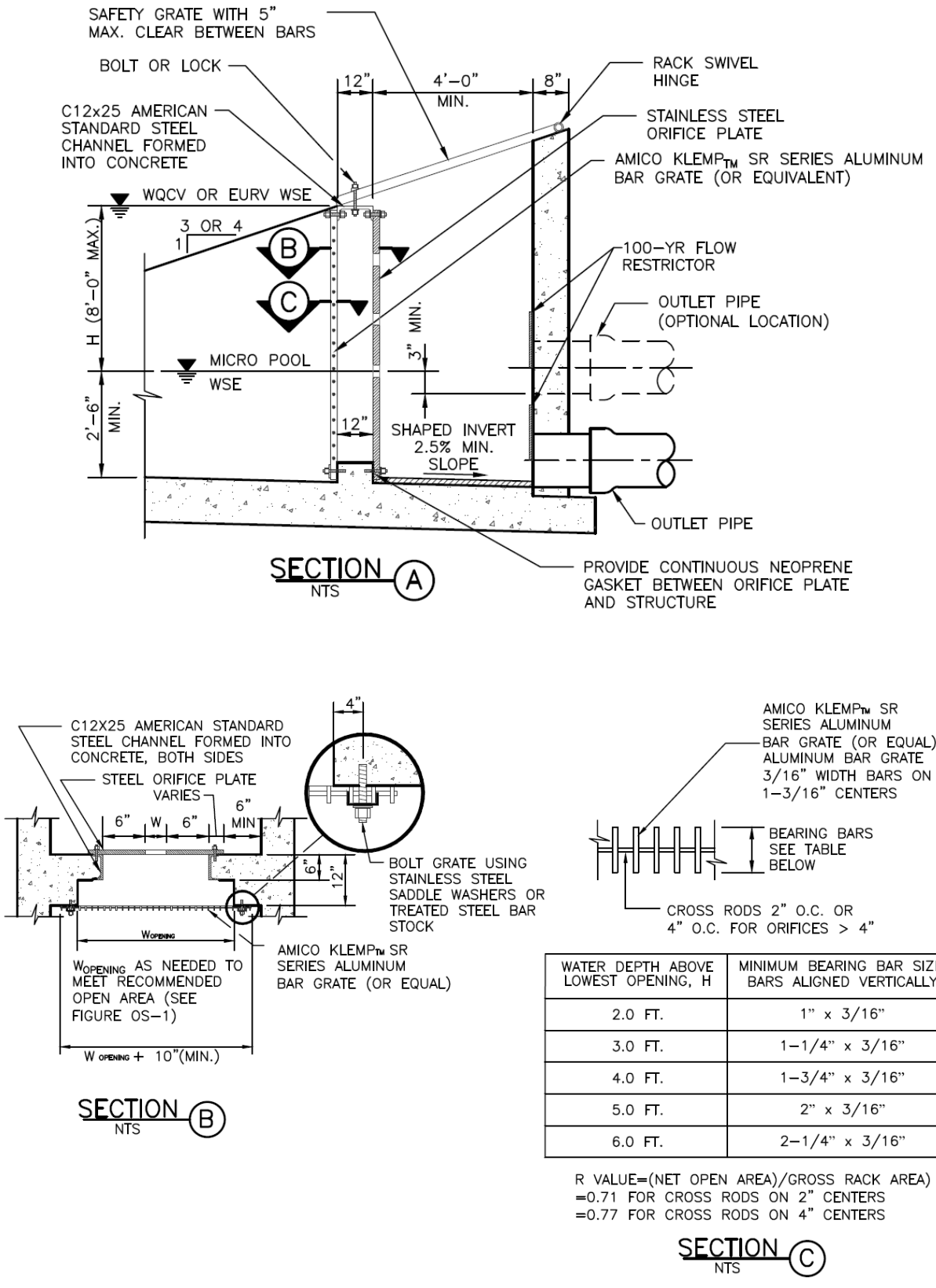


Figure OS-5. Typical outlet structure with well screen trash rack



WATER DEPTH ABOVE LOWEST OPENING, H	MINIMUM BEARING BAR SIZE, BARS ALIGNED VERTICALLY
2.0 FT.	1" x 3/16"
3.0 FT.	1–1/4" x 3/16"
4.0 FT.	1–3/4" x 3/16"
5.0 FT.	2" x 3/16"
6.0 FT.	2–1/4" x 3/16"

Figure OS-6. Typical outlet structure with bar grate trash rack

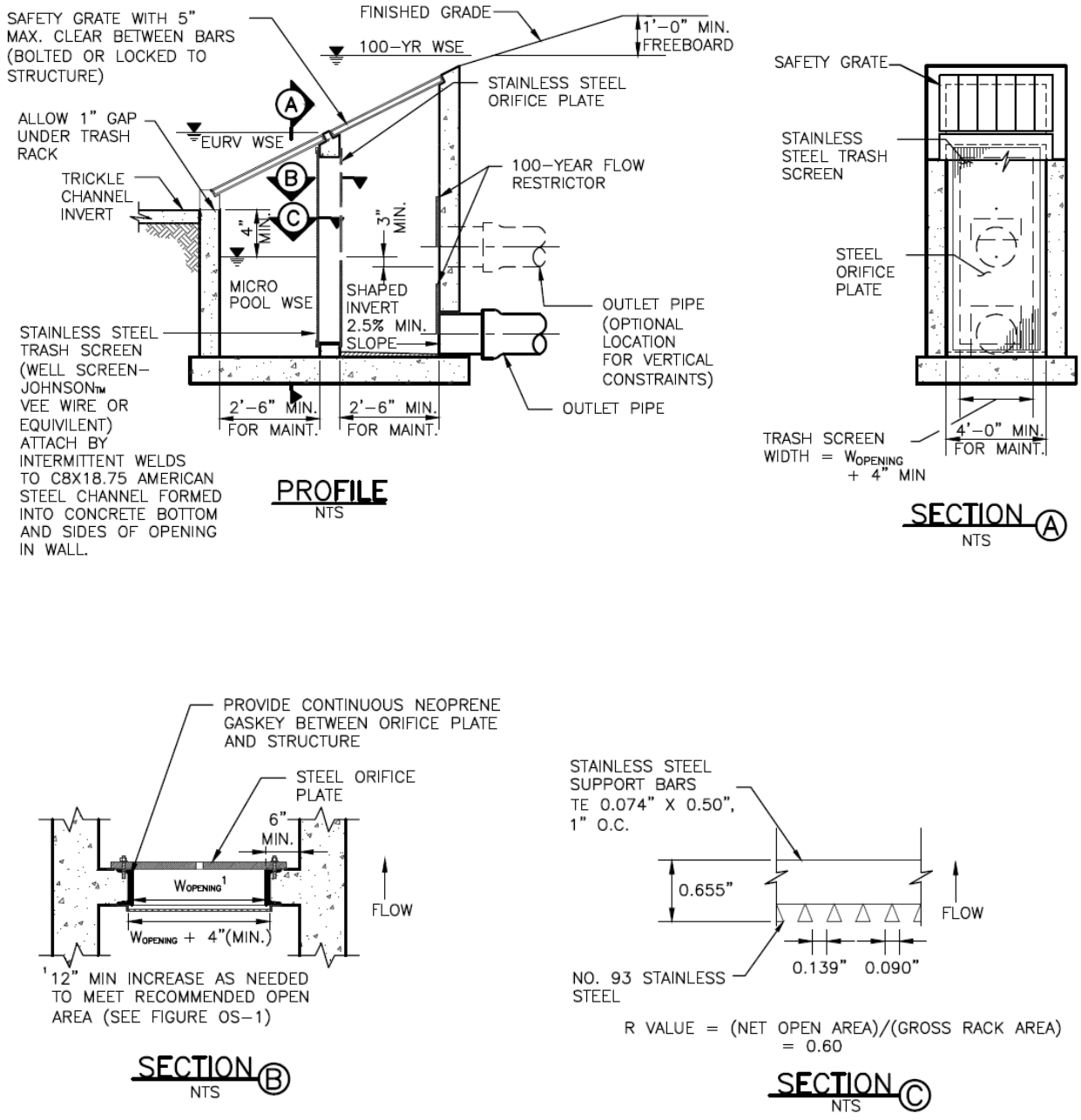


Figure OS-7. Full spectrum detention outlet structure for 5-acre impervious area or less

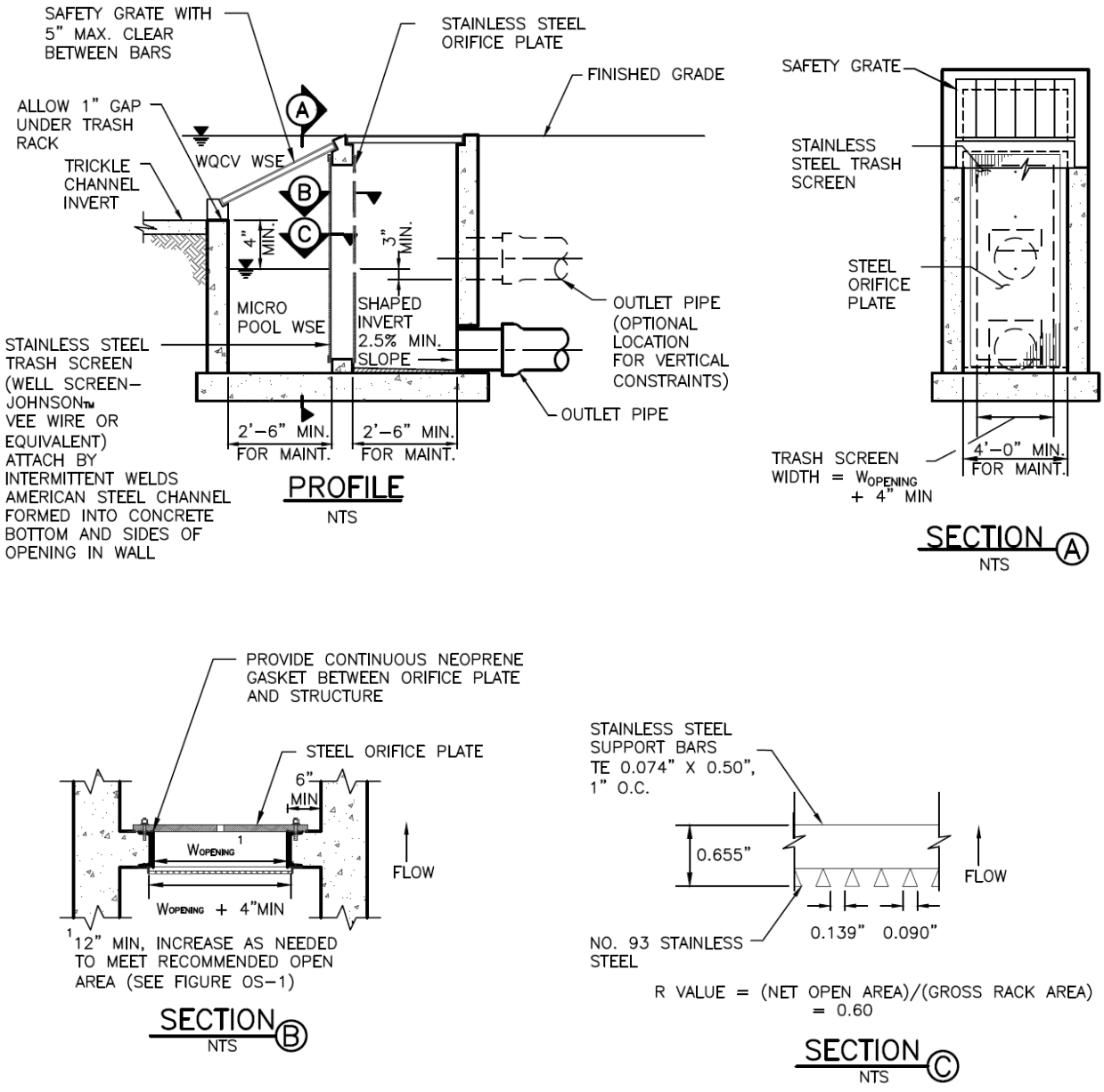


Figure OS-8. WQCV outlet structure for 5-acre impervious area or less

Chapter 5
Source Control BMPs

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Source Control BMP Fact Sheets
S-1 Covering Outdoor Storage and Handling Areas
S-2 Spill Prevention, Containment and Control
S-3 Disposal of Household Waste
S-4 Illicit Discharge Controls
S-5 Good Housekeeping
S-6 Preventative Maintenance
S-7 Vehicle Maintenance, Fueling and Storage
S-8 Use of Pesticides, Herbicides and Fertilizers
S-9 Landscape Maintenance
S-10 Snow and Ice Management
S-11 Street Sweeping and Cleaning
S-12 Storm Sewer System Cleaning

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1.0 Introduction

Proactively controlling pollutants at their source is fundamental to effective stormwater quality management and is part of the Four Step Process outlined in Chapter 1 of this manual. Typically, it is easier and more cost-effective to prevent stormwater pollution than to remove contaminants once they have entered the storm sewer system or receiving water. Local governments, industries, businesses and homeowners all have opportunities to implement source control practices that help prevent pollution. A good source control BMP is one that is effective at stopping and/or redirecting pollutants prior to entering the storm sewer system. A source control BMP can be a structural component of a planned site (e.g. a covered area for material storage) or a procedural BMP. The latter depend on behavior change accomplished through public education, training and development of standard operating procedures.

This chapter provides BMP Fact Sheets for common source control practices that can be integrated into overall stormwater management plans by local governments, industries and businesses. BMPs applicable to homeowners can also be used for integration into local government public education and awareness efforts related to stormwater quality.

Effective source control also requires awareness of discharges such as commercial washing of outdoor structures, which produces process wastewater that is not appropriate for discharge to the storm drain system. Table 5-1 summarizes types of pollutants generated at various types of facilities that may be reduced from implementation of the source controls found in this chapter. General guidance for selecting source control practices follows, along with the Source Control BMP Fact Sheets.

Table 5-1. Potential Pollutant Sources and Types with Applicable Source Control BMPs

	Type of Facility				Pollutants Associated with Activity					Source Control BMP Fact Sheets
Potential Pollutant Sources	Municipal	Industrial	Commercial	Residential	Sediment/ Litter/ Debris	Nutrients/ Organic Matter	Bacteria	Hydro-carbons	Toxics/ Chemicals/ Paint	
Outdoor Material Storage and Handling	x	x	x		x	x		x	x	Covering Outdoor Storage & Handling Areas Spill Prevention, Containment & Control
Heavy Equipment and Vehicle Maintenance/Storage Activities	x	x	x					x	x	Covering Outdoor Storage & Handling Areas Spill Prevention, Containment & Control Vehicle Maintenance, Fueling & Storage
Parked Vehicles	x	x	x	x	x			x		Vehicle Maintenance, Fueling & Storage
Vehicle Fueling	x	x	x					x		Vehicle Maintenance, Fueling & Storage
Roads	x	x	x		x	x	x	x		Street Sweeping
Deicing Chemicals/Snow Storage	x	x	x	x	x	x	x	x		Snow and Ice Management
Waste Storage/Disposal Practices	x	x	x	x	x	x	x	x	x	Good Housekeeping Illicit Discharge Control
Landsapes (e.g. fertilizers, herbicides, pesticides, excessive irrgation)	x	x	x	x	x	x	x	x	x	Landscape Management Pesticide, Herbicide& Fertilizer Application & Handling
Storm Drain System (accumulated materials)	x				x	x	x	x	x	Storm Sewer System Cleaning
Pets				x		x	x			Good Housekeeping Illicit Discharge Control

2.0 Structural Source Controls

Site operations and potential pollution source control needs should be considered early in the planning and design process. This will reduce the load of pollutants into stormwater and may also facilitate site operations and reduce maintenance requirements for on-site treatment BMPs. Representative questions that should be considered prior to finalizing the site layout include:

Photograph 5-1. This commercial materials storage area drains directly to a storm drain. Effective site design would have located this storage area away from a storm drain and directed runoff to a landscape bed or provided additional covering and containment that would both protect the material and reduce pollutant loading to the storm sewer.

1. What materials are stored on-site?
2. How are these materials handled and moved through the site?
3. What on-site operations take place that could potentially cause materials to enter the storm sewer system?
4. Where and how might these materials enter the storm sewer?
5. How can storage and handling areas and drainage facilities be designed to reduce pollutant loading? Is it feasible to cover these areas?
6. When a spill occurs, how and where will it be controlled and contained? Are structural spill containment measures needed? What is the relationship between these areas and planned treatment BMPs (Chapter 2) for the site?

Use good judgment when planning your site and consider BMP Fact Sheets *S-1 Covering of Storage and Handling Areas* and *S-2 Spill Prevention, Containment and Control* early in the planning and design process. Structural source control measures must also be combined with appropriate employee training. For example, if a covered structure and spill containment area are constructed at an industrial site, but employees conduct operations subject to spills (e.g., drum storage) in other portions of the site, the structural BMP will not be effective.

3.0 Procedural Source Control BMPs

Procedural BMPs are actions or procedures that can be implemented to reduce pollutant loading. These practices are critical at stormwater "hotspots," but can also be effective when behavior change in residential areas occurs over entire watersheds. Examples of stormwater hotspots and the operations that cause pollution at hotspots are provided in the inset on the following page and in Table 5-2.

3.1 Municipal Operations

Communities regulated under Phase 1 or Phase 2 of the NPDES program are required to develop a program to:

- Prevent or reduce the amount of polluted stormwater generated by municipal operations;
- Educate employees to incorporate pollution prevention and good housekeeping practices into municipal operations; and
- Identify BMPs and measurable goals for the prevention or reduction of the amount of polluted stormwater that is generated by municipal operations.

Developing an effective municipal pollution prevention and good housekeeping program involves implementing a program that 1) is specifically designed for a community, taking into consideration how information is communicated and how training is provided and received, and 2) incorporates sound standard practices for various operations. Many communities nationally and in the metro Denver area have developed such standard operating procedures. The Fact Sheets provided in this chapter may be used to develop such procedures or to supplement existing procedures. Development of a program that is specifically tailored to a community should begin with evaluation of the following questions (Center for Watershed Protection 2008):

Examples of Stormwater "Hotspots"

- Fleet storage areas
- Solid waste facilities
- Wastewater treatment plants
- Composting facilities
- Nurseries and garden centers
- Restaurants
- Industrial rooftops
- Recycling facilities
- Maintenance facilities
- Gas stations
- Fast-food drive-thru areas
- Airports

1. What municipal operations are conducted within the community?
2. What stormwater pollutants are associated with the operations?
3. Who is responsible for managing each of the operations?
4. What is the primary pollutant of concern in the subwatershed?
5. Which of the operations has the greatest influence on water quality and should be the focus of the community's pollution prevention/good housekeeping efforts?
6. What specific pollution prevention/good housekeeping practices should be implemented to improve the operations?
7. How much will the pollution prevention/good housekeeping practices cost?
8. Who will be responsible for implementing the pollution prevention/good housekeeping practices?
9. How will progress made in pollution prevention/good housekeeping be evaluated?

Developing a Municipal Program

Urban Subwatershed Restoration Series Manual 9: Municipal Pollution Prevents/Good Housekeeping Practices prepared by The Center for Watershed Protection (2008), outlines a detailed approach for developing a municipal pollution prevention/good housekeeping program. The manual is available to download at no cost at www.cwp.org.

Table 5-2. Polluting Activities Associated With Common Hotspot Operations

(Source: Center for Watershed Protection 2005)

Polluting Activities Associated With Common Hotspot Operations	
Hotspot Operation	Polluting Activity
Vehicle Operations	▪ Improper disposal of fluids down shop and storm drains ▪ Spilled fuel, leaks and drips from wrecked vehicles ▪ Hosing of outdoor work areas ▪ Wash water from cleaning ▪ Uncovered outdoor storage of liquids/oils/batteries spills ▪ Pollutant wash-off from parking lot
Outdoor Materials	▪ Spills at loading areas ▪ Hosing/washing of loading areas into shop or storm drains ▪ Wash-off of uncovered bulk materials and liquids stored outside ▪ Leaks and spills
Waste Management	▪ Spills and leaks of liquid ▪ Dumping into storm drains ▪ Leaking dumpsters ▪ Dumpster juice ▪ Wash-off of dumpster spillage
Physical Plant Maintenance	▪ Discharges from power washing and steam cleaning ▪ Wash-off of fine particles from painting/sandblasting operations ▪ Rinse water and wash water discharges during cleanup ▪ Temporary outdoor storage ▪ Runoff from degreasing and re-surfacing
Turf and Landscaping	▪ Non-target irrigation ▪ Runoff of nutrients and pesticides ▪ Deposition and subsequent wash-off of soil and organic matter on impervious surfaces ▪ Improper rinsing of fertilizer/pesticide applicators

3.2 Commercial and Industrial Operations

Commercial and industrial source controls focus primarily on reducing exposure of materials to rainfall and runoff and preventing non-stormwater discharges to storm sewers. Check federal and state requirements for obtaining and complying with stormwater discharge permits. The following BMP Fact Sheets are targeted to commercial and industrial operations:

- S-1 Covering Outdoor Storage & Handling Areas
- S-2 Spill Prevention Containment and Control
- S-5 Good Housekeeping

- S-6 Preventative Maintenance
- S-7 Vehicle Maintenance, Fueling & Storage
- S-10 Snow and Ice Management

Other fact sheets related to landscape management may also be helpful at commercial and industrial sites with landscaping.

3.3 Residential Activities

Although residential activities that may pollute stormwater runoff are typically conducted on a smaller scale than industrial, commercial and municipal operations, the cumulative impact of residential sources of pollution can be significant. As discussed in Section 3.1, municipal stormwater programs should include efforts to reduce pollution from residential areas within their jurisdiction. This is often accomplished through a combination of ordinances, public education efforts and incentives. BMP Fact Sheets provided in this chapter that are applicable to residential sources of pollution include:

- S-3 Disposal of Household Waste
- S-4 Illicit Discharge Controls
- S-5 Good Housekeeping
- S-8 Use of Pesticides, Herbicides and Fertilizers
- S-9 Landscape Maintenance
- S-10 Snow and Ice Management

4.0 Combining Source Control BMPs to Target Pollutants of Concern

In many cases, local governments will need to combine multiple source control practices and strategies to target control of specific pollutants. For impaired streams that have been assigned Total Maximum Daily Loads (TMDLs), municipal stormwater discharge permittees may receive a wasteload allocation, resulting in specific requirements to reduce pollutant loading in their stormwater permits. For example, bacteria is a leading cause of stream impairment nationally and in Colorado. Table 5-3 provides an example of a multi-faceted source control plan targeted toward reducing bacteria loading to streams. Similar combinations of source control practices can be targeted toward nutrients and other pollutants. To produce long-term behavioral change, a well-planned and executed public education campaign may be needed, combined with incentives and fines.

Table 5-3. Example Source Control Plan Targeting Bacteria
(Source: Colorado E. coli Work Group and WWE 2009)

Bacteria Source	Potential BMP/Management Strategy
Urban Areas	
Domestic Pets (dogs and cats)	Signage to pick up dog waste, providing pet waste bags and garbage cans. Enforcement of pet waste ordinances. Use of dog parks away from environmentally sensitive areas.
Urban Wildlife	Reduce food waste sources from commercial waste/grease spillage entering the storm drain.
Illicit Connections to Storm Sewers	Identification and removal of illicit sanitary and floor drain connections through municipal stormwater dry weather survey programs.
Leaking Sanitary Sewer Lines	"TVing" sanitary sewer lines to identify leaks or breaks that may cause seepage of untreated sanitary wastewater to streams or storm sewers.
Illegal Dumping	Enforcement, by municipal stormwater programs, related to illegal dumping.
Runoff from Urban Areas	Encouraging low impact development and development designs that minimize directly connected impervious areas, allowing stormwater to seep into the ground rather than run off into storm sewers. See Chapters 3 and 4.
Dry Weather Irrigation Flows	Dry weather flows from storm sewers can be reduced through better-controlled lawn/park irrigation practices.
Transient Populations	Support of city shelters and services to reduce homelessness.
Open Space	
Waterfowl Canadian Geese	Population controls (e.g., egg oiling, addling, dog harassment). See www.geesepeace.org for more information. Habitat modification is another potential BMP. Restoration of degraded riparian buffers.
Wildlife: Beavers, deer, raccoons, coyotes, mice	Consult with Colorado Division of Wildlife (CDOW); consider controls to make storm drains less desirable as animal homes; beaver trapping and relocation may be a consideration. Restoration of degraded riparian buffers.
Domestic Pets	See description above. In addition, strategic trail design incorporating vegetative buffers and grading away from the stream. Restoration of degraded riparian buffers.

5.0 References

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Covering Outdoor Storage and Handling Areas S-1

Description

When raw materials, byproducts, finished products, storage tanks, and other materials are stored or handled outdoors, stormwater runoff that comes in contact with the materials can become contaminated. Proactively covering storage and handling areas can be an effective source control for such areas. Coverings can be permanent or temporary and consist of tarp, plastic sheeting, roofing, enclosed structures, or other approaches that reduce exposure of materials to rainfall, runoff, and wind.

Photograph CS-1. Covered truck loading dock helps reduce exposure of materials to runoff.

Appropriate Uses

Covering is appropriate for areas where solids (e.g., gravel, salt, compost, building materials) or liquids (e.g., oil, gas, tar) are stored, prepared, or transferred. Consider covering the following areas:

- **Loading and Unloading**: Loading and unloading operations usually take place outside on docks, truck terminals, or outside storage or staging areas at industrial and commercial sites. Materials spilled, leaked, or lost during loading and unloading may collect in the soil or other surfaces and be carried away by runoff, or when the area is cleaned. In addition to spills to the ground surface, rainfall may wash pollutants off machinery used to unload and load materials. Materials may be spilled during transfer between storage facilities and truck or rail car during pumping of liquids, pneumatic transfer of dry chemicals, mechanical transfer using conveyor systems, or transfers of bags, boxes, drums, or other containers by forklift, trucks, or other material handling equipment.

- **Aboveground Tanks/Liquid Storage**: Accidental releases of chemicals from above-ground liquid storage tanks can contaminate stormwater with a variety of pollutants. Several common causes of accidental releases from above-ground tanks include: external corrosion and structural failure, problems due to improper installation, spills and overfills due to operator error, failure of piping systems, and leaks or spills during pumping of liquids or gases between trucks or rail cars to a storage facility.

- **Outside Manufacturing**: Common outside manufacturing activities may include parts assembly, rock grinding or crushing, metals painting or coating, grinding or sanding, degreasing, concrete manufacturing, parts cleaning or operations that use hazardous materials. These activities can result in dry deposition of dust, metal and wood shavings and liquid discharges of dripping or leaking fluids from equipment or processes and other residuals being washed away in storm runoff. In addition to the manufacturing process, outside storage of materials and waste products may occur in conjunction with outside manufacturing.

- **Waste Management**: Wastes spilled, leached, or lost from outdoor waste management areas or outside manufacturing activities may accumulate in soils or on other surfaces and be carried away by rainfall runoff. There is also the potential for liquid wastes from surface impoundments to overflow to surface waters or soak the soil where they can be picked up by runoff. Possible stormwater

contaminants include toxic compounds, oil and grease, oxygen-demanding organics, paints and solvents, heavy metals and high levels of suspended solids. Lack of coverage of waste receptacles can result in rainwater seeping through the material and collecting contaminants or the material being blown around the site and into the stormwater collection system. Typical contaminant sources include: landfills, waste piles, wastewater and solid waste treatment and disposal, land application sites, dumpsters, or unlabeled drums.

- **Outside Storage of Materials**: Raw materials, intermediate products, byproducts, process residuals, finished products, containers, and materials storage areas can be sources of pollutants such as metals, oils and grease, sediment and other contaminants. Pollutant transport can occur when solid materials wash off or dissolve into water, or when spills or leaks occur.

- **Salt Storage:** Salt left exposed to rain or snow may migrate to the storm sewer or contaminate soils. Salt spilled or blown onto the ground during loading or unloading will dissolve in stormwater runoff. Stormwater contaminated with salt in high concentrations can be harmful to vegetation, aquatic life and groundwater quality. Typical contaminant sources include salt stored outside in piles or bags, salt loading and unloading areas, and salt/sand storage piles used for deicing operations.

Practice Guidelines

- Where practical, conduct operations indoors. Where impractical, select an appropriate temporary or permanent covering to reduce exposure of materials to rainfall and runoff.

- The type of covering selected depends on a variety of factors such as the type and size of activity being conducted and materials involved. Types of cover range from relatively inexpensive tarps and plastic sheeting to overhead structures or fully enclosed buildings equipped with ventilation, lighting, etc.

- Covering practices should be combined with Good Housekeeping BMPs to be most effective. Spill containment berms are also often needed at industrial sites.

- Measures such as tarps and plastic sheets typically require more frequent inspection and maintenance than constructed facilities.

Spill Prevention, Containment and Control S-2

Description

Spills and leaks of solid and liquid materials processed, handled or stored outdoors can be a significant source of stormwater pollutants. Spilled substances can reach receiving waters when runoff washes these materials from impervious surfaces or when spills directly enter the storm sewer system during dry weather conditions.

Photograph SPCC-1. Use of secondary containment around supplies stored outside helps to reduce the likelihood of spill and leaks reaching the storm sewer system in runoff. Photo courtesy of Tom Gore.

Effective spill control includes both spill prevention and spill response measures and depends on proper employee training for spill response measures and may also include structural spill containment, particularly at industrial locations. Structural spill containment measures typically include temporary or permanent curbs or berms that surround a potential spill site. Berms may be constructed of concrete, earthen material, metal, synthetic liners, or other material that will safely contain the spill. Spill control devices may also include valves, slide gates, or other devices that can control and contain spilled material before it reaches the storm sewer system or receiving waters.

Appropriate Uses

Implement spill prevention, containment and control measures at municipal, commercial and industrial facilities in areas where materials may be spilled in quantities that may adversely impact receiving waters when discharged directly or through the storm sewer system. Check local, state, and/or federal regulations to determine when spill containment and control measures are required by law. Spill Prevention, Control and Countermeasures Plans may be required for certain facilities handling oil and hazardous substances sunder Section 311(j)(1)(C) of the federal Clean Water Act.

Practice Guidelines

Also See These BMP Fact Sheets

- Covering Storage/Handling Areas
- Good Housekeeping
- Vehicle Fueling, Maintenance, Washing & Storage
- Preventative Maintenance

Spill Prevention Measures

- Train employees on potential sources of pollution on-site and provide clear, common-sense spill prevention practices. Require that these practices be strictly followed.
- Identify equipment that may be exposed to stormwater, pollutants that may be generated and possible sources of leaks or discharges.
- Perform regular inspection and preventative maintenance of equipment to ensure proper operation and to check for leaks or evidence of discharge (stains). Provide clear procedures to ensure that needed repairs are completed and provide temporary leak containment until such repairs can be implemented.

- Drain or replace motor oil and other automotive fluids in a designated area away from storm sewer inlets. Collect spent fluids and recycle or dispose of properly. Never dispose of these fluids in the storm sewer or sanitary sewer.

- In fueling areas, clean up spills with dry methods (absorbents) and use damp cloths on gas pumps and damp mops on paved surfaces. Never use a hose to "wash down" a fuel spill.

- Where practical, reduce stormwater contact with equipment and materials by implementing indoor or covered storage, implementing stormwater run-on control measures and following good housekeeping practices.

Identification of Spill Areas

Identify potential spill areas, potential spill volumes, material types, frequency of material use, and drainage paths from spill areas with relation to storm sewer inlets, adjacent waterbodies, structural BMPs, and containment structures. Use this information to determine the types of spill prevention and control measures needed specific to the site conditions. Examples of potential spill locations include:

- Loading and unloading areas

- Outdoor storage areas

- Outdoor manufacturing or processing activities

- Waste disposal/storage areas

- Areas that generate significant dust or particulates (that may be subsequently deposited on the ground)

- Salt piles

- Areas prone to spills based on past experience at the site

- Locations where other routine maintenance activities occur such as equipment maintenance and cleaning, pesticide/fertilizer application, etc.

Additionally, areas where smaller leaks may occur such as parking should also have basic spill cleanup procedures.

Material Handling Procedures

From a water quality perspective, the primary principle behind effective material handling practices is to minimize exposure to stormwater. This can be accomplished by storing the material indoors under weather-resistant covering, elevating the material off the ground by using pallets, and diverting stormwater around materials storage areas. Representative outdoor materials handling procedures include:

- Keep bulk solid materials such as raw materials, sand, gravel, topsoil, compost, concrete, packing materials, metal products and other materials covered and protected from stormwater.

- When practical, store materials on impermeable surfaces.

- Store hazardous materials according to federal, state, and local hazardous materials requirements.

- Adopt procedures that reduce the chance of spills or leaks during filling or transfer of materials.
- Substitute less toxic or non-toxic materials for toxic materials.
- Store containers that are easily punctured or damaged away from high traffic areas (i.e., adopt a materials flow/plant layout plan).
- Add waste-capture containers such as collection pans for lubricating fluids.
- Store drums and containers with liquid materials on impermeable surfaces and provide secondary containment where appropriate. Drums stored outdoors should be located on pallets to minimize contact with runoff.

Spill Response Procedures and Equipment

Spill response procedures should be tailored to site-specific conditions and industry-specific regulatory requirements. General spill response procedures include:

- Containment and cleanup of spills should begin promptly after the spill is observed.
- Sweep up small quantities of dry chemical or solids to reduce exposure to runoff. Shoveling may be used for larger quantities of materials.
- Absorbents should be readily accessible in fueling areas or other areas susceptible to spills.
- Wipe up small spills with a shop rag, store shop rags in appropriate containers, dispose of rags properly or use a professional industrial cleaning service.
- Contain medium-sized spills with absorbents (e.g., kitty litter, sawdust) and use inflatable berms or absorbent “snakes” as temporary booms for the spill. Store and dispose of absorbents properly. Wet/dry vacuums may also be used, but not for volatile fluids.
- Develop procedures and locations for containing and storing leaking containers.
- Install drip pans below minor equipment leaks and properly dispose of collected material until a repair can be made.
- For large spills, first contain the spill and plug storm drain inlets where the liquid may migrate off-site, then clean up the spill.
- Excavation of spill areas to removed contaminated material may be required where large liquid spills occur on unpaved surfaces.
- An inventory of cleanup materials should be maintained onsite and strategically located based on the types and quantities of chemicals present.

Structural Spill Containment Measures

Two general approaches are often used when implementing spill containment measures. The first approach is designed to contain the entire spill. The second approach uses curbing to route spilled material to a collection basin. Both containment berming and curbing should be sized to safely contain or convey to a collection basin a spill from the largest storage tank, rail car, tank truck, or other containment device in the possible spill area. The spill containment area must have an impermeable surface (e.g.,

impermeable liner, asphalt or concrete) to prevent groundwater contamination. The containment system must be designed to enable collection and removal of spilled material through a pump or vacuum trucks, use of sorbent or gelling material, or other measures. Material removed from the spill area must be disposed of or recycled according to local, state, and federal standards.

If the capacity of the containment berming or the collection basin is exceeded, supplemental spill control measures should be available such as a portable containment device, sorbent materials, or gelling agents that eventually solidify the material. Water that collects within containment areas due to rainfall or snowmelt must be appropriately treated before release from the spill area.

Spill Plan Development

Many industries are required by federal law to have a Spill Prevention, Control and Countermeasures Plan (SPCC) that meets specific regulatory criteria when certain types and quantities of materials are used or processed at a site. These plans can be instrumental in developing a spill control plan for stormwater management purposes. Even if an SPCC plan is not legally required at a site, a spill control plan for stormwater management purposes may be necessary. Representative information appropriate for a spill control plan, building on concepts previously introduced in this Fact Sheet, includes:

- Site plan showing where materials are stored and handled, and where associated activities occur.
- Notification procedures to be used in the event of an accident
- Instructions for clean-up procedures.
- A designated person with spill response and clean-up authority.
- Training of key personnel in plan and clean-up procedures.
- Signs posted at critical locations providing a summary of SPCC plan information, phone numbers, contacts, equipment locations, etc.
- Provisions requiring spills to be cleaned up, corrective actions taken, or countermeasures implemented immediately.
- Provisions for absorbents to be made available for use in fuel areas, and for containers to be available for used absorbents.
- Prohibition on washing absorbents into the storm drainage system or into the sanitary sewer system via floor drains.
- Provision for emergency spill containment and clean-up kits in accessible and convenient locations. Kits should contain the appropriate clean-up materials applicable to the materials stored at the site.

Key Spill Notification Contacts in Colorado

- Colorado Department of Public Health and Environment Toll-Free 24-hour Environmental Emergency Spill Reporting Line: 1-877-518-5608
- National Response Center: 1-800-424-8802 (24-hour)
- Local Emergency Planning Committee (OEM): 303-273-162
- Division of Oil & Public Safety-Storage Tanks: 303-318-8547
- Oil and Gas Conservation Commission: 303-894-2100 or 1-888-235-1101 (toll-free spill/complaint line)

Description

Improperly disposed household wastes are a source of stormwater pollution. These wastes can include household chemicals, pet waste, yard waste, litter, automotive maintenance waste, and others. These materials can be transported in stormwater when the materials are dumped directly into the storm drains or when they are spilled on impervious surfaces and washed into the storm sewer system. Household wastes can contribute solids, nutrients, oxygen demanding substances, toxic substances, and bacteria to receiving waters. Improper disposal of household wastes on the ground surface can also lead to groundwater contamination.

Photograph DHW-1. Placing storm drain markers (or stenciling) at storm sewer inlets is a public education tool that can be used to educate citizens and discourage improper disposal of household waste in storm drains. Photo courtesy of Nonpoint Source Colorado.

Proper disposal of household waste is dependent on behavioral change, which can be encouraged through public education programs and local ordinances that prohibit improper disposal of household waste. Additionally, local governments can provide appropriate facilities for proper disposal of waste.

This Fact Sheet focuses primarily on household waste. See the Good Housekeeping Fact Sheet for additional information on waste management at commercial and industrial sites.

Appropriate Uses

Educational efforts related to proper disposal of household waste can be targeted to homeowners and businesses through municipal programs, civic groups, and others. Local governments should consider measures needed in the following general categories:

- **Household/Commercial Waste**: Household waste includes materials discarded on the land surface or into the stormwater system from residential and commercial areas. Wastes from commercial businesses are generated by stores, restaurants, hotels, offices, and other non-manufacturing activities. Household waste disposal objectives include containing and properly disposing of refuse (garbage), reducing litter, and encouraging proper household toxic waste disposal through public education and access to appropriate disposal facilities.

- **Litter**: Most litter is biodegradable and can create an oxygen demand in water as it decomposes. Examples of litter are paper products, used diapers, etc. Research by Keep America Beautiful, Inc. (1990) has shown that people litter where litter has already accumulated. Also according to Keep America Beautiful, Inc. (1987), pedestrians and motorists account for less than 25 percent of litter, with the other sources being household waste, commercial and industrial waste, haulage vehicles, loading docks, and construction sites. Reduction of litter through proper disposal can reduce its accumulation on the urban landscape and its eventual entry into the stormwater system.

- **Pet Waste**: Pet waste deposited on the ground can be transported by the storm drainage system to receiving waters or by overland flow into waterways. Fecal matter potentially contains pathogenic viruses and bacteria; it also creates an oxygen demand in water. The majority of improperly disposed pet waste occurs in public areas, such as streets and parks. Pet waste ordinances are common in municipalities; however, these are difficult to enforce, especially with limited municipal resources. Education can help bring this problem to the public's attention, and can thereby reduce deposition of pet waste on urban surfaces.

- **Yard Waste**: Yard waste includes limbs, leaves and grass clippings that can contribute nutrients, lawn chemicals, and oxygen demand to receiving waters when washed into storm sewers and waterways. Public education efforts on the benefits of composting and on proper disposal of yard waste can help to reduce the volume of yard waste entering the stormwater system and receiving waters. Most yard waste can be reused following composting, with the exception of weeds and diseased plant materials.

Composting

Composting is a natural method for recycling organics such as yard trimmings and food scraps, which comprise nearly a quarter of municipal solids waste generated (Keep America Beautiful 2010). Nearly half of all U.S. states now ban yard waste from landfills because it represents such a large volume that can be productively composted. Composted yard waste used as mulch or soil amendment can provide landscape water conservation benefits, reduce the burden on landfills and is protective of water quality.

- **Used Oil and Automotive Fluids**: Used oil and automotive fluids including antifreeze, brake fluid, transmission fluid, grease, other lubricants, and petroleum-based cleaning solvents are wastes generated during automobile maintenance by residential households and commercial businesses. These can enter the storm drainage system if poured directly into storm inlets or from residual on concrete or asphalt exposed to precipitation. Improper disposal of used oil and automotive fluids causes receiving waters to become contaminated with hydrocarbons and residual metals that can be toxic to stream organisms. Used oil and other petroleum products can be recycled and are accepted by many auto parts stores and repair shops. Public education on the location of these centers, the benefits of recycling, prevention of fluid leaks, and the importance of proper disposal for improving stormwater quality can reduce the amounts of oil and used automotive fluids reaching receiving waters.

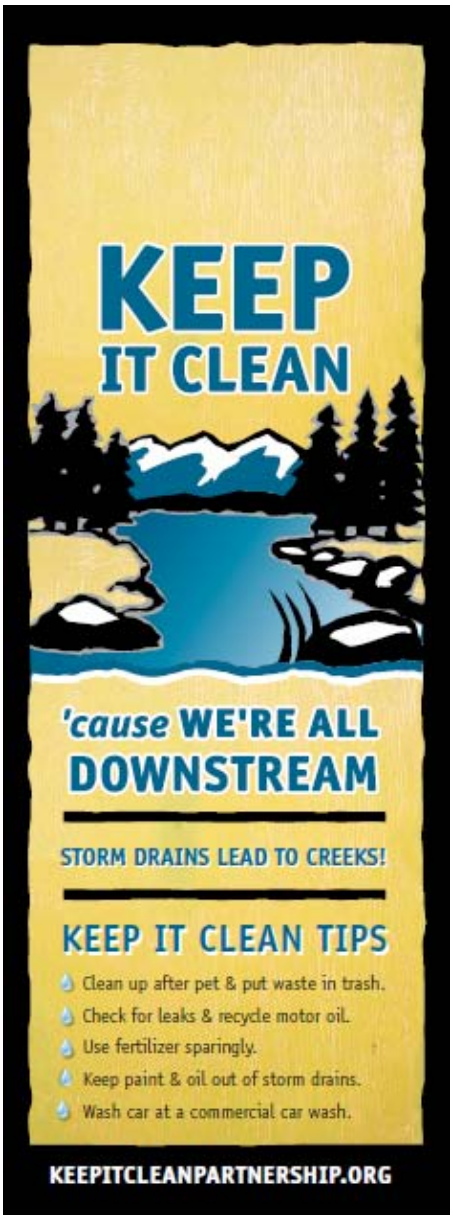
- **Toxic Wastes**: Toxic wastes are generated in small quantities by residential households and commercial businesses. Examples include paint, solvents, putties, cleaners, waxes, polishes, oil products, aerosols, acids, caustics, pesticides, herbicides, and certain medicines or cosmetics. These products and their containers should always be disposed of in accordance with the product label or recycled, if appropriate. When such toxic substances are improperly disposed of by dumping on impervious surfaces or into street gutters or storm inlets, stormwater can transport these materials to receiving waters.

Municipal Recycling Programs

Many communities throughout the country have implemented municipal recycling programs, rather than relying on citizens to research and seek out recycling opportunities on their own. Curbside recycling programs and municipal education campaigns can improve the success of recycling programs. For more information on implementing a municipal recycling program, visit a variety of U.S. Environmental Protection Agency websites such as: http://www.epa.gov/epawaste/conserve/rrr/index.htm and http://www.epa.gov/region4/waste/rcra/mgtoolkit/index.html or review well developed local programs such as Denver Recycles.

Practice Guidelines

To reduce improper disposal of household waste, implement public education efforts regarding how improper disposal of wastes can degrade the quality of streams, rivers, lakes, and wetlands. Local governments have many public education options that can be tailored to fit local needs and budget constraints the best. Within local governments, opportunities for coordinated efforts among multiple departments may be beneficial. For example, properly composting of yard waste can provide a stormwater benefit when these materials are kept out of the gutter, as well as a water conservation benefit when the materials are reused as mulch and a solid waste management benefit when these materials are kept out of landfills. Similarly, public works and parks and recreation departments both benefit from efforts related to pet waste disposal signage as well as disposal facilities in parks.



Photograph DHW-2. Check with state and local water quality agencies for public education materials such as this door hanger developed by the Keep It Clean Partnership that can be adopted for use in your community. Photo courtesy of Nonpoint Source Colorado.

Representative public education strategies may include:

- Development, publication, and distribution of brochures.
- Utility bill inserts, flyers, and handbills.
- Newspaper articles and/or advertisements.
- Development and distribution of educational videos.
- Public workshops, field demonstrations, or presentations to targeted civic organizations, youth organizations, etc.
- Developing and offering school curricula or assembly programs.
- Creating posters, signs, and graphics for installation at parks, school hallways, trails, etc.
- Storm drain stenciling to discourage dumping of materials into storm drains.
- Signs, including graphics, on dumpsters and other locations encouraging proper waste disposal.
- Signs in parks and along streets on pet waste control and ordinances.
- Brochures and utility bill inserts on separation of wastes and recycling.
- Advertising the locations of existing toxic disposal sites and waste recycling centers.
- Advertising the locations of existing automobile fluids and used oil disposal sites.

- Developing campaigns promoting voluntary neighborhood clean-up efforts.
- Advertisements or notices of private locations accepting yard waste for composting.
- Information on backyard or neighborhood composting and proper disposal of yard waste.

In addition to public education efforts, local governments can provide facilities that provide readily available proper disposal opportunities. These practices include:

- Establishing and maintaining household toxics disposal sites.
- Annual or curbside collection of household toxics.
- Pet waste disposal bags in public parks.
- Providing waste containers in problem litter areas.
- Requiring waste-haulage truck covers.
- Seasonal or on-going collection programs for grass clippings, tree branches, and leaves with disposal at composting or chipping facilities, paired with distribution programs for reuse of composted or chipped materials.

With regard to household toxics, local governments should be aware that collection and disposal of household wastes is expensive. Such programs require adequate training of operators, analysis of unknown materials, safe transport and containers, extensive recordkeeping and awareness of regulatory requirements (e.g., the federal Resource Conservation and Recovery Act) regarding disposal of such materials.

Illicit Discharge Controls S-4

Description

Illicit discharges are non-stormwater discharges into a storm drain system, with some limited exceptions specified in state and local discharge permits (e.g., fire fighting water, springs, and others). Examples of illicit discharges include illegal dumping (e.g., used oil), accidental spills, failing septic systems, improper disposal of sewage from recreational activities such as boating or camping, and improper plumbing of sanitary discharges from residences and commercial or industrial establishments into the storm sewer system. A common cause of illicit discharges is connection of building or garage or floor drains to the storm sewer system.

Photograph IDC-1. Mapping and dry weather investigation of storm sewer outfalls is an important tool in identifying and removing illicit connections. Photo courtesy of WWE.

Control of illicit discharges involves a multi-faceted effort based on knowledge of the storm sewer system, use of ordinances to prohibit illicit discharges, development of a coordinated plan to detect and address illicit discharges, and a public education program to increase awareness of the problems caused by illicit discharges.

Appropriate Uses

Illicit discharge control measures are usually implemented by municipal governments and metropolitan districts, but may also be relevant to campus-scale developments or industries. Illicit discharge controls are closely related to practices identified in the Good Housekeeping BMP Fact Sheet.

Practice Guidelines

Practice guidelines for illicit discharge controls are discussed in three general categories:

1. Public education to reduce illegal dumping and discharges,
2. Municipal actions to identify and remove illegal connections to the storm sewer system, and
3. Accidental spill response measures.

Public Education to Reduce Illegal Dumping and Discharges

Public education and awareness are the foundation for reducing illegal dumping and some types of illicit discharges. For example, many citizens may not be aware that storm sewers drain to streams rather than wastewater treatment plants or may not be aware of the environmental damage caused by discharging soapy water, pet waste and other household wastes into the storm sewer system. Local governments should select public awareness and education approaches most effective for their communities, which may include a combination of some of these practices:

- Enactment of clearly written ordinances prohibiting illegal dumping and illicit connections. Many local governments already have such ordinances; however, citizens are often unaware of these. Publicity including news articles, door hangers, utility bill inserts, radio or TV advertisements, website highlights and other measures can be used to increase awareness. Such efforts may be particularly effective when connected to a specific water quality problem such as stream or lake impairments due to bacteria and/or nutrients.

- Storm drain stenciling involves placing a marker or using a stencil to paint a message on storm drains to discourage dumping down the storm drain. These messages are a public education tool so that citizens are aware that the materials that they dump down to the storm drain are discharged to a stream, as opposed to a wastewater treatment plant.

- Provide citizens with readily available contact information to report illegal dumping. Install a "hotline" telephone number to handle calls from citizens reporting illegal dumping or accidental spills.

- Create brochures and other guidance for businesses related to illegal discharges to the storm drain. Educational efforts should not only alert business owners that non-stormwater discharges are not allowed, but also provide guidance on BMPs to implement. For example, power washing discharges are process wastewater that may not be discharged to the storm sewer system. When power washing is conducted, storm drain inlet protection, wet vacuuming, collection systems, and/or other appropriate measures to prevent washwater from entering the storm drain system should be implemented.

Illicit Connections

Eliminating illicit connections plumbed into the storm drain system involves two different components:

1. Identifying and removing existing illicit connections; and

2. Preventing new illicit connections.

Removing Existing Connections

Existing illicit connections of sanitary sewers to the storm drainage system in existing developments can be identified by a systematic dry weather inspection of storm sewer outfalls following readily available illicit discharge detection and elimination guidance available from EPA. Initial screening typically involves mapping all storm sewer outfalls and conducting field inspections to identify suspect outfalls based on odor, sewage-related residue (e.g., toilet paper), discoloration, dry weather flows, etc. Grab samples of dry-weather discharges can be collected at suspect locations and analyzed for targeted water quality constituents (e.g., E. coli, temperature, pH, surfactants). Where illicit connections are probable, more advanced techniques can be used to isolate the likely source of the connection. Techniques such as temperature probes (to track diurnal temperature changes indicative of shower use suggesting a sanitary connection to a storm sewer), optical brightener screening (indicator of detergents), zinc chloride smoke testing, fluorometric dye testing, television camera inspections and other approaches can be used as follow-up measures. Once the illicit connection has been identified, the plumbing can be corrected and proper connections to the sanitary sewer system implemented.

Preventing Illicit Connections

Program elements to prevent illicit connections include:

- Ensure that existing building and plumbing codes prohibit physical connections of non-stormwater discharges to the storm drain system.
- Have a program in place to review and approve any proposed connection into a storm sewer.
- Require visual inspection of new developments or redevelopments during the construction phase to ensure that proper plumbing connections are implemented. Train field inspectors and develop field inspection procedures that prevent new illicit connections of sanitary sewer lines to storm sewers.

Accidental Spill Response

Although the storage, transport and disposal of hazardous and toxic substances is a highly regulated activity under state and federal laws, accidents will inevitably occur, resulting in potential release of chemicals and wastes into the storm sewer system. Most local police, fire, or other departments are trained and equipped to respond to such spills. Local governments should work with response personnel to ensure current mapping of storm drains and BMPs and review training procedures for spill response and cleanup. Proper training combined with readily available knowledge of the storm sewer system and appropriate spill control materials can result in more effective protection and blocking of the drainage system during spill response.

Additional Illicit Discharge Detection and Elimination Guidance

The Center for Watershed Protection and Robert Pitt (2004) prepared *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments* under EPA funding to provide guidance to communities in developing effective management programs and field guidance to reduce illicit discharges. This manual provides detailed guidance and field forms that can be used identify illicit connections.

Description

Good housekeeping practices are designed to maintain a clean and orderly work environment. The most effective first steps towards preventing pollution in stormwater from work sites simply involve using common sense to improve the facility's basic housekeeping methods. Poor housekeeping practices result in increased waste and potential for stormwater contamination.

Photograph GH-1. Use dry clean-up methods to remove spilled materials. Photo courtesy of Colorado Nonpoint Source Program.

A clean and orderly work site reduces the possibility of accidental spills caused by mishandling of chemicals and equipment and should reduce safety hazards to personnel. A well-maintained material and chemical storage area will reduce the possibility of stormwater mixing with pollutants.

Some simple procedures a facility can use to promote good housekeeping include improved operation and maintenance of machinery and processes, material storage practices, material inventory controls, routine and regular clean-up schedules, maintaining well organized work areas, signage, and educational programs for employees and the general public about all of these practices.

Appropriate Uses

Good housekeeping practices require education and training, typically targeted to industries and businesses, municipal employees, as well as the general public.

Practice Guidelines

Good housekeeping practices include these general areas:

- Operation and Maintenance
- Material Storage
- Material Inventory
- Training and Participation.

Operation and Maintenance

Consider implementing the following practices:

- Maintain dry and clean floors and ground surfaces by using brooms, shovels, vacuums or cleaning machines, rather than wet clean-up methods.
- Regularly collect and dispose of garbage and waste material.

- Routinely inspect equipment to ensure that it is functioning properly without leaking and conduct preventative maintenance and needed repairs.
- Train employees on proper clean up and spill response procedures.
- Designate separate areas of the site for auto parking, vehicle refueling and routine maintenance.
- Promptly clean up leaks, drips and other spills.
- Cover and maintain dumpsters and waste receptacles. Add additional dumpsters or increase frequency of waste collection if overflowing conditions reoccur.
- Where outdoor painting and sanding occur, implement these practices:
    - Conduct these activities in designated areas that provide adequate protection to prevent overspray and uncontrolled emissions. All operations should be conducted on paved surfaces to facilitate cleanup.
    - Use portable containment as necessary for outside operations.
    - Clean up and properly dispose of excess paint, paint chips, protective coatings, grit waste, etc.
- Maintain vegetation on facility grounds in a manner that minimizes erosion. Follow the Landscape Maintenance and Pesticide, Herbicide and Fertilizer Usage BMPs to ensure that minimum amounts of chemicals needed for healthy vegetation are applied in a manner that minimizes transport of these materials in runoff.

Material Storage Practices

Proper storage techniques include the following:

- Provide adequate aisle space to facilitate material transfer and ease of access for inspection.
- Store containers, drums, and bags away from direct traffic routes to reduce container damage resulting in accidental spills.
- Stack containers according to manufacturer's instructions to avoid damaging the containers from improper weight distribution. Also store materials in accordance with directions in Material Safety Data Sheets (MSDSs).
- Store containers on pallets or similar devices to prevent corrosion of containers that results from containers coming in contact with moisture on the ground.
- Store toxic or hazardous liquids within curbed areas or secondary containers.

Material Inventory Practices

An up-to-date materials inventory can keep material costs down by preventing overstocking, track how materials are stored and handled onsite, and identify which materials and activities pose the most risk to the environment. Assign responsibility of hazardous material inventory to individuals trained to handle such materials. A material inventory should include these steps:

- Identify all chemical substances present at work site. Perform a walk-through of the site, review

purchase orders, list all chemical substances used and obtain Material Safety Data Sheets (MSDS) for all chemicals.

- Label all containers. Labels should provide name and type of substance, stock number, expiration date, health hazards, handling suggestions, and first aid information. Much of, this information can be found on an MSDS.

- Clearly identify special handling, storage, use and disposal considerations for hazardous materials on the material inventory.

- Institute a shelf-life program to improve material tracking and inventory that can reduce the amount of materials that are overstocked and ensure proper disposal of expired materials. Careful tracking of materials ordered can result in more efficient materials use. Decisions on the amounts of hazardous materials that are stored on site should include an evaluation of any emergency control systems that are in place. All storage areas for hazardous materials should be designed to contain spills.

Training and Participation

Frequent and proper training in good housekeeping techniques reduces the likelihood that chemicals or equipment will be mishandled. To promote good housekeeping, consider implementing these practices:

- Discuss good housekeeping practices in training programs and meetings.

- Publicize pollution prevention concepts through posters or signs.

- Post bulletin boards with updated good housekeeping procedures, tips and reminders.

Description

Preventative maintenance involves proactive routine inspection and testing of plant equipment and operational systems to prevent leaks and spills. A preventative maintenance program should also include inspections of conveyance channels, storm sewers, inlets, catch basins, stormwater detention areas, and other water quality treatment systems associated with the site.

Photograph PM-1. Preventative maintenance can reduce the frequency and occurrence of leaked or spilled material that can be transported in stormwater runoff.

Appropriate Uses

This BMP is applicable to municipal, industrial and commercial sites. Preventative maintenance programs typically incorporate practices identified in the Good Housekeeping, Materials Storage and Handling, Vehicle Fueling, Maintenance and Storage, and other source control BMPs. See the Structural BMP Maintenance chapter for preventative maintenance for stormwater BMPs.

Practice Guidelines

Elements of a good preventative maintenance program should include:

- Identification of equipment or systems, which may malfunction and cause spills, leaks, or other situations that could lead to contamination of stormwater runoff. Typical equipment to inspect includes pipes, pumps, storage tanks and bins, pressure vessels, pressure release valves, process and material handling equipment.
- Once equipment and areas to be inspected have been identified at the facility, establish schedules and procedures for routine inspections and scheduling repairs.
- Periodic testing of plant equipment for structural soundness is a key element in a preventative maintenance program.
- Promptly repair or replace defective equipment found during inspection and testing.
- Keep spare parts for equipment that needs frequent repair.
- Replace worn parts prior to failure.
- Implement, maintain and regularly review a record keeping system for scheduling tests and documenting inspections in the preventative maintenance program. Be sure to follow inspections promptly with completion of needed repairs. Clearly record the problem and the specific actions taken to correct the problem. Photos can be helpful components of such records. An annual review of these records should be conducted to evaluate the overall effectiveness of the preventative maintenance program. Refinements to the preventative maintenance procedures and tasking should be implemented as necessary.

Description

Photograph VF-1. Use drip pans to collect leaks from vehicles until repairs can be completed. Photo courtesy of Tom Gore.

Areas where vehicles are fueled, maintained, and stored/parked can be pollutant "hot spots" that can result in hydrocarbons, trace metals, and other pollutants being transported in stormwater runoff. Proper fueling operations, storage of automotive fluids and effective spill cleanup procedures can help reduce contamination of stormwater runoff from vehicle maintenance and fueling facilities.

Fuel-related spills can occur due to inattention during fueling or "topping off" fuel tanks. Common activities at commercial, industrial and municipal maintenance shops include parts cleaning, vehicle fluid replacement, and equipment replacement and repair. Some of the wastes generated at automobile maintenance facilities include solvents (degreasers, paint thinners, etc.), antifreeze, brake fluid and brake pad dust, battery acid, motor oil, fuel, and lubricating grease. Fleet storage areas and customer and employee parking can also be a source of vehicle-related contamination from leaks, antifreeze spills, etc.

Appropriate Uses

These BMP guidelines are applicable to vehicle maintenance, fueling, fleet storage and parking facilities. Be aware that washing vehicles and equipment outdoors or in areas where wash water flows onto the ground can pollute stormwater. Vehicle wash water is considered process wastewater that should not be discharged to the storm sewer system. Consult state and federal discharge permit requirements for proper disposal of vehicle washwater, which is typically accomplished through discharge to the sanitary sewer system.

Practice Guidelines[1]

Vehicle Maintenance

The most effective way to minimize wastes generated by automotive maintenance activities is to prevent their production in the first place. Consider adopting these practices:

- Perform maintenance activities inside or under cover. When repairs cannot be performed indoors, be sure to use drip pans or absorbents.
- Keep equipment clean and free of excessive oil and grease buildup.

[1] Guidelines adapted from the USEPA Menu of BMPs.

- Promptly cleanup spills using dry methods and properly dispose of waste. When water is required, use as little as possible to clean spills, leaks, and drips.
- Use a solvent collection service to collect spent solvent used for parts cleaning. Where practical, use detergent-based, steam cleaning, or pressure-based cleaning systems instead of organic solvent degreasers when practical. (Be aware that cleaning water discharged into the sanitary sewer may require pre-treatment prior to discharge.)
- When using liquids for cleaning, use a centralized station to ensure that solvents and residues stay in one area. Locate drip pans and draining boards to direct solvents back into a solvent sink or holding tank for reuse.
- Store used oil for recycling in labeled tanks. Locate used oil tanks and drums away from storm drains, flowing streams, and preferably indoors.
- Use non-hazardous or less hazardous alternatives when practical. For example, replace chlorinated organic solvents with non-chlorinated ones like kerosene or mineral spirits.
- Properly recycle or dispose of grease, oil, antifreeze, brake fluid, cleaning solutions, hydraulic fluid, batteries, transmission fluid, worn parts, filters, and rags.
- Drain and crush oil filters before recycling or disposal.
- Drain all fluids and remove batteries from salvage vehicles and equipment.
- Closely monitor parked vehicles for leaks and place pans under any leaks to collect the fluids for proper disposal or recycling.
- Install berms or other measures to contain spills and prevent work surface runoff from entering storm drains.
- Develop and follow a spill prevention plan. This includes a variety of measures such as spill kits and knowing where storm drains are located and how to protect them (e.g., drain mat, berm) when larger spills occur. (See the Spill Prevention, Containment and Control BMP for more information.)
- Conduct periodic employee training to reinforce proper disposal practices.
- Promptly transfer used fluids to recycling drums or hazardous waste containers.
- Store cracked batteries in leak-proof secondary containers.
- Inspect outdoor storage areas regularly for drips, spills and improperly stored materials (unlabeled containers, auto parts that might contain grease or fluids, etc.). This is particularly important for parking areas for vehicles awaiting repair.
- Structural stormwater BMPs in vehicle hotspot areas require routine cleanout of oil and grease, sometimes monthly or more frequently. During periods of heavy rainfall, cleanout is required more often to ensure that pollutants are not washed through the trap. Sediment removal is also required on a regular basis to keep the BMP working efficiently.

Vehicle Fueling

- Designated fueling areas should be designed to prevent stormwater runoff and spills. For example, fuel-dispensing areas should be paved with concrete or an equivalent impervious surface, with an adequate slope to prevent ponding, and separated from the rest of the site by a grade break or berm that prevents run-on of stormwater.

- Fuel dispensing areas should be covered. The cover's minimum dimensions must be equal to or greater than the area within the grade break or the fuel dispensing area so that the fueling area is completely covered. It may be necessary to install and maintain an oil capture device in catch basins that have the potential to receive runoff from the fueling area.

- For facilities where equipment is being fueled with a mobile fuel truck, establish a designated fueling area. Place temporary "caps" over nearby catch basins or manhole covers so that if a spill occurs, it is prevented from entering the storm drain. A form of secondary containment should be used when transferring fuel from the tank truck to the fuel tank. Storm drains in the vicinity should also be covered. Install vapor recovery nozzles to help control drips, as well as reduce air pollution.

- Keep spill response information and spill cleanup materials onsite and readily available.

- Fuel-dispensing areas should be inspected regularly and repair promptly completed. Inspectors should:

    - Check for external corrosion and structural failure in aboveground tanks.

    - Check for spills and overfills due to operator error.

    - Check for failure of any piping systems.

    - Check for leaks or spills during pumping of liquids or gases from a truck or rail car to a storage facility or vice versa.

    - Visually inspect new tank or container installations for loose fittings, poor welds, and improper or poorly fitted gaskets.

    - Inspect tank foundations, connections, coatings, tank walls, and piping systems. Look for corrosion, leaks, cracks, scratches, and other physical damage that may weaken the tank or container system.

- Aboveground and belowground tanks should be tested periodically for integrity by a qualified professional.

- Dry cleanup methods should be employed when cleaning up fuel-dispensing areas. Such methods include sweeping to remove litter and debris and using rags and absorbents for leaks and spills. Water should not be used to wash these areas. During routine cleaning, use a damp cloth on the pumps and a damp mop on the pavement, rather than spraying with a hose. Fuel dispensing nozzles should be fitted with "hold-open latches" (automatic shutoff) except where prohibited by local fire departments. Signs can be posted at the fuel dispenser or island warning vehicle owners/operators against "topping off" vehicle fuel tanks.

- Written procedures that describe these BMPs should be provided to employees who will be using fueling systems.

Description

Pesticides, herbicides, fertilizers, fuel and other landscape maintenance chemicals must be properly applied, stored, handled and disposed of to prevent contamination of surface water and groundwater. Misuse of pesticides and herbicides can result in adverse impacts to aquatic life, even at low concentrations. Misuse of fertilizer can result in increased algae growth in waterbodies due to excessive phosphorus and nitrogen loading.

Photograph PHF-1. Pesticide, fertilizer, and herbicide applications should be applied in the minimum quantities necessary to achieve specific landscaping objectives, while keeping chemicals out of storm drain systems. Photo courtesy of WWE.

Appropriate Uses

This BMP applies to both commercial and municipal landscaping operations, as well as to homeowners and homeowner associations. For commercial operations, the scale of chemical usage and handling is greater; therefore, additional measures are often required under federal and state law.

Practice Guidelines[1]

Public education regarding appropriate landscape chemical application and handling is an important action that local governments can take to reduce the likelihood that landscape chemicals are washed into storm drains and receiving waters through runoff. Local governments can make landscape care information available on websites, in utility mailers, lawn care centers, and other locations. A variety of professional organizations for lawn care professionals already exist and can be contacted for additional information or partnered with for both public education and landscape professional educational efforts and certification programs (See www.ext.colostate.edu and www.greenco.org.).

General Guidelines for Pesticide, Herbicide, and Fertilizer Application

- Apply fertilizers, pesticides, and other chemicals according to manufacturer's directions. The label is the law for pesticide usage. Apply pesticides and herbicides only when needed and use in a manner to minimize off-target effects. See the Landscape Management Fact Sheet for fertilizer application guidelines.
- Accurately diagnose the pest. Disease and insect symptoms can mimic each other in many plants. A fungicide will not control an insect, and an insecticide will not control a disease.
- Be aware that commercial chemical applicators must receive thorough training, licensure and proper certification prior to chemical use. Consult Colorado Department of Agriculture (CDA) Regulations for specific requirements.

[1] These practice guidelines have been adapted from the *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (GreenCO and WWE 2008). See that manual for additional detail and references.

- Know characteristics of the application site, including soil type and depth to groundwater to avoid migration of chemicals into groundwater.
- Select pesticides and herbicides best suited to the characteristics of the target site and the particular pest or weed. Half-life, solubility, and adsorption should be compared to site characteristics to determine the safest chemical. Choose least toxic and less persistent sprays whenever possible based on comparison of labels and associated material safety data sheets.
- Employ application techniques that increase efficiency and allow the lowest effective application rate. Carefully calibrate application equipment and follow all label instructions.
- Recognize that it is not realistic for a landscape to be completely pest-free or weed-free. Consider using Integrated Pest Management (IPM) strategies to minimize chemical usage.
- Keep pesticide and fertilizer equipment properly calibrated according to the manufacturer's instructions and in good repair. Recalibrate equipment periodically to compensate for wear in pumps, nozzles and metering systems. Calibrate sprayers when new nozzles are installed.
- All mixing and loading operations must occur on an impervious surface.

Integrated Pest Management (IPM)

Integrated pest management (IPM) (also known as Plant Health Care) is the practice of using targeted biological, chemical, cultural, and physical measures to manage pests while minimizing or eliminating the use of chemical pesticides. IPM measures benefit the landscape and help reduce the likelihood that lawn chemicals will be washed into storm drainage systems in stormwater runoff. The pros and cons of various tools should be weighed and used in an integrated manner to achieve pest control objectives in a safe, effective, and cost-effective manner. Basic IPM practices that can be adopted include:

- Consider spot treatments of pests rather than treating the entire area.
- Consider pest occurrence and history when developing pest management strategies.
- Time pesticide application to minimize host plant damage and maximize pest control.
- Rotate annual garden plants to reduce the buildup of soil-borne pests. Clean up plant litter and remove weeds before they go to seed. Remove infested plant residue from the garden in the fall so that pests do not over-winter there.
- Implement cultural controls such as proper plant selection, planting time, and planting method to reduce susceptibility to insects, pests, and diseases, thereby reducing pesticide usage.
- Implement mechanical and physical controls where practical as an alternative to chemical application. Examples include a wide variety of practices such as "collars" around seedlings, mulching, solar heating, syringing, handpicking, mowing, hoeing, and traps.
- Use biological controls where appropriate to reduce pesticide usage. For example, introduce natural enemies of pests such as lady beetles and green lacewings. (Note: pesticides may kill these natural enemies.)
- Consider applying environmentally friendly chemical alternatives such as insecticidal soaps, horticultural oils, and other such measures when practical and effective and when mechanical approaches are impractical.

Application Practices

- Keep records of pesticide application and provide signage as required by law.
- Do not apply pesticides or herbicides during high temperatures, windy conditions or immediately prior to heavy rainfall or irrigation.
- Treat for and control noxious weeds prior to installing the landscape using an herbicide targeted to the weeds that are present and applied in accordance with the product label.
- Be aware that some pesticide formulations are not compatible with other pesticides and combining them may result in increased potency and phytotoxicity.

Managing Mosquitoes in Stormwater Facilities
(Adapted from: Peairs and Cranshaw 2007)

The key to mosquito control is larval management. Larvae occur in specific areas and can be controlled by modifying the habitat through drainage or insecticides applied to larval breeding sites. Weekly mosquito inspections at stormwater facilities with targeted treatments are frequently less costly and more effective than regular widespread application of insecticides. These inspections can be performed by a mosquito control source and typically start in mid-May and extend to mid-September. Mosquito control measures must be cost effective and environmentally sound. Consider alternatives before application of conventional chemical insecticides.

- **Habitat Modification:** Eliminating breeding sites, or habitat modification, is an effective and long-term solution. Proper maintenance of stormwater BMPs to avoid shallow standing water is important.
- **Natural Predators:** Fish, dragonfly nymphs, and diving beetles are natural predators of mosquito larvae; dragonflies, birds, and bats feed on adults. Consult the Colorado Division of Wildlife for recommendations, restrictions and regulations regarding mosquito-eating fish.
- **Insecticides:** Microbial insecticides such as the bacteria "Bti" (*Bacillus thuringiensis israeliensis*) can be as effective as chemical insecticides. Bti is toxic only to mosquito and midge larvae. It is not hazardous to non-target organisms but can reduce midge populations that serve as fish food.

  "Soft" chemical insecticides, such as the insect growth regulator methoprene, are toxic only to insects and other arthropods. They are similar to certain insect hormones and create imbalances in the levels of hormones needed for proper mosquito growth and development. They do not directly harm fish or other wildlife but can reduce the amount of available food.

  Mosquito larvae also can be controlled by the application of larvicidal oils or chemical insecticides to the water where they occur or are suspected to occur. Remember, several alternatives to conventional chemical larvicides have been developed because of concerns about applying chemicals to water that might be used for drinking or that contains fish and other aquatic life.

If larval control fails, adult mosquito control may be necessary. Adult control generally is done with insecticide applications using ground equipment or aircraft. For more information visit: www.ext.colostate.edu/westnile/mosquito_mgt.html or www.ext.colostate.edu/westnile/faq.html.

- Maintain a buffer zone around wells or surface water where pesticides are not applied. Consult local regulations and landscape ordinances, as well as the product label, for distances, which may vary depending on the type of chemical and the sensitivity of the waterbody. The purpose of this practice is to keep pesticides and herbicides out of surface waterbodies.

Storage Practices

- Storage areas should be secure and covered, preventing exposure to rain and unauthorized access. Commercial and municipal facilities should provide basic safety equipment such as fire extinguishers, warning signs (e.g., "no smoking"), adequate light and ventilation, and spill clean-up materials should be present. Floors and shelves should be non-porous (e.g., metal, concrete) to prevent sorption of chemicals. If possible, temperature control should be provided to avoid excessive heat or cold. Storage areas should be kept clear of combustible material and debris.

- Commercial operations handling large quantities of pesticides and fertilizers should consult the Colorado Department of Agriculture for storage and handling requirements. Commercial greenhouses and nurseries that are storing recycled water laden with fertilizer may need to provide secondary containment to contain the water in the event of a tank rupture or leak.

- Store chemicals in their original containers, tightly closed, with labels intact. Also inspect them regularly for leaks. Store nitrate-based and other oxidizing fertilizers separately from solvents, fuels, and pesticides to reduce fire risk. Follow the general principle of storing like chemicals together. Dry chemicals should be stored above liquids and on pallets to ensure that they do not get wet.

- Locate chemical storage and maintenance areas, as well as vehicle refueling and maintenance areas, away from wells and surface waterbodies in accordance with local regulations, typically at least 50 to 100 feet away.

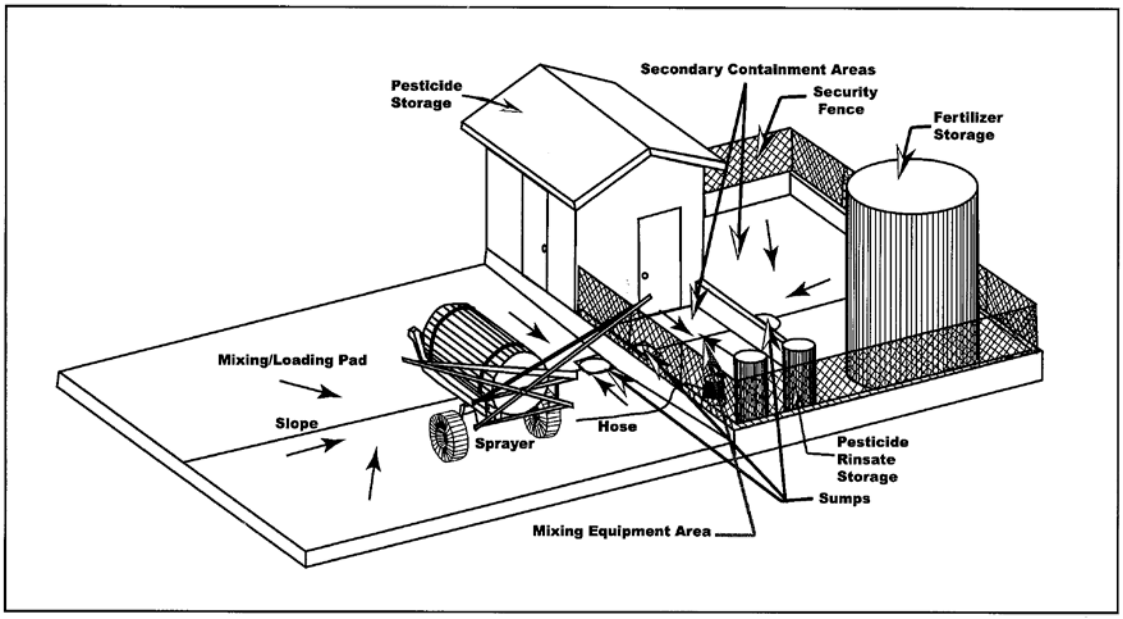


Figure PHF-1. Example Combined Pesticide and Fertilizer Storage and Mixing Area**.** Figure courtesy of *Designing Facilities for Pesticides and Fertilizer Containment*, Midwest Planning Service, Agricultural Engineering, Iowa State University 1991.

- Make available all Material Safety Data Sheets (MSDSs) in a readily accessible area. A list of all hazardous chemicals in the work place must be completed to ensure that all MSDSs are readily available.

- Do not store large quantities of pesticides for long periods of time. Adopt the "first in, first out" principle, using the oldest products first to ensure that the shelf life does not expire. Buy smaller quantities of pesticides and fertilizers, thereby reducing storage issues.

Spills and Disposal

- Never pour lawn and garden chemicals or rinse water down storm drains (or sanitary drains) and keep chemicals off impervious surfaces (e.g., streets, gutters) during application.

- Follow label directions for disposal. This typically involves triple-rinsing empty containers, puncturing and crushing. All visible chemicals should be cleaned from the container prior to disposal. Use local recycling or hazardous waste collection centers to dispose of unused chemicals.

- Properly manage chemical spills by cleaning them up as soon as possible, controlling actively spilling or leaking materials, containing the spilled material (e.g., with absorbents, sand), collecting the spilled material, storing or disposing of the spilled material, and following relevant spill reporting requirements. "Washing down" a spill with water is not an appropriate cleanup approach.

- Commercial operations should be aware of and comply with basic spill reporting requirements required by law, and keep chemical spill cleanup equipment, personal protective equipment and emergency phone numbers available when handling chemicals and their containers.

For More Information on Legal Requirements

Many federal and state regulations address pesticide, herbicide, and other chemical usage. These sources should be consulted for the most current legal requirements related to chemical handling, storage, application, disposal, and reporting of chemical spills. Examples include the federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the Superfund Amendments and Reauthorization Act (SARA), the Emergency Planning and Community-Right-to-Know Act (EPCRA), and Occupational Safety and Health Administration (OSHA) requirements, particularly the Hazard Communication Standard. Colorado-related regulations include the Colorado Pesticide Applicator's Act, and the Colorado Water Quality Control Act (25-8-601 and 25-8-606), Senate Bill 90-126, and The Agricultural Chemicals and Groundwater Protection Act, which identifies special requirements for facilities handling more than 3,000 pounds (or 500 gallons) of bulk-formulated pesticides.

Description

Proper landscape maintenance, including maintenance of vegetated stormwater BMPs, is important to reduce nutrient and chemical loading to the storm drain system, reduce nuisance flows and standing water in stormwater BMPs, and maintain healthy vegetation that helps minimize erosion. Additionally, when landscapes and vegetated BMPs are over-irrigated, the ground remains saturated and capacity to infiltrate runoff is reduced.

Photograph LM-1. Over-irrigation and overspray can wash fertilizers and lawn chemicals into the storm drain system. These flows can comingle with storm runoff and cause nuisance flow conditions in stormwater BMPs. Photo courtesy of the City of Westminster.

Appropriate Uses

Appropriate lawn care practices are applicable to residential, commercial, municipal, and some industrial operations.

Practice Guidelines[1]

Practice guidelines for a healthy lawn that reduces pollution during both wet and dry weather conditions include a combination of practices such as mowing, aeration, fertilization, and irrigation. Also, see the Pesticide, Herbicide, and Fertilizer Usage BMP for information on proper use of these chemicals and Integrated Pest Management (IPM) strategies.

Lawn Mowing and Grass Clipping Waste Disposal

- Keep lawn clippings and debris out of gutters. When blowing walkways or mowing lawns, direct equipment so that the clippings blow back onto the lawn rather than into the street, or collect clippings blown onto the street and properly dispose of them.
- Mulch-mowing turfgrass at a height of 2.5 to 3 inches helps turfgrass develop deeper root systems. No more than one-third of the grass blade should be removed in a single mowing. Mulched grass clippings can return roughly 25 to 30% of the needed nitrogen that grass requires to be healthy, thereby reducing fertilizer requirements. Avoid throwing grass clippings onto streets and sidewalks to reduce nutrient pollution to surface waterbodies.
- Minimize thatch development by mowing at appropriate frequencies and heights for the grass type, avoiding overwatering, preventing over fertilization, and aerating the turf.

[1] These practice guidelines have been adapted from the *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (GreenCO and WWE 2008). See this manual for additional detail and references.

Lawn Aeration

- Aerate turf once or twice per year, as needed, in the early spring and/or late fall to aid in capturing the natural precipitation during non-weed germination periods and prior to adding organic materials and fertilizers. Aeration reduces soil compaction and helps control thatch in lawns while helping water and fertilizer move into the root zone.

- A lawn can be aerated at any time the ground is not frozen, but should not be done when it is extremely hot and dry. Heavy traffic areas will require aeration more frequently.

- Do not use spike-type aerators, which compact the soil. Holes should be two to three inches deep and no more than two to four inches apart. Lawns should be thoroughly watered the day before aerating so plugs can be pulled more deeply and easily. Mark all sprinkler heads, shallow irrigation lines, and buried cable TV lines before aerating so those lines will not be damaged.

Phosphorus

Phosphorus is commonly overused and application should be based on soil tests. Phosphorus washing into surface waterbodies leads to excessive algae growth.

Phosphorous does not move out of the soil like nitrogen, so constant additions are unnecessary.

Fertilizer Application

- Apply fertilizer when needed to achieve a clearly defined objective such as increasing shoot growth, root growth, flowering or fruiting; enhancing foliage color, and plant appearance; or correcting or preventing nutrient deficiencies.

- Because manufactured fertilizers can be relatively high in nutrient content, it is critical to follow the manufacturer's directions, using the minimum amount recommended. Over-application "burns" leaves and may lead to water pollution, thatch buildup, excessive mowing, and weed growth.

- Only apply nutrients the plants can use. Fertilizer labels identify product contents in terms of ratios that indicate percentage of ingredients by product weight.

Soil Testing

There are several qualified laboratories in Colorado that provide soils tests to determine recommendations for fertilizer type and application rates. There are also commercially available quick test kits that are less accurate but could be used by a homeowner. Without an analysis, a homeowner may be buying unnecessary fertilizer or applying too much. A $20 to $40 soil analysis has potential to save an owner much more.

The CSU Extension program offers a soil testing service. Contact the CSU Extension for your county or visit http://www.ext.colostate.edu for more information including a list of laboratories.

- When practical and appropriate, base fertilizer application on soil analysis. Be aware that at many new development sites, soil conditions following grading often no longer consist of topsoil. "Basement" soils with poor texture and low nutrient content may be present. As a result, soil amendment is often needed to improve the physical properties (tilth) of the soil to provide a better environment for plant roots to improve nutrient uptake. Soil analysis can help to identify soil amendments that improve both the physical and nutrient characteristics of the soil, as well as identify fertilization requirements.

- Utilize split applications of slow-release (controlled-release) fertilizer forms such as IBDU, sulfur-coated urea and natural organic-based fertilizers (not to be confused with raw manure) to minimize the risk of nutrients leaching into groundwater or running off in surface water. When properly applied, other forms of fertilizer can also be safely used, provided that over-watering and over-fertilization do not occur.

- When applying fertilizer, broadcast it uniformly over the targeted area of the landscape. Keep fertilizer off streets, sidewalks, and driveways to prevent water pollution. Fertilizer that inadvertently falls on impervious surfaces should be swept back onto the lawn.

- Recommendations for fertilizer application vary among industry professionals. CSU Extension's fertilizer recommendations for established Colorado lawns are provided in the table below. Site-specific conditions should also be considered when determining the need for fertilizer.

Table LM-1. CSU Extension Recommendations for Nitrogen Application Rate

	Nitrogen Application Rate in Pounds/1,000 sq. ft.				
Turfgrass Species	Mid-March to April[A,B]	May to Mid-June[B]	July to Early August[B]	Mid-August to Mid-September[B, C]	Early October to Early November[B, D]
High Maintenance Bluegrass Ryegrass	0.5-1	1	Not Required	1	1-2 (optional)
Low Maintenance Bluegrass	0.5	0.5-1	Not Required	1	1 (optional)
Tall Fescue	0.5	0.5-1	Not Required	1	1 (optional)
Fine Fescue	0.5	0.5-1	Not Required	0.5-1	None
Buffalo grass, Blue Grama, Bermuda grass	None	0.5-1	0.5-1	None	None

Notes:

[A] The March-April nitrogen application may not be needed if prior fall fertilization was completed. If spring green-up and growth is satisfactory, delay fertilizing to May or June.

[B] Application rates may be reduced by 1/4 to 1/3 when grass clippings are left on the lawn.

[C] On very sandy soils do not fertilize turf after late September to prevent nitrogen from leaching into groundwater during the winter months.

[D] Apply when the grass is still green and at least 2-3 weeks prior to the ground freezing. Optional nitrogen applications are indicated for use where higher quality or heavily-used turf is present.

Source: T. Koski and V. Skinner, CSU Extension, 2003.

- If possible, properly irrigate turf following fertilization to help grass utilize applied nutrients and to minimize the potential for fertilizer burn. Care should be taken to avoid excessive irrigation that would result in fertilizer being washed away. Similarly, avoid application of fertilizer immediately prior to heavy rainfall.

- Fall is the best time of year to fertilize bluegrass lawns. Over-application of nitrogen fertilizer in April may cause grass to grow too fast before roots can support the growth, resulting in less heat tolerance.

- Generally, the Colorado Nursery and Greenhouse Association recommends waiting until the second growing season to fertilize ornamental (woody) plants. Commercial fertilizer should not be used in the backfill where it comes in direct contact with the roots.

- Maintain a buffer zone around wells or surface waterbodies where fertilizers are not applied to minimize pollution. Consult the fertilizer product label and local regulations and landscape ordinances for appropriate distances. Research in this area is limited; however, CSU Extension recommends a buffer of 6 to 10 feet for mowed turf areas.

- In areas with sandy soils, it is particularly important to avoid over-application of fertilizer that could leach into groundwater. These areas may be particularly well suited to slow-release fertilizer forms and conservative application rates.

Lawn Irrigation

- The approximate amount of water that needs to be applied **each week** for an average, traditional lawn to supplement normal rainfall is listed in Table 2. (Water utilities may provide additional guidance in terms of suggested run-times for various sprinkler types; http://www.denverwater.org/Conservation/.)

Table LM-2. General Guideline for Approximate Supplemental Water for an Average Traditional Lawn (inches per week)

Condition[3]	April[1]	May	June	July	Aug	Sept	Oct[2]
Non-Drought Conditions	1/4"	1"	1½"	1½"	1¼"	1"	1/2"
During Drought Restrictions (approx. 20% reduction)	1/4"	3/4"	1¼"	1¼"	1"	3/4"	1/2"

[1] For established lawns, water may not be required during April. Base decision on weather conditions.
[2] For established lawns, water is typically not required after Oct 15.
[3] Under less-than-average rainfall conditions, the amounts shown in the chart should be increased. If there is greater-than-normal rainfall, then the amount of supplemental water should be reduced.

- Consult with the CSU Extension Turfgrass program for recommendations for irrigating turfgrasses with lower water requirements (e.g. blue grama, buffalo grass). For native grasses, irrigation may be unnecessary or limited to certain conditions.

- Irrigate the lawn uniformly until the soil is moist to a depth of 4 to 6 inches to encourage deep roots. Frequent, light sprinklings moisten only the surface and may cause shallow-rooted turf and increase weed seed germination. Properly maintain the irrigation system to ensure that the irrigation is being applied at appropriate rates and to the turfgrass, not the sidewalk.

- Maintain irrigation systems in good operating condition with uniform distribution of water. "Smart" irrigation controllers and weather sensors can reduce water waste by shutting off irrigation during storm events and helping owners water according to the needs of the plants to replace water lost to evapotranspiration (ET).

- Proper irrigation can minimize the amount of fertilizer and other chemicals that are leached below the root zone of the grass or washed away by runoff.

Description

For obvious safety reasons, snow removal in Colorado is important; however, snow removal and management practices can adversely impact vegetation, soils, water quality, and air quality. Snow removal contractors and operators should be knowledgeable of these potential impacts and choose management measures with the fewest adverse impacts, while still protecting the public safety, health and welfare.

Photograph SIM-1. Snow storage locations should be clearly communicated to snow removal contractors and located where they can drain to stormwater BMPs or landscaped areas. Photo courtesy of WWE.

Appropriate Uses

Snow and ice management procedures are relevant for homeowners, contractors, business owners, and transportation departments.

Practice Guidelines[1]

- Physical removal of snow and ice by shovels, snowplows, or snow blowers usually has the least water quality and landscape impacts, provided that storage areas are not piled directly on landscape plants or drained directly to receiving waters. Plan for snow storage locations that minimize water quality and landscape impacts prior to winter.
- Ensure that equipment is calibrated to optimum levels according to manufacturer's instructions.
- Consider placing barriers in targeted site-specific locations (i.e., along streams or direct drainages) to route deicing material away from waterbodies.
- Reduce plowing speed in sensitive areas to prevent exposure to deicing material.
- Designate snow storage areas in locations that enable runoff to be directed to stormwater BMPs for treatment, when practicable.
- The use of deicing chemicals can have a severe impact on plants growing near roads and sidewalks. This can become a water quality issue when plants die and erosion results. Many deicing chemicals are salts and can adversely affect plants through either direct contact with foliage or through buildup in the soil over time. Representative impacts include:

[1]These practice guidelines have been adapted from the *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (GreenCO and WWE 2008). See this manual for additional detail and references.

- Direct contact often occurs when the deicing chemicals accumulate on the plants due to drift during application, or when snow or ice containing the chemical is shoveled or blown onto nearby plants. Because these chemicals are salts, direct contact with the foliage may result in burning due to a rapid dehydration effect.

- Buildup of de-icing chemicals in the soil may have even more detrimental effects. Repeated application over time (either during a particular winter season or over many seasons) may damage plants by making their roots unable to take up water. Symptoms will include wilting even when the soil is moist, leaf burn or needle tip burn, stunting or lack of vigor, and/or deficiency symptoms for one or more plant nutrients. The structure of clay soils can be changed to the point that they are unable to support plant life.

- Deicing chemicals that are considered safer to use around plants include calcium magnesium acetate (CMA) or calcium chloride. As with all chemicals used in the landscape, be sure to read and follow label instructions and do not over apply.

- The Colorado Department of Transportation (CDOT) has conducted multiple studies on deicing chemicals. The SeaCrest Group (2001) studied three groups of deicers for CDOT that were chloride-based, acetate-based, and sanding materials. The chloride-based deicers included magnesium chloride (FreezGard Zero® with Shield LS®, Ice-Stop™ CI, Caliber™ M1000, Ice Ban™ M50), calcium chloride (Liquidow®, Armor®), and sodium chloride (road salt and Ice Slicer®). The acetate-based deicers include Calcium Magnesium Acetate (CMA®), Potassium Acetate (CF7®), Sodium Acetate (NAAC®), and CMAK™ (a mixture of CMA and Potassium Acetate). Table 1 contains a partial summary of the study findings.

- Highlights of the SeaCrest (2001) study regarding impacts associated with the three categories include:

  - The chloride-based deicers have been shown to have adverse effects on terrestrial vegetation. Damage to vegetation from deicing salts has been reported to a distance of 100-650 feet. However, there is a wide range of tolerance of different species of plants to the effects of chlorides. The chloride ions in deicers increase the salinity of the soil near the roadways where they are applied. The magnesium and calcium ions increase the stability and permeability of the soil, whereas sodium ions decrease soil stability and permeability.

  - The acetate-based deicers are organic and have different kinds of effects on the environment than the chloride-based deicers. The acetate ions are broken down by soil microorganisms and may result in oxygen depletion of the soil, which can impact vegetation; however, the acetate deicers CMA and Potassium Acetate (CMAK) are not harmful to terrestrial vegetation at the concentrations typically used on roadways. However, NAAC may potentially have an adverse effect on vegetation because of the presence of the sodium ion, which decreases the stability and permeability of the soil. The depletion of oxygen in the soil from the breakdown of the acetate ion can have a negative effect on plant growth, but field evidence of this effect is limited.

  - Sand is not a deicer, but is used for snow and ice control because it improves traction. Sand has a negative effect on water quality as a result of the increased turbidity caused by the presence of sand particles in water. Excessive quantities of sand can smother vegetation.

Table SIM-1. Potential Environmental Impacts of Various Deicers
(Source: The SeaCrest Group 2001)[2]

Deicer/ Parameter	Inhibited Magnesium Chloride (Liquid)	Caliber + Magnesium Chloride (Liquid)	Ice Ban + Magnesium Chloride (Liquid)	Sodium Chloride/ Ice Slicer (Solid)	Inhibited Calcium Chloride (Liquid)	CMA (Solid/ Liquid)	CMAK (Liquid)	Potassium Acetate (Liquid)	NAAC (Solid)	Sand
Chemicals	Trace metals	Trace metals, phosphorus, ammonia	Trace metals, phosphorus, ammonia, nitrates	Trace metals	Trace metals, ammonia, nitrates.	Trace metals	Trace metals, ammonia, nitrates.	Trace metals	Trace metals, phosphorus	Trace metals
Soil	Improves structure, increases salinity	Improves structure, increases salinity, oxygen depletion	Improves structure, increases salinity, oxygen depletion	Increases salinity; decreases stability	Improves structure, increases salinity	Improves structure; oxygen depletion	Improves structure; oxygen depletion	Improves structure; oxygen depletion	Decreases stability; oxygen depletion	Minimal effects
Water Quality	Increases salinity	Increases salinity; oxygen depletion	Increases salinity; oxygen depletion	Increases salinity	Increases salinity		Oxygen depletion	Oxygen depletion	Oxygen depletion	Increases turbidity
Air Quality	Minimal air pollution	Minimal air pollution	Minimal air pollution	Some air pollution	Minimal air pollution	Minimal air pollution	Minimal air pollution	Minimal air pollution	Some air pollution	High air pollution potential
Aquatic Organisms	Relatively low toxicity	Relatively low toxicity	Moderate toxicity	Relatively low toxicity	Relatively low toxicity	Relatively low toxicity	Moderate toxicity	Moderate toxicity	Relatively low toxicity	Can cover benthic organisms and cause mortality
Terrestrial Vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Minimal damage to vegetation	Minimal damage to vegetation	Minimal damage to vegetation	Effects to vegetation not determined	Can cover vegetation and cause mortality
Terrestrial Animals	Does not attract wildlife	Does not attract wildlife	Does not attract wildlife	Attracts wildlife contributing to road kills	Does not attract wildlife	Not expected to attract wildlife	Not expected to attract wildlife	Not expected to attract wildlife	May attract wildlife contributing to roadkills	May cover burrows of small animals and cause mortality

Note: Trace metals that may be present include arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. Soil comments related to structure refer to the affect on soil stability, which relates to erosion. See http://www.coloradodot.info/programs/research/pdfs/2001/deicers.pdf/view for more information.

- Where practicable, do not use deicers to melt snow or ice completely, but to make their removal easier. Deicers melt down through the ice or snow to the hard surface, then spread out underneath. This undercuts and loosens the snow so shoveling and plowing can be done. For this reason, it is helpful to apply deicers prior to snow events in some cases.

- Research has shown that the shape of deicing particles affects the speed of their penetration through ice. Uniformly shaped spherical pellets of about 1/16 inch to 3/16 inch penetrate ice faster and more efficiently than other shapes.

- Try to avoid the use of rock salt since it is generally most damaging to plants, soils and concrete and metal surfaces. In areas where deicing salts are unavoidable, select plants with higher salt tolerances.

[2] The SeaCrest Group, 2001. *Evaluation of Selected Deicers Based on a Review of the Literature,* Report No. CDOT-DTD-2001-15. Prepared for Colorado Department of Transportation Research Branch.

- Do not plow snow directly into streams or wetlands. Snow storage and disposal areas should be located in an area where snowmelt can infiltrate into the ground, filter through a vegetated buffer or be otherwise treated prior to reaching streams and wetlands. Provide adequate storage volume to trap sediment left behind by melting snow and plan regular maintenance to remove accumulated sediment.

- In areas subject to heavy chemical deicing use, flushing the soil with water after the last freeze may alleviate burn potential. Year-round proper plant care will also make plants more tolerant to salt exposure. However, for the overall health of the landscape, the goal should be to reduce or minimize the use of deicing chemicals where they are not necessary for safety reasons.

- If an electric/mechanical snow melting device is used to dispose of removed snow (e.g., The Can snow melter, Snow Dragon, etc.), the owner or operator must obtain the appropriate permit prior to discharge. Snowmelt from melting machines is typically considered process wastewater.

Description

Street sweeping uses mechanical pavement cleaning practices to reduce sediment, litter and other debris washed into storm sewers by runoff. This can reduce pollutant loading to receiving waters and in some cases reduce clogging of storm sewers and prolong the life of infiltration oriented BMPs and reduce clogging of outlet structures in detention BMPs.

Different designs are available with typical sweepers categorized as a broom and conveyor belt sweeper, wet or dry vacuum-assisted sweepers, and regenerative-air sweepers. The effectiveness of street sweeping is dependent upon particle loadings in the area being swept, street texture, moisture conditions, parked car management, equipment operating conditions and frequency of cleaning (Pitt et al. 2004).

Photograph SSC-1. Monthly street sweeping from April through November removed nearly 40,690 cubic yards of sediment/debris from Denver streets in 2009. Photo courtesy of Denver Public Works.

Appropriate Uses

Street sweeping is an appropriate technique in urban areas where sediment and litter accumulation on streets is of concern for aesthetic, sanitary, water quality, and air quality reasons. From a pollutant loading perspective, street cleaning equipment can be most effective in areas where the surface to be cleaned is the major source of contaminants. These areas include freeways, large commercial parking lots, and paved storage areas (Pitt et al. 2004). Where significant sediment accumulation occurs on pervious surfaces tributary to infiltration BMPs, street sweeping may help to reduce clogging of infiltration media. In areas where construction activity is occurring, street sweeping should occur as part of construction site stormwater management plans. Vacuuming of permeable pavement systems is also considered a basic routine maintenance practice to maintain the BMP in effective operating condition. See the maintenance chapter for more information on permeable pavement systems. Not all sweepers are appropriate for this application.

Practice Guidelines[1]

1. Post street sweeping schedules with signs and on local government websites so that cars are not parked on the street during designated sweeping days.

2. Sweeping frequency is dependent on local government budget, staffing, and equipment availability, but monthly sweeping during non-winter months is a common approach in the metro Denver urban

[1] Practice guidelines adapted from CASQA (2003) *California Stormwater BMP Handbook*, Practice SC-70 Road and Street Maintenance.

area. Consider increasing sweeping frequency based on factors such as traffic volume, land use, field observations of sediment and trash accumulation, proximity to watercourses, etc. For example:

- Increase the sweeping frequency for streets with high pollutant loadings, especially in high traffic and industrial areas.
- Conduct street sweeping prior to wetter seasons to remove accumulated sediments.
- Increase the sweeping frequency for streets in special problem areas such as special events, high litter or erosion zones.

3. Perform street cleaning during dry weather if possible.
4. Avoid wet cleaning the street; instead, utilize dry methods where possible.
5. Maintain cleaning equipment in good working condition and purchase replacement equipment as needed. Old sweepers should be replaced with more technologically advanced sweepers (preferably regenerative air sweepers) that maximize pollutant removal.
6. Operate sweepers at manufacturer recommended optimal speed levels to increase effectiveness.
7. Regularly inspect vehicles and equipment for leaks and repair promptly.
8. Keep accurate logs of the number of curb-miles swept and the amount of waste collected.
9. Dispose of street sweeping debris and dirt at a landfill.
10. Do not store swept material along the side of the street or near a storm drain inlet.

Changes in Street Sweeper Technology (Source: Center for Watershed Protection 2002)

At one time, street sweepers were thought to have great potential to remove stormwater pollutants from urban street surfaces and were widely touted as a stormwater treatment practice in many communities. Street sweeping gradually fell out of favor, largely as a result of performance monitoring conducted as part of the National Urban Runoff Program (NURP). These studies generally concluded that street sweepers were not very effective in reducing pollutant loads (USEPA, 1983). The primary reason for the mediocre performance was that mechanical sweepers of that era were unable to pick up fine-grained sediment particles that carry a substantial portion of the stormwater pollutant load. In addition, the performance of sweepers is constrained by that portion of a street's stormwater pollutant load delivered from outside street pavements (e.g., pollutants that wash onto the street from adjacent areas or are directly deposited on the street by rainfall). Street sweeping technology, however, has evolved considerably since the days of the NURP testing. Today, communities have a choice in three basic sweeping technologies to clean their urban streets: traditional mechanical sweepers that utilize a broom and conveyor belt, vacuum-assisted sweepers, and regenerative-air sweepers (those that blast air onto the pavement to loosen sediment particles and vacuum them into a hopper).

For more information, see
http://www.cwp.org/Resource_Library/Center_Docs/PWP/ELC_PWP121.pdf

Storm Sewer System Cleaning S-12

Description[1]

Photograph SSC-1. Storm drain cleaning may help to remove pollutant sources and helps to maintain the capacity of the storm pipes.

Periodic storm sewer system cleaning can help to remove accumulated sediment, trash, and other substances from various components of the storm sewer system including inlets, pipes and stormwater BMPs. Some common pollutants found in storm drains include: trash and debris, sediments, oil and grease, antifreeze, paints, cleaners and solvents, pesticides, fertilizers, animal waste, and detergents. Routine cleaning reduces the amount of pollutants, trash, and debris both in the storm drain system and in receiving waters. Clogged drains and storm drain inlets can cause the drains to overflow, leading to increased erosion (Livingston et al. 1997). Cleaning increases dissolved oxygen, reduces levels of bacteria, and supports in-stream habitat. Areas with relatively flat grades or low flows should be given special attention because they rarely achieve high enough flows to flush themselves (Ferguson et al. 1997).

Appropriate Uses

Storm sewer system cleaning is typically conducted by local governments or state agencies; however, homeowners associations, businesses and industries are usually responsible for maintaining system components on their sites.

Due to the cost and time involved with storm sewer system cleaning, communities may target recurrent problem areas or use another type of prioritization system for maintenance. Also see the BMP Maintenance chapter for BMP-specific maintenance requirements.

Practice Guidelines

A variety of jet/vacuum vehicles can be used to remove debris from stormwater catch basins and pipes. This equipment breaks up clogged/accumulated material with high-pressure water jets and vacuums the material from the sewer. Water used in storm drain cleaning must be collected and properly disposed of, typically at a sanitary wastewater treatment facility.

Simpler methods in localized areas can also include manual trash collection and shoveling from inlets and outlets.

[1] Guidelines adapted from Center for Watershed Protection (2009) *Urban Stormwater Restoration Manual Series 8: Municipal Practices and Programs*.

S-12 Storm Sewer System Cleaning

Frequency and prioritization of storm sewer cleaning is affected by multiple factors such as the activity and intensity of use in the tributary area (e.g., parking lot, stadium), storm sewer system design, municipal budgets (staff and equipment), and other factors.

To be most effective, storm sewer cleaning needs an effective recordkeeping system and clearly defined procedures. CWP (2009) recommends the following practices:

- **Tracking**: The location and maintenance of storm drains should be tracked using a database and spatial referencing system (e.g., Global Positioning System or Geographic Information System). Additionally, knowing the type and era of the storm drain system may be of use since some inlets/catch basins are designed to be self-cleaning while others have some trapping capacity.

- **Frequency**: Should be defined such that blockage of storm sewer outlet is prevented and it is recommended that the sump should not exceed 40- 50 percent of its capacity. Semi-annual cleanouts in residential streets and monthly cleanouts for industrial streets are suggested by Pitt and Bissonnett (1984) and Mineart and Singh (1994). More frequent cleanouts should be scheduled in the fall as leaves can contribute 25% of nutrient loadings in catch basins.

- **Technology**: A variety of methods of cleaning catch basins are available, including manual cleaning, eductor vehicles, vacuum cleaning and vacuum combination jet cleaning. Choose the approach that is most effective for site conditions, taking into consideration budget, equipment, and staffing constraints.

- **Staff training**: Operators need to be properly trained in catch basin maintenance including waste collection and disposal methods. Staff should also be trained to report water quality problems and illicit discharges.

- **Material disposal**: Most catch basin waste is of acceptable quality for landfills. If it is suspected that catch basin waste contains hazardous material, it should be tested and disposed of accordingly. Maintenance personnel should keep a log of the amount of sediment collected and the removal date at the catch basin.

Chapter 6
BMP Maintenance

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1.0 Introduction

In order for stormwater BMPs to be effective, proper maintenance is essential. Maintenance includes both routinely scheduled activities, as well as non-routine repairs that may be required after large storms, or as a result of other unforeseen problems. BMP maintenance is the responsibility of the entity owning the BMP; however, local governments with municipal separate storm sewer system (MS4) permits are responsible for ensuring that maintenance of privately owned BMPs occurs within their MS4.

BMPs should be designed with maintenance as one of the key design considerations. Planning-level design guidance pertaining to maintenance is included in the individual Fact Sheets contained within this manual. This chapter focuses on maintenance of in-service BMPs and provides recommendations for private BMP owners, as well as for MS4 permittees responsible for ensuring proper maintenance for both public and private facilities within their MS4.

2.0 Defining Maintenance Responsibility for Public and Private Facilities

Identifying who is responsible for maintenance of BMPs and ensuring that an adequate budget is allocated for maintenance is critical to the long-term success of BMPs. Maintenance responsibility may be assigned in different ways:

- Publically owned BMPs are maintained by the MS4 permittee.
- Publically owned regional drainage facilities located within the UDFCD service area may be maintained by UDFCD when specific maintenance eligibility criteria are met (subject to funding limitations).
- Privately owned BMPs typically are maintained by the property owner, homeowner's association, or property manager.
- Privately owned BMPs may be maintained by the MS4 permittee under a written agreement with the owner, with appropriate fees assessed for maintenance services.

MS4 permittees can utilize a variety of legal approaches to ensure maintenance of stormwater BMPs. Representative measures include:

- Agreements establishing legally binding BMP maintenance requirements and responsibilities.
- Permit obligations specifying BMP requirements; or
- Municipal legislative action or rulemaking authority.

Examples of some of the specific requirements for BMP maintenance suggested for legal agreements by the Watershed Management Institute (1997) include:

- **General Assurances:** Identify requirements for proper operation and maintenance, conditions for modification of facilities, dedicated easements, binding covenants, operation, and maintenance plans, and inspection requirements.
- **Warranty Period:** Require the original developer to be responsible for maintenance and operation during a defined short-term period and identify the entity responsible for long-term operation. The

party responsible for long-term maintenance must have appropriate legal authority to own, operate maintain, and raise funds to complete needed maintenance.

- **Proof of Legal Authority:** Require that the entity meet certain conditions verifying its legal authority to ensure maintenance.

- **Conditions for Phased Projects:** Clearly specify how maintenance responsibilities are allocated over the long-term for a project that is phased in over time. This includes identifying access points during each phase.

- **Remedies:** Clearly define remedies in the event that the facility is not being properly maintained.

For public facilities, one of the key issues is ensuring that adequate staff and budget are provided to the department responsible for maintenance. Ponds, lakes, and wetland BMPs should be built only if assurances are provided that adequate maintenance staff and resources are identified in advance.

Photograph 6-1. Sediment removal from a forebay at the regional Shop Creek BMP System.

For private facilities, such as those owned and maintained by homeowners' associations, there is often a lack of understanding of maintenance required for BMPs. Maintenance plans should be prepared and submitted as part of the development review/approval process and be provided to the owner(s) upon sale of the development. It is also important to educate the general public on the purpose and function of stormwater BMPs. This is critical in cases where Low Impact Development (LID) or landscape-based BMPs are distributed throughout multiple parcels in developments. In addition to legally binding maintenance agreements, it is also helpful to have easy-to-understand informational brochures that describe the functions and maintenance requirements for these facilities.

3.0 Developing a Maintenance Plan

Maintenance plans can be prepared as stand-alone documents, or be made part of a construction set. This is typically based on the preference of the reviewing entity or MS4 permittee. The following outlines key components of a maintenance plan:

1. A simple drawing of the site development showing the locations of all stormwater quality BMPs at the site and key components such as forebays, inlets, outlets, low flow channels or other components that require inspections or maintenance. The drawing should be kept on-site at the property or the property management office. Any changes to the facility over time should be noted on the drawing.

2. A brief description of the inspection and maintenance procedures and frequencies.

3. A brief description of the maintenance requirements and expected frequency of actions, which can be obtained from discussion within this chapter. Include instruction on how to access each

component of each BMP and with what equipment. It is important to identify all maintenance requirements related directly to the water quality functions of the BMP and provide information concerning future site work that could potentially impact the integrity of the BMP. This is particularly true for landscaped BMPs. For example, the following maintenance requirements may be important for a rain garden:

- Provide frequent weed control in the first three years following installation and as needed for the life of the facility. Weeding should be performed mechanically, either by hand or by mowing (after establishment of the vegetation).
- Remove debris from area and outlet.
- Ensure cleanout caps remains watertight.

Additionally, the maintenance plans should identify constraints and considerations for future work that have the potential to affect the performance of the BMP. For example, the following prohibitions would typically be included in a maintenance plan for a rain garden:

- Do not place conventional sod on the surface of the rain garden.
- Do not plant trees within 10 feet of the rain garden.
- Do not place fill in the rain garden.
- Do not puncture impermeable liner, (if present).

4. An inspection form or checklist appropriate for the facilities in place at the site. A log of inspection forms should be kept onsite or at the property management office to demonstrate that routine inspections and maintenance are occurring.

5. Contact information for the entity responsible for maintenance of the facility. For example, this could be a homeowner's association, municipality, or other entity. (For BMPs maintained by UDFCD, the owner, rather than UDFCD, should be contacted.)

6. Copies of legally binding agreements associated with the facility that show that the facility owner is aware of, and will abide by, their maintenance responsibilities.

7. Other items as appropriate for specific conditions, which may include any of the following:

   - For ponds, include a permanent control point and other critical elevations, (i.e. bottom of pond, EURV, 100-year WSE, or overflow).
   - Provide the estimated baseflow used for the design and other hydrologic information for larger watersheds.
   - List information pertaining to materials testing for any contaminant testing requirements for removed sediment.
   - Include post-maintenance considerations, (e.g., restoration of flow paths).
   - Provide for long-term monitoring requirements, (e.g., 404 permit reports).

It is also important to note that the guidelines included in this manual should always be combined

with common sense and good judgment based on field observations and practical experience. Often, there will be maintenance requirements that are specific to a given site in addition to the general maintenance guidance provided in this manual.

On a general note with regard to BMPs that have a vegetation component or involve weed and pest control, UDFCD strongly advocates the use of Integrated Pest Management (IPM) practices that help to reduce the level of chemical applications through a variety of management practices. IPM is discussed in BMP Fact Sheet S-8 located in Chapter 5.

Although water quality monitoring is not typically required as part of maintenance agreements, it is encouraged as an effective tool for determining if the BMP is functioning effectively. Stormwater quality monitoring guidelines can be downloaded from the International Stormwater BMP Database website (www.bmpdatabase.org).

Additional References for Stormwater BMP Maintenance

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North Carolina State University Cooperative Extension. 2006. Bioretention Performance, Design, Construction, and Maintenance. http://www.bae.ncsu.edu/stormwater/PublicationFiles/Bioretention2006.pdf

Santa Clara Valley Urban Runoff Pollution Prevention Program Example BMP Inspection and Maintenance Checklist. http://www.scvurppp-w2k.com/bmp_om_forms.htm

Southeast Metro Stormwater Authority (SEMSWA) Stormwater Management Facility Operation and Maintenance (O&M) Manual. www.semswa.org

Watershed Management Institute. 1997. Operation, Maintenance and Management of Stormwater Management Systems. Ingleside, MD: Watershed Management Institute.

4.0 Grass Buffers and Swales

Grass buffers and swales require maintenance of the turf cover and repair of rill or gully development. Healthy vegetation can often be maintained without using fertilizers because runoff from lawns and other areas contains the needed nutrients. Periodically inspecting the vegetation over the first few years will help to identify emerging problems and help to plan for long-term restorative maintenance needs. This section presents a summary of specific maintenance requirements and a suggested frequency of action.

Photograph 6-2. A lack of sediment removal in this grass swale has resulted in a grade change due to growth over the deposition and ponding upstream.

4.1 Inspection

Inspect vegetation at least twice annually for uniform cover and traffic impacts. Check for sediment accumulation and rill and gully development.

4.2 Debris and Litter Removal

Remove litter and debris to prevent rill and gully development from preferential flow paths around accumulated debris, enhance aesthetics, and prevent floatables from being washed offsite. This should be done as needed based on inspection, but no less than two times per year.

4.3 Aeration

Aerating manicured grass will supply the soil and roots with air. It reduces soil compaction and helps control thatch while helping water move into the root zone. Aeration is done by punching holes in the ground using an aerator with hollow punches that pull the soil cores or "plugs" from the ground. Holes should be at least 2 inches deep and no more than 4 inches apart.

Aeration should be performed at least once per year when the ground is not frozen. Water the turf thoroughly prior to aeration. Mark sprinkler heads and shallow utilities such as irrigation lines and cable TV lines to ensure those lines will not be damaged. Avoid aerating in extremely hot and dry conditions. Heavy traffic areas may require aeration more frequently.

4.4 Mowing

When starting from seed, mow native/drought-tolerant grasses only when required to deter weeds during the first three years. Following this period, mowing of native/drought tolerant grass may stop or be reduced to maintain a length of no less than six inches. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See the inset for additional recommendations from the CSU Extension.

4.5 Irrigation Scheduling and Maintenance

Adjust irrigation schedules throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, with more irrigation needed during July and August. Native grass should not require irrigation after establishment, except during prolonged dry periods when supplemental, temporary irrigation may aid in maintaining healthy vegetation cover. Check for broken sprinkler heads and repair them, as needed. Do not overwater. Signs of overwatering and/or broken sprinkler heads may include soggy areas and unevenly distributed areas of lush growth.

Completely drain and blowout the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

CSU Extension Recommendations for Mowing Manicured Turf (Source: T. Koski and V. Skinner, 2003)

The two most important facets of mowing are mowing height and frequency. The minimum height for any lawn is 2 inches. The preferred mowing height for all Colorado species is 2.5 to 3 inches. Mowing to less than 2 inches can result in decreased drought and heat tolerance and higher incidence of insects, diseases and weeds. Mow the lawn at the same height all year. There is no reason to mow the turf shorter in late fall.

Mow the turf often enough so no more than 1/3 of the grass height is removed at any single mowing. If your mowing height is 2 inches, mow the grass when it is 3 inches tall. You may have to mow a bluegrass or fescue lawn every three to four days during the spring when it is actively growing but only once every seven to 10 days when growth is slowed by heat, drought or cold. Buffalograss lawns may require mowing once every 10 to 20 days, depending on how much they are watered.

If weather or another factor prevents mowing at the proper time, raise the height of the mower temporarily to avoid cutting too much at one time. Cut the grass again a few days later at the normal mowing height.

4.6 Fertilizer, Herbicide, and Pesticide Application

Use the minimum amount of biodegradable nontoxic fertilizers and herbicides needed to establish and maintain dense vegetation cover that is reasonably free of weeds. Fertilizer application may be significantly reduced or eliminated by the use of mulch-mowers, as opposed to bagging and removing clippings. To keep clippings out of receiving waters, maintain a 25-foot buffer adjacent to open water areas where clippings are bagged. Hand-pull the weeds in areas with limited weed problems.

Frequency of fertilizer, herbicide, and pesticide application should be on an as-needed basis only and should decrease following establishment of vegetation. See BMP Fact Sheet S-8 in Chapter 5 for additional information. For additional information on managing vegetation in a manner that conserves water and protects water quality, see the 2008 *GreenCO Best Management Practices Manual* (www.greenco.org) for a series of Colorado-based BMP fact sheets on topics such as irrigation, plant care, and soil amendments.

4.7 Sediment Removal

Remove sediment as needed based on inspection. Frequency depends on site-specific conditions. For planning purposes, it can be estimated that 3 to 10% of the swale length or buffer interface length will require sediment removal on an annual basis.

- **For Grass Buffers**: Using a shovel, remove sediment at the interface between the impervious area and buffer.

- **For Grass Swales**: Remove accumulated sediment near culverts and in channels to maintain flow capacity. Spot replace the grass areas as necessary.

Reseed and/or patch damaged areas in buffer, sideslopes, and/or channel to maintain healthy vegetative cover. This should be conducted as needed based on inspection. Over time, and depending on pollutant loads, a portion of the buffer or swale may need to be rehabilitated due to sediment deposition. Periodic sediment removal will reduce the frequency of revegetation required. Expect turf replacement for the buffer interface area every 10 to 20 years.

5.0 Bioretention (Rain Garden or Porous Landscape Detention)

The primary maintenance objective for bioretention, also known as porous landscape detention, is to keep vegetation healthy, remove sediment and trash, and ensure that the facility is draining properly. The growing medium may need to be replaced eventually to maintain performance. This section summarizes key maintenance considerations for bioretention.

5.1 Inspection

Inspect the infiltrating surface at least twice annually following precipitation events to determine if the bioretention area is providing acceptable infiltration. Bioretention facilities are designed with a maximum depth for the WQCV of one foot and soils that will typically drain the WQCV over approximately 12 hours. If standing water persists for more than 24 hours after runoff has ceased, clogging should be further investigated and remedied. Additionally, check for erosion and repair as necessary.

5.2 Debris and Litter Removal

Remove debris and litter from the infiltrating surface to minimize clogging of the media. Remove debris and litter from the overflow structure.

5.3 Mowing and Plant Care

- **All vegetation**: Maintain healthy, weed-free vegetation. Weeds should be removed before they flower. The frequency of weeding will depend on the planting scheme and cover. When the growing media is covered with mulch or densely vegetated, less frequent weeding will be required.

- **Grasses**: When started from seed, allow time for germination and establishment of grass prior to mowing. If mowing is required during this period for weed control, it should be accomplished with hand-held string trimmers to minimize disturbance to the seedbed. After established, mow as desired or as needed for weed control. Following this period, mowing of native/drought tolerant grasses may stop or be reduced to maintain a length of no less than 6 inches. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See Section 4.4 for additional guidance on mowing.

5.4 Irrigation Scheduling and Maintenance

Adjust irrigation throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, while more irrigation is needed during the peak summer months. Native grasses and other drought tolerant plantings should not typically require routine irrigation after establishment, except during prolonged dry periods.

Check for broken sprinkler heads and repair them, as needed. Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

5.5 Replacement of Wood Mulch

Replace wood mulch only when needed to maintain a mulch depth of up to approximately 3 inches. Excess mulch will reduce the volume available for storage.

5.6 Sediment Removal and Growing Media Replacement

If ponded water is observed in a bioretention cell more than 24 hours after the end of a runoff event, check underdrain outfall locations and clean-outs for blockages. Maintenance activities to restore infiltration capacity of bioretention facilities will vary with the degree and nature of the clogging. If clogging is primarily related to sediment accumulation on the filter surface, infiltration may be improved by removing excess accumulated sediment and scarifying the surface of the filter with a rake. If the clogging is due to migration of sediments deeper into the pore spaces of the media, removal and replacement of all or a portion of the media may be required. The frequency of media replacement will depend on site-specific pollutant loading characteristics. Based on experience to date in the metro Denver area, the required frequency of media replacement is not known. To date UDFCD is not aware of any rain gardens constructed to the recommendations of these criteria that have required full replacement of the growing media. Although surface clogging of the media is expected over time, established root systems promote infiltration. This means that mature vegetation that covers the filter surface should increase the life span of the growing media, serving to promote infiltration even as the media surface clogs.

6.0 Green Roofs

A five-year maintenance plan should be established prior to the completion of all new green roofs. Both plant maintenance and inspection of various roof structural elements will be required regularly. Additionally, green roof plants require regular attention and care including irrigation, weeding, fertilizing, pruning, and replanting. While the first several years following green roof construction are critical for establishing vegetation, controlling weeds, and detecting problems such as leaks, a long-term maintenance plan will also be necessary. During the first five years, the maintenance plan should be refined and adjusted based on experience to develop an effective long-term plan.

Photograph 6-3. When inspecting roof drains, remove any surrounding rock as well as the inlet grate and visually inspect the drainpipe to ensure it is free of any extraneous materials.

6.1 Inspection

Green roof inspection should be conducted at least three times per year. At a minimum, the following areas require inspection:

- Inspect joints, borders or other features that pass through the roof to remove roots and identify damage that could lead to leaks. For example, inspect abutting vertical walls, roof vent pipes, outlets, air conditioning units, and perimeter areas. Joints with facades must provide open access for inspection, maintenance, and upkeep.

- A vegetation-free zone of approximately one foot should be maintained at the border of roof edges and at drain openings on the roof. Vegetation-free zones should be lined with pavers, stones, or gravel. Drains must remain free of vegetation and foreign objects. In order to allow for regular inspections and maintenance, drains on a green roof must remain permanently accessible.

- Because of the severe consequences of drain backups, inspection of drainage flow paths is crucial. Remove the inlet cover and visually inspect drainage pipes for roots or other material that could impede the flow of water.

- Plants are susceptible to poor drainage in the soil. If too much water is present and unable to drain, the plants will drown or rot. Routine inspections of drains should take place approximately three times per year as well as after precipitation events of 0.6 inches or more.

- Inspect the irrigation system for leaks or malfunctions. Uneven vegetative growth or dying plants should serve as indicators of potential irrigation system problems.

6.2 Plant Care and Media Replacement

As with any garden, plant replacement will be required periodically throughout the life of a green roof. For green roofs serving stormwater functions, heat-tolerant plants with shallow, spreading and fibrous

root systems are recommended. Plant selection is crucial on roofs with intense wind and light such as roofs of skyscrapers or roofs that receive reflected solar radiation from other structures. Additionally, certain portions of the roof may experience more intense sunlight and or reflected heat, requiring additional care or irrigation system adjustments.

Care of the plants on a green roof will require the most attention during the critical establishment phase. A horticultural professional should work with individuals caring for the new roof to organize schedules and routines for hand weeding, thinning, pruning, fertilizing, irrigation system scheduling and adjustments, and plant replacement. Watering and weeding are particularly important for the first two years of the green roof. For overall health of the green roof, weeds should be identified and removed early and often.

If the growing medium needs to be replaced, it should be replaced in accordance with the original design specifications, unless these specifications have been identified as a cause of poor plant growth or green roof performance. Any substitutions or adjustments to the original green roof media must be balanced carefully to meet loading limits, drainage requirements, and characteristics conducive to healthy plant growth.

When caring for plants or adjusting growing media, care should be taken to avoid use of materials likely to result in nutrient export from the green roof. For example, growing media and compost should have a low phosphorus index (P index). Appropriate plants with low fertilization requirements should be chosen. If used, fertilizer application should be minimized to levels necessary only for plant health.

6.3 Irrigation Scheduling and Maintenance

Green roofs in Colorado should be equipped with irrigation systems, even if the ultimate goal is for the plants to rely primarily on natural precipitation. Irrigation schedules should be based on the evapotranspiration (ET) requirements of the plants, the type of irrigation system used (e.g., drip or spray), and changing ET over the growing season. Irrigation systems equipped with advanced irrigation controllers based on soil moisture can help facilitate watering according to the changing water needs of the plants. If advanced systems are not used, irrigation should be manually adjusted during the growing season to replace water lost through ET. During the first two years of plant establishment, regular irrigation will likely be needed. After plant establishment, it may be possible to reduce supplemental irrigation during non-drought conditions.

Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

7.0 Extended Detention Basins (EDBs)

EDBs have low to moderate maintenance requirements on a routine basis, but may require significant maintenance once every 15 to 25 years. Maintenance frequency depends on the amount of construction activity within the tributary watershed, the erosion control measures implemented, the size of the watershed, and the design of the facility.

7.1 Inspection

Inspect the EDB at least twice annually, observing the amount of sediment in the forebay and checking for debris at the outlet structure.

7.2 Debris and Litter Removal

Remove debris and litter from the detention area as required to minimize clogging of the outlet.

7.3 Mowing and Plant Care

When starting from seed, mow native/drought tolerant grasses only when required to deter weeds during the first three years. Following this period, mowing of native/drought tolerant grass may stop or be reduced to maintain a height of no less than 6 inches (higher mowing heights are associated with deeper roots and greater drought tolerance). In general, mowing should be done as needed to maintain appropriate height and control weeds. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See Section 4 of this chapter for additional recommendations from the CSU Extension.

7.4 Aeration

For EDBs with manicured grass, aeration will supply the soil and roots with air and increase infiltration. It reduces soil compaction and helps control thatch while helping water move into the root zone. Aeration is done by punching holes in the ground using an aerator with hollow punches that pull the soil cores or "plugs" from the ground. Holes should be at least 2 inches deep and no more than 4 inches apart.

Aeration should be performed at least once per year when the ground is not frozen. Water the turf thoroughly prior to aeration. Mark sprinkler heads and shallow utilities such as irrigation lines and cable TV lines to ensure those lines will not be damaged. Avoid aerating in extremely hot and dry conditions. Heavy traffic areas may require aeration more frequently.

7.5 Mosquito Control

Although the design provided in this manual implements practices specifically developed to deter mosquito breeding, some level of mosquito control may be necessary if the BMP is located in close proximity to outdoor amenities. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. Treatment should be targeted toward mosquito larvae. Mosquitoes are more difficult to control when they are adults. This typically requires neighborhood fogging with an insecticide.

The use of larvicidal briquettes or "dunks" may be appropriate. These are typically effective for about one month and perform best when the basin has a hard bottom (e.g., concrete lined micropool).

Facts on Mosquito Breeding

Although mosquitoes prefer shallow, stagnant water, they can breed within the top 6 to 8 inches of deeper pools.

Mosquitoes need nutrients and prefer shelter from direct sunlight.

Mosquitoes can go from egg to adult within 72 hours.

The most common mosquitoes in Colorado include the *Aedes Vexans* and the *Culex Tarsalis*. Both have similar needs for breeding and development.

7.6 Irrigation Scheduling and Maintenance

Adjust irrigation throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, with more irrigation needed during July and August. Native grass and other drought tolerant plantings should not require irrigation after establishment.

Check for broken sprinkler heads and repair them, as needed. Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

7.7 Sediment Removal from the Forebay, Trickle Channel, and Micropool

Remove sediment from the forebay and trickle channel annually. If portions of the watershed are not developed or if roadway or landscaping projects are taking place in the watershed, the required frequency of sediment removal in the forebay may be as often as after each storm event. The forebay should be maintained in such a way that it does not provide a significant source of resuspended sediment in the stormwater runoff.

Sediment removal from the micropool is required about once every one to four years, and should occur when the depth of the pool has been reduced to approximately 18 inches. Small micropools may be vacuumed and larger pools may need to be pumped in order to remove all sediment from the micropool bottom. Removing sediment from the micropool will benefit mosquito control. Ensure that the sediment is disposed of properly and not placed elsewhere in the basin.

7.8 Sediment Removal from the Basin Bottom

Remove sediment from the bottom of the basin when accumulated sediment occupies about 20% of the water quality design volume or when sediment accumulation results in poor drainage within the basin. The required frequency may be every 15 to 25 years or more frequently in basins where construction activities are occurring.

7.9 Erosion and Structural Repairs

Repair basin inlets, outlets, trickle channels, and all other structural components required for the basin to operate as intended. Repair and vegetate eroded areas as needed following inspection.

8.0 Sand Filters

Sand filters have relatively low routine maintenance requirements. Maintenance frequency depends on pollutant loads in runoff, the amount of construction activity within the tributary watershed, the erosion control measures implemented, the size of the watershed, and the design of the facility.

8.1 Inspection

Inspect the detention area once or twice annually following precipitation events to determine if the sand filter is providing acceptable infiltration. Also check for erosion and repair as necessary.

8.2 Debris and Litter Removal

Remove debris and litter from detention area to minimize clogging of the media. Remove debris and litter from the overflow structure.

8.3 Filter Surface Maintenance

Scarify the top 2 inches of sand on the surface of the filter. This may be required once every two to five years depending on observed drain times. After this has been done two or three times, replenish the top few inches of the filter with clean coarse sand (AASHTO C-33 or CDOT Class C filter material) to the original elevation. Maintain a minimum sand depth of 12 inches. Eventually, the entire sand layer may require replacement.

8.4 Erosion and Structural Repairs

Repair basin inlets, outlets, and all other structural components required for the BMP to operate as intended. Repair and vegetate any eroded side slopes as needed following inspection.

9.0 Retention Ponds and Constructed Wetland Ponds

9.1 Inspection

Inspect the pond at least annually. Note the amount of sediment in the forebay and look for debris at the outlet structure.

9.2 Debris and Litter Removal

Remove debris and litter from the pond as needed. This includes floating debris that could clog the outlet or overflow structure.

9.3 Aquatic Plant Harvesting

Harvesting plants will permanently remove nutrients from the system, although removal of vegetation can also resuspend sediment and leave areas susceptible to erosion. Additionally, the plants growing on the safety wetland bench of a retention pond help prevent drowning accidents by demarking the pond boundary and creating a visual barrier. For this reason, UDFCD does not recommend harvesting vegetation completely as routine maintenance. However, aquatic plant harvesting can be performed if desired to maintain volume or eliminate nuisances related to overgrowth of vegetation. When this is the case, perform this activity during the dry season (November to February). This can be performed manually or with specialized machinery.

If a reduction in cattails is desired, harvest them annually, especially in areas of new growth. Cut them at the base of the plant just below the waterline, or slowly pull the shoot out from the base. Cattail removal should be done during late summer to deprive the roots of food and reduce their ability to survive winter.

9.4 Mosquito Control

Mosquito control may be necessary if the BMP is located in proximity to outdoor amenities. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections and treatment can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. The use of larvicidal briquettes or "dunks" is not recommended for ponds due to their size and configuration.

Weekly mosquito inspections with targeted treatments are frequently less costly and more effective than regular widespread application of insecticide.

9.5 Sediment Removal from the Forebay

Remove sediment from the forebay before it becomes a significant source of pollutants for the remainder of the pond. More frequent removal will benefit long-term maintenance practices. For dry forebays, sediment removal should occur once a year. Sediment removal in wet forebays should occur approximately once every four years or when build up of sediment results in excessive algae growth or mosquito production. Ensure that the sediment is disposed of properly and not placed elsewhere in the pond.

9.6 Sediment Removal from the Pond Bottom

Removal of sediment from the bottom of the pond may be required every 10 to 20 years to maintain volume and deter algae growth. This typically requires heavy equipment, designated corridors, and considerable expense. Harvesting of vegetation may also be desirable for nutrient removal. When removing vegetation from the pond, take care not to create or leave areas of disturbed soil susceptible to erosion. If removal of vegetation results in disturbed soils, implement proper erosion and sediment control BMPs until vegetative cover is reestablished.

For constructed wetland ponds, reestablish growth zone depths and replant if necessary.

10.0 Constructed Wetland Channels

10.1 Inspection

Inspect the channel at least annually. Look for signs of erosion.

10.2 Debris and Litter Removal

Remove debris and litter as needed.

10.3 Aquatic Plant Harvesting

Harvesting plants will permanently remove nutrients from the system although removal of vegetation can also resuspend sediment and leave areas susceptible to erosion. For this reason, UDFCD does not recommend harvesting vegetation as routine maintenance. However, aquatic plant harvesting can be performed if desired to maintain volume or eliminate nuisances related to overgrowth of vegetation. When this is the case, perform this activity during the dry season (November to February). This can be performed manually or with specialized machinery.

Photograph 6-4. This broom sweeper will only remove debris from the pavement surface. Broom sweepers are not designed to remove solids from the void space of a permeable pavement. Use a vacuum or regenerative air sweeper to help maintain or restore infiltration through the wearing course.

If a reduction in cattails is desired, harvest them annually, especially in areas of new growth. Cut them at the base of the plant just below the waterline, or slowly pull the shoot out from the base. Cattail removal should be done during late summer to deprive the roots of food and reduce their ability to survive winter.

10.4 Sediment Removal

If the channel becomes overgrown with plants and sediment, it may need to be graded back to the original design and revegetated. The frequency of this activity is dependent on the site characteristics and should not be more than once every 10 to 20 years.

11.0 Permeable Pavement Systems

The key maintenance objective for any permeable pavement system is to know when runoff is no longer rapidly infiltrating into the surface, which is typically due to void spaces becoming clogged and requiring sediment removal. This section identifies key maintenance considerations for various types of permeable pavement BMPs.

11.1 Inspection

Inspect pavement condition and observe infiltration at least annually, either during a rain event or with a garden hose to ensure that water infiltrates into the surface. Video, photographs, or notes can be helpful in measuring loss of infiltration over time. Systematic measurement of surface infiltration of pervious concrete, Permeable Interlocking Concrete Pavers (PICP), concrete grid pavement, and porous asphalt[1] can be accomplished using ASTM C1701 Standard Test Method for Infiltration Rate of In Place Pervious Concrete.

[1] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.

11.2 Debris Removal, Sweeping, and Vacuuming

- **All Pavements:** Debris should be removed, routinely, as a source control measure. Typically, sites that require frequent sweeping already plan for this activity as part of their ongoing maintenance program. For example, a grocery store may sweep weekly or monthly. Depending on the season, city streets also may have a monthly plan for sweeping. This is frequently performed with a broom sweeper such as the one shown in Photo 6-4. Although this type of sweeper can be effective at removing solids and debris from the surface, it will not remove solids from the void space of a permeable pavement. Use a vacuum or regenerative air sweeper to help maintain or restore infiltration. If the pavement has not been properly maintained, a vacuum sweeper will likely be needed.

- **PICP, Concrete Grid Pavements (with aggregate infill), Pervious Concrete, and Porous Asphalt[1]:** Use a regenerative air or vacuum sweeper after any significant site work (e.g., landscaping) and approximately twice per year to maintain infiltration rates. This should be done on a warm dry day for best results. Do not use water with the sweeper. The frequency is site specific and inspections of the pavement may show that biannual vacuuming is more frequent than necessary. After vacuuming PICP and Concrete Grid Pavers, replace infill aggregate as needed.

11.3 Snow Removal

In general, permeable pavements do not form ice to the same extent as conventional pavements. Additionally, conventional liquid treatments (deicers) will not stay at the surface of a permeable pavement as needed for the treatment to be effective. Sand should not be applied to a permeable pavement as it can reduce infiltration. Plowing is the recommended snow removal process. Conventional plowing operations should not cause damage to the pavements.

- **PICP and Concrete Grid:** Deicers may be used on PICP and grid pavers; however, it may not be effective for the reason stated above. Sand should not be used. If sand is accidently used, use a vacuum sweeper to remove the sand. Mechanical snow and ice removal should be used.

- **Pervious Concrete:** Do not use liquid or solid deicers or sand on pervious concrete. Deicers can damage the concrete and sand will reduce infiltration. Mechanical snow and ice removal should be used.

- **Porous Asphalt[2]:** Use liquid or solid deicers sparingly; mechanical snow and ice removal is preferred. Do not apply sand to porous asphalt.

11.4 Full and Partial Replacement of the Pavement or Infill Material

- **PICP and Concrete Grid:** Concrete pavers, when installed correctly, should have a long service life. If a repair is required, it is frequently due to poor placement of the paver blocks. Follow industry guidelines for installation and replacement after underground repairs.

  If surface is completely clogged and rendering a minimal surface infiltration rate, restoration of surface infiltration can be achieved by removing the first ½ to 1 inch of soiled aggregate infill

[2] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.

material with a vacuum sweeper. After cleaning, the openings in the PICP will need to be refilled with clean aggregate infill materials. Replacement of the infill is best accomplished with push brooms.

- **Porous Gravel:** Remove and replace areas of excessive wear or reduced infiltration as needed. The frequency is dependent on site characteristics including site uses, vegetation, and materials.

- **Pervious Concrete:** Partial replacement of pervious concrete should be avoided. If clogged, power washing or power blowing should be attempted prior to partial replacement because saw cutting will cause raveling of the concrete. Any patches should extend to existing isolated joints. Conventional concrete may be used in patches, provided that 90 percent of the original pervious surface is maintained.

- **Reinforced Grass:** Remove and replace the sod cover as needed to maintain a healthy vegetative cover or when the sod layer accumulates significant amount of sediment (i.e., >1.5 inches). Maintenance and routine repairs should be performed annually, with sod replacement approximately every 10 to 25 years. When replacing sod, use a high infiltration variety such as sod grown in sandy loam.

- **Porous Asphalt[3]:** Conventional asphalt may be used in patches, provided that 90 percent of the original permeable surface is maintained.

12.0 Underground BMPs

Maintenance requirements of underground BMPs can vary greatly depending on the type of BMP. Frequent inspections (approximately every three months) are recommended in the first two years in order to determine the appropriate interval of maintenance for a given BMP. This section provides general recommendations for assorted underground BMPs. For proprietary devices, the manufacturer should provide detailed maintenance requirements specific for the BMP.

12.1 Inspection

- **All Underground BMPs:** Inspect underground BMPs at least quarterly for the first two years of operation and then twice a year for the life of the BMP, if a reduced inspection schedule is warranted based on the initial two years. Specifically look for debris that could cause the structure to bypass water quality flows. Strong odors may also indicate that the facility is not draining properly. Inspection should be performed by a person who is familiar with the operation and configuration of the BMP.

- **Inlet Inserts:** Inspect inlet inserts frequently; at a minimum, inspect after every storm event exceeding 0.6 inches. Removal of flow blocking debris is critical for flood control.

12.2 Debris Removal, Cartridge Replacement, and Vacuuming

- **All Underground BMPs:** Follow the manufacturer's recommended maintenance requirements and remove any flow blocking debris as soon as possible following inspection.

[3] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.

- **Filter Cartridges:** Inspection of filter cartridges is recommended twice yearly. Replacement of filter cartridges is anticipated on an annual basis. Depending on site characteristics, the replacement frequency may be extended to no less than once every three years. However, semi-annual inspection should continue to ensure that proper function of the system is maintained. Maintenance is required when any of the following conditions exist:
  - If there is more than 4 inches of accumulated sediment on the vault floor.
  - If there is more than ¼ inch of accumulation on the top of the cartridge.
  - If there is more than 4 inches of standing water in the cartridge bay for more than 24 hours after the end of a rain event.
  - If the pore space between media granules is full.
  - If inspection is conducted during an average rainfall event and the system remains in bypass condition (water over the internal outlet baffle wall or submerged cartridges).
  - If hazardous material release (automotive fluids or other) is reported.
  - If pronounced scum line (≥ 1/4" thick) is present above top cap.
  - If system has not been maintained for three years.
- **Hydrodynamic Separators:** Vacuum units at least once annually and more frequently as needed, based on inspections.

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Chapter 7
Construction BMPs

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1.0 Introduction

Effective management of stormwater runoff during construction activities is critical to the protection of water resources. The Federal Clean Water Act and the Colorado Water Quality Control Act require stormwater discharge permits during construction at development and redevelopment sites that disturb one or more acres of land. Some local governments also require these permits for sites that disturb less than one acre. Both erosion and sediment controls are necessary for effective construction site management as well as effective material management and site management practices (Figure 7-1). Protection of waterways from construction-related pollution is the ultimate objective of these practices.

This chapter provides an overview of erosion and sediment control principles and information on construction best management practices (BMPs). BMP Fact Sheets are provided, containing information on applicability, installation, maintenance, and design details with notes. The Fact Sheets are stand-alone documents that can be inserted directly into a Stormwater Management Plan (SWMP). Information is also provided on construction in or adjacent to waterways, construction dewatering, and linear construction projects, such as roadways and utilities.

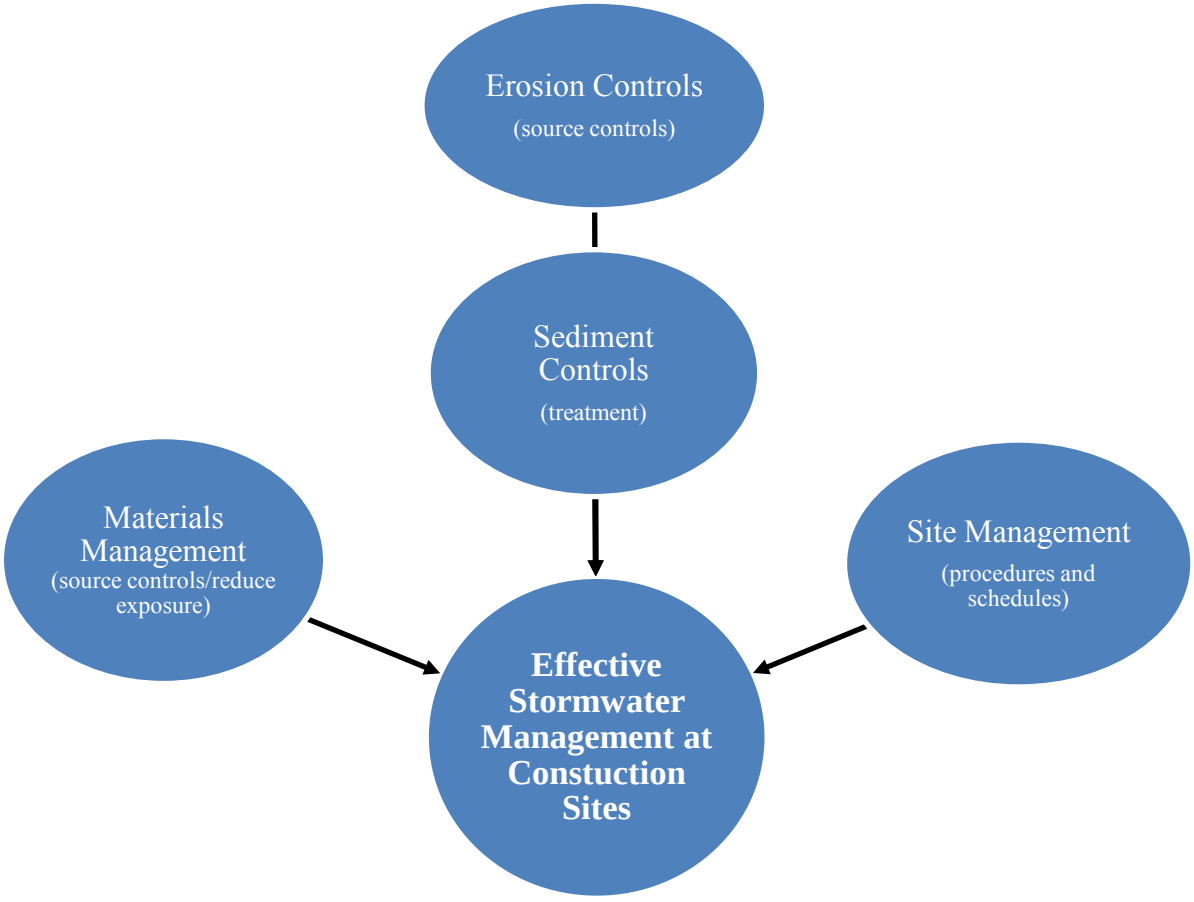

Figure 7-1. Components of Effective Stormwater Management at Construction Sites

2.0 Fundamental Erosion and Sediment Control Principles

2.1 Erosion

Photograph 7-2. Erosion is a common occurrence during construction activities, which can result in sediment movement off site and deposition in waterways when not properly managed. (Photo courtesy of Douglas County)

Soil erosion can generally be defined as the removal of soil by wind and water. Although soil erosion is a natural process, accelerated soil erosion occurs on construction sites due to activities that disturb the natural soil and vegetation.

Water erosion has five primary mechanisms: raindrop erosion, sheet erosion, rill erosion, gully erosion, and channel erosion. Raindrops dislodge soil particles, making them more susceptible to movement by overland water flow. Shallow surface flows on soil rarely move as a uniform sheet for more than several feet before concentrating in surface irregularities, known as rills. As the flow changes from a shallow sheet to a deeper rill flow, the flow velocity and shear stresses increase, which detach and transport soil particles. This action begins to cut into the soil mantle and form small channels. Rills are small, well-defined channels that are only a few inches deep. Gullies occur as the flows in rills come together into larger channels. The major difference between rill and gully erosion is size. Rills caused by erosion can be smoothed out by standard surface treatments such as harrowing. Gully erosion, however, typically requires heavy equipment to regrade and stabilize the land surface.

Wind erosion occurs when winds of sufficient velocity create movement of soil particles. The potential for wind erosion is dependent upon soil cover, soil particle size, wind velocity, duration of wind and unsheltered distance.

Erodibility of soils is affected by multiple factors including physical soil characteristics, slope steepness, slope lengths, vegetative cover, and rainfall characteristics. Physical properties of soils such as particle size, cohesiveness, and density affect erodibility. Loose silt and sand-sized particles typically are more susceptible to erosion than "sticky" clay soils. Rocky soils are less susceptible to wind erosion, but are often found on steep slopes that are subject to water erosion. Most of the soils in Colorado are susceptible to wind or water erosion, or both. When surface vegetative cover and soil structure are disturbed during construction, the soil is more susceptible to erosion. Vegetation plays a critical role in controlling erosion. Roots bind soil together and the leaves or blades of grass reduce raindrop impact forces on the soil. Grass, tree litter and other ground cover not only intercept precipitation and allow infiltration, but also reduce runoff velocity and shear stress at the surface. Vegetation reduces wind velocity at the ground surface, and provides a rougher surface that can trap particles moving along the ground. Once vegetation is removed, soils become more susceptible to erosion.

2.2 Sedimentation

Sedimentation occurs when eroded soil transported in wind or water is deposited from its suspended state. During a typical rainstorm in Colorado, runoff normally builds up rapidly to a peak and then diminishes. Because the amount of sediment a watercourse can carry is dependent upon the velocity and volume of runoff, sediment is eventually deposited as runoff decreases. The deposited sediments may be resuspended when future runoff events occur. In this way, sediments are moved progressively downstream in the waterway system.

2.3 Effective Erosion and Sediment Control

It is better to minimize erosion than to rely solely on sedimentation removal from construction site runoff. Erosion control BMPs limit the amount and rate of erosion occurring on disturbed areas. Sediment control BMPs attempt to capture the soil that has been eroded before it leaves the construction site. Despite the use of both erosion control and sediment control BMPs, some amount of sediment will remain in runoff leaving a construction site, but the use of a "treatment train" of practices can help to minimize offsite transport of sediment. The last line of treatment such as inlet protection and sediment basins should be viewed as "polishing" BMPs, as opposed to the only treatment on the site. Section 4 of this chapter provides an overview of erosion and sediment controls, followed by BMP Fact Sheets providing design details and guidance for effective use of various erosion and sediment control practices. BMPs should be combined and selected to meet these objectives:

- Conduct land-disturbing activities in a manner that effectively reduces accelerated soil erosion and reduces sediment movement and deposition off site.
- Schedule construction activities to minimize the total amount of soil exposed at any given time.
- Establish temporary or permanent cover on areas that have been disturbed as soon as practical after grading is completed.
- Design and construct temporary or permanent facilities to limit the flow of water to non-erosive velocities for the conveyance of water around, through, or from the disturbed area.
- Remove sediment caused by accelerated soil erosion from surface runoff water before it leaves the site.
- Stabilize disturbed areas with permanent vegetative cover and provide permanent stormwater quality control measures for the post-construction condition.

State Construction Phase Permitting

Stormwater runoff controls from construction sites are mandated by the Federal Water Pollution Control Act (Clean Water Act). In Colorado, the EPA has delegated authority to the Colorado Department of Public Health and Environment (CDPHE). CDPHE, specifically the Water Quality Control Division, issues stormwater and wastewater discharge permits under the Colorado Discharge Permit System (CDPS) Regulation promulgated by the Water Quality Control Commission.

3.0 Colorado Construction Stormwater Discharge Permits

Within UDFCD's boundary, development or redevelopment projects with one or more acres of potential disturbance are often required to obtain both local and state permits related to construction-phase stormwater discharges. The area of disturbance includes construction activities that are part of a larger common plan of development or sale and may include "separate" areas where construction practices will occur at different times. Areas used for staging, materials storage, temporary construction site access, off-site borrow areas and other construction related activities should also be included when determining the project area and area of disturbance permitted. In some cases, a construction discharge permit will be required by the local government, but not the state. Although CDPHE typically does not require permit coverage for construction activities that disturb less than one acre, provided the activities are not part of a large plan of development, some municipalities require stormwater permits for sites that disturb less than one acre, especially if construction is proximate to a floodplain and/or receiving water, steep slopes, and/or areas of known contamination.

The CDPHE typically issues construction permits under the CDPS General Permit for stormwater discharges associated with construction activities. Under certain conditions, CDPHE may require an individual permit. This may be required due to the size of disturbance, evidence of noncompliance under a previous permit, and/or quality and use of the receiving waters. The CDPS General Permit requires the owner and/or operator (frequently the contractor) to develop a SWMP. Although CDPHE does not require that the SWMP be submitted for approval, most local governments require submittal of a SWMP (or comparable document) which is reviewed by the local government and must be approved prior to issuance of construction-related permits (e.g., grading permit, land disturbance permit). Because SWMPs are "living documents" that must be updated and maintained as the phases of construction progress, ideally, one master document should be developed that is inclusive of both the state and local requirements, as opposed to maintaining duplicate records. Many local governments require documentation that goes beyond the state permit requirements.

Always obtain the state permit application and guidance directly from the state agency to ensure that all currently applicable requirements are met. In Colorado, this information can be obtained from the CDPHE CDPS General Permit for Stormwater Discharges Associated with Construction Activities. Also, check local government programs as they may have specific requirements more stringent than the minimum criteria specified by the state.

Table 7-1. Comparison of State and Local Construction-Phase Stormwater Permits in Colorado

	State	**Local Government** (programs vary, not inclusive)
Nomenclature	▪ Colorado Discharge Permit System (CDPS) General Permit for Stormwater Discharges Associated with Construction Activities ▪ CDPS Individual Permit for Stormwater Discharges Associated with Construction Activities	▪ Construction Activities Stormwater Discharge Permit (CASDP) ▪ Grading, Erosion, and Sediment Control Permit (GESC) ▪ Grading Permit ▪ Land Disturbance Permit ▪ Sewage Use and Drainage Permit (SUDP)
Triggers	▪ Area of potential disturbance is greater than one acre (This area includes construction activities that are part of a larger common plan of development or sale. Areas used for staging, materials storage, temporary construction site access, off-site borrow areas and other construction related activities should also be included.)	▪ State Construction Phase Stormwater Permit required ▪ Potential for erosion based on site characteristics (i.e. steep topography, highly erodible soils) ▪ Contaminated soils on site ▪ Sites within a designated 100-year floodplain and/or proximity to active waterway
Required Items	▪ Application ▪ Stormwater Management Plan (SWMP). In other parts of the country, this may be referred to as a Stormwater Pollution Prevention Plan (SWPPP) ▪ Annual Fee	▪ Application ▪ SWMP with requirements that frequently exceed the requirements listed in the state permit ▪ Fee

3.1 Preparing and Implementing a Stormwater Management Plan (SWMP)

A SWMP should be developed prior to construction and kept current for the duration of construction. This section includes recommendations for SWMP preparation and BMP inspection, maintenance and removal.

3.1.1 General SWMP Recommendations

- At a minimum, a SWMP should communicate and satisfy the following:
  - Identify all potential sources of pollution which may affect the quality of stormwater discharges associated with construction activity;
  - Describe the practices to be used to reduce the pollutants in stormwater discharges associated with construction activity including the installation, implementation and maintenance requirements; and
  - Be prepared in accordance with good engineering practices and be updated throughout construction and stabilization of the site.
- Implement the provisions of the SWMP as written and updated, from commencement of construction activity until final stabilization is complete. The SWMP typically requires additions or other modifications once construction commences, and documentation of all modifications and amendments is typically required by the construction stormwater permit. UDFCD recommends that the contractor maintain records of all inspections, BMP maintenance, and communications with the owner and/or engineer. This should be kept on-site, with the SWMP. UDFCD recommends that these records be recognized as part of the SWMP but that changes to the practices identified in the SWMP should not be made without the approval of an engineer.
- The SWMP should include additional discussion or plans for any special requirements of the site. Special requirements include Spill Prevention Control and Countermeasure (SPCC) plans under Section 311 of the Clean Water Act, or BMP programs otherwise required by another CDPS permit.

3.1.2 SWMP Elements

The SWMP should include the following as a minimum. When some sections are not applicable, include a statement to that effect.

- **Site Description:** Clearly describe the construction activity, including:
  - The nature of the construction activity at the site.
  - The proposed sequence for major activities.
  - Estimates of the total area of the site, and the area and location expected to be disturbed by clearing, excavation, grading, or other construction activities.
  - A summary of any existing data used in the development of the site construction plans or SWMP that describe the soil or existing potential for soil erosion.
  - A description of the existing vegetation at the site and an estimate of the percent vegetative ground cover.
  - The location and description of all potential pollution sources, including ground surface disturbing activities (see CDPHE Stormwater General Permit for description), vehicle fueling, storage of fertilizers or chemicals, etc.

- The location and description of any anticipated allowable sources of non-stormwater discharge at the site, e.g., uncontaminated springs, landscape irrigation return flow, construction dewatering, and concrete washout.

- The name of the receiving water(s) and the size, type and location of any outfall(s). If the stormwater discharge is to a municipal separate storm sewer system, the name of that system, the location of the storm sewer discharge, and the ultimate receiving water(s).

- **Site Map.** Include a legible site map(s), showing the entire site, identifying:

  - Construction site boundaries;

  - All areas of ground surface disturbance;

  - Areas of cut and fill;

  - Areas used for storage of building materials, equipment, soil, or waste;

  - Locations of dedicated asphalt or concrete batch plants;

  - Locations of all structural BMPs;

  - Locations of non-structural BMPs as applicable; and

  - Locations of springs, streams, wetlands and other surface waters.

- **Stormwater Management Controls.** Include a description of all stormwater management controls that will be implemented as part of the construction activity to control pollutants in stormwater discharges. The appropriateness and priorities of stormwater management controls in the SWMP should reflect the potential pollutant sources identified at the facility. The description of stormwater management controls should address the following components, at a minimum:

  - SWMP Administrator. Identify a specific individual(s), position, or title that is responsible for developing, implementing, maintaining, and revising the SWMP. This designated individual(s) should address all aspects of the facility's SWMP.

  - Identification of Potential Pollutant Sources. Identify and describe sources that may contribute pollutants to runoff, and provide means of control through BMP selection and implementation. At a minimum, evaluate each of the following potential sources of pollution:

    1. All disturbed and stored soils;

    2. Vehicle tracking of sediments;

    3. Management of contaminated soils;

    4. Loading and unloading operations;

    5. Outdoor storage activities (building materials, fertilizers, chemicals, etc.);

    6. Vehicle and equipment maintenance and fueling;

    7. Significant dust or particulate generating processes;

8. Routine maintenance activities involving fertilizers, pesticides, detergents, fuels, solvents, oils, etc.;

9. On-site waste management practices (waste piles, liquid wastes, dumpsters, etc.);

10. Concrete truck/equipment washing, including the concrete truck chute and associated fixtures and equipment;

11. Dedicated asphalt and concrete batch plants;

12. Non-industrial waste sources such as worker trash and portable toilets; and

13. Other areas or procedures where potential spills can occur.

- **BMPs for Construction Stormwater Pollution Prevention.** Identify and describe appropriate BMPs including those listed in this section. Provide enough detail for each BMP to ensure proper implementation, operation, and maintenance.

  - Structural Practices for Erosion and Sediment Control. (e.g., wattles/sediment control logs and temporary or permanent sediment basins).

  - Non-Structural Practices for Erosion and Sediment Control. (e.g., temporary vegetation and permanent vegetation).

  - Phased BMP Implementation. Describe the relationship between the phases of construction, and the implementation and maintenance of both structural and non-structural stormwater management controls. Project phases might include different operations such as clearing and grubbing; road construction; utility and infrastructure installation; vertical construction; final grading; and final stabilization.

  - Materials Handling and Spill Prevention. Materials of interest could include: exposed storage of building materials; paints and solvents; fertilizers or chemicals; waste material; and equipment maintenance or fueling procedures.

  - Dedicated Concrete or Asphalt Batch Plants.

  - Vehicle Tracking Control. This BMP includes minimizing (as practicable) the number of areas where construction vehicles are required to move from unpaved to paved areas as well as providing structural BMPs at each location.

  - Waste Management and Disposal, Including Concrete Washout.

  - Groundwater and Stormwater Dewatering. These activities often require a separate permit that includes sampling of processed waters. However, in some cases, these activities can be conducted without a separate permit when processed water is not discharged from the site as surface runoff or discharged into surface waters. The SWMP should describe how these waters will be used (i.e., land application, infiltration, evaporation) and how the specific practices at the site will ensure that these waters are not discharged via runoff.

- **Final Stabilization and Long-Term Stormwater Management**

  - The SWMP should describe the practices used to achieve final stabilization of all disturbed areas at the site and any planned practices to control pollutants in stormwater discharges that will occur after construction operations have been completed at the site.

  - Final stabilization practices for obtaining a vegetative cover should include, as appropriate: seed mix selection and application methods; soil preparation and amendments; soil stabilization practices (e.g., crimped straw, hydro mulch or rolled erosion control products); and appropriate sediment control BMPs as needed until final stabilization is achieved; etc.

  - Final stabilization is reached when all ground surface disturbing activities at the site have been completed, and uniform vegetative cover has been established with an individual plant density of at least 70 percent of pre-disturbance levels, or equivalent permanent, physical erosion reduction methods have been employed.

- **Inspection and Maintenance.** The SWMP should describe the inspection and maintenance procedures implemented at the site to maintain all erosion and sediment control practices and other protective practices identified in the SWMP in good and effective operating condition. UDFCD recommends providing an inspection checklist for the project.

3.2 Inspections

Routine and post-storm inspections of BMPs are essential to identify maintenance necessary for the BMPs to remain in effective operating conditions. The frequency of inspections is typically influenced by multiple factors including the weather, the phase of construction, activities on site, and the types of BMPs. Checklists and other forms of documentation are also important to meet the requirements of a construction stormwater permit.

3.2.1 Inspection Frequency

In Colorado, the CDPS General Permit requires documented inspections on a biweekly basis and within 24 hours of a storm event, with some limited, temporary exceptions for inactive sites. UDFCD recommends spot-checking BMPs every workday. This is typically reasonable to achieve and can help to ensure that the BMPs remain in good working condition. For example, vehicle tracking of sediment onto the roadway is a common problem that often requires maintenance more frequently than weekly. Curb socks, inlet protection and silt fence are other BMPs that are prone to damage and displacement, also benefiting from more frequent inspections.

When the site or portions of the site are awaiting final stabilization (e.g., vegetative cover), where construction is essentially complete, the recommended frequency of inspection is at least once every month. Be sure that this change is documented and in accordance with relevant permit requirements prior to reducing the inspection schedule.

When snow cover exists over the entire site for an extended period, inspections are not always feasible. Document this condition, including date of snowfall and date of melting conditions, and be aware of and prepare for areas where melting conditions may pose a risk of surface erosion.

Local inspection requirements may be more stringent than CDPS permit requirements. For example, many local governments require weekly, rather than bi-weekly, documented inspections. Some local governments may not allow relaxed inspection schedules for sites that have been completed, but are awaiting final stabilization or for winter conditions.

3.2.2 Inspection Records

Always check the requirements of the permit for required documentation of specific inspection items. Typically, these items can be incorporated into a checklist. Standard checklists may be developed and used for various types of construction projects (e.g., channel work, large-scale phased construction projects, or small urban sites). This kind of tool can help ensure the proper function of BMPs and provide a consistent approach to required documentation.

The checklist should always include the date and name/title of personnel making the inspection. It should include an area to note BMP failures, observed deviations from the SWMP, necessary repairs or corrective measures, corrective actions taken, and general observations.

3.3 Maintenance

Consider using a free internet application that provides real-time weather alerts to keep aware of inclement weather and plan ahead for staff to inspect and maintain BMPs.

Proactive maintenance is fundamental to effective BMP performance. Rather than maintaining the BMP in a reactive manner following failure, provide proactive maintenance that may help to reduce the likelihood of failure. The types and frequencies of maintenance are BMP-specific. The BMP Fact Sheets in this chapter describe the maintenance needs for each BMP, with some BMP types requiring more attention.

Maintain BMPs so that they function as intended. This includes removing accumulated sediment before it limits the effectiveness of the BMP. Identify needed maintenance activities during site inspections or during general observations of site conditions. Where BMPs have failed, repairs or changes should be initiated as soon as practical, to minimize the discharge of pollutants.

Where the BMPs specified in the SWMP are not functioning effectively at the site, modifications should be made that may include different or additional layers of BMPs. When new BMPs are installed or BMPs are replaced, check the permit for documentation requirements. This may require communication with the owner and/or engineer and, at a minimum, should be documented in the inspection and maintenance records (logbook).

3.4 Disposition of Temporary Measures

Most temporary erosion and sediment control measures must be removed within 30 days after final site stabilization is achieved. The BMP Fact Sheets in this chapter provide guidance for final disposition of temporary measures. This may be as simple as removing silt fence, or more complex such as removing accumulated sediment from a construction phase sedimentation basin that will be used as a post-construction extended detention basin. Some biodegradable BMPs, such as erosion control blankets, are designed to remain in place and would create new areas of disturbance if removed. See the BMP Fact Sheets for guidance on BMPs that may be left in place as a part of final stabilization. For some BMPs

such as sediment control logs/straw wattles, some materials may be biodegradable (straw), but there may be components of the BMP that biodegrade slowly (stakes) or not at all (plastic netting). Always check local requirements for guidance on construction BMPs that may remain in place.

Temporary erosion control measures should not be removed until all areas tributary to the temporary controls have achieved final stabilization. It may be necessary to maintain some of the control measures for an extended period of time, until the upgradient areas have been fully stabilized, and vegetation has sufficiently matured to provide adequate cover. Trapped sediment and disturbed soil areas resulting from the disposal of temporary measures must be returned to final plan grades and permanently stabilized to prevent further soil erosion.

Whenever post-construction BMPs are used for sediment controls during construction, the plan should include the steps and actions needed to refurbish these facilities to a fully operational form as post-construction BMPs. The final site work will not be accepted by the local jurisdiction until these BMPs are in final and acceptable form as the original design calls for, which includes lines and grades, volumes, outlet structures, trash racks, landscaping and other measures specified in the site development plans prepared by the design engineer.

3.5 2009 Federal Effluent Limitation Guidelines

On December 1, 2009, the EPA published Effluent Limitation Guidelines in the Federal Register (Volume 74, Number 229, pages 62997-63057) establishing technology-based effluent limitation guidelines (ELGs) and new source performance standards (NSPS) for the construction and development industry. This rule requires construction site owners and operators to implement a range of erosion and sediment control measures and pollution prevention practices to control pollutants in discharges from construction sites. Additionally, the rule requires monitoring and sampling of stormwater discharges and compliance with a numeric standard for turbidity in these discharges for larger construction sites (i.e., 10 acres or more). The rule, including numeric effluent limits, was legally challenged in 2010 and, as of October 2010, EPA is in the process of reconsidering the numeric effluent limits from the rule. Other portions of the rule will remain in effect while EPA reevaluates the numeric limits.

In Colorado, unless constructing a federal project or working on an Indian reservation, construction stormwater discharge permits are issued by CDPHE under the CDPS General Permit for Stormwater Discharges Associated with Construction Activity (CDPS Permit No. COR-030000). This permit was first issued in 1997, and is effective through June 30, 2012. It is anticipated that CDPHE will issue a new general permit in 2012 that will reflect the guidelines, with the possible exception of the numeric limits which may still be under reevaluation at the time that CDPHE issues the new permit. Existing state stormwater requirements will remain in effect until a new general permit is issued.

4.0 Overview of Construction BMPs

Construction BMPs include not only erosion and sediment control BMPs, but also material management and site management BMPs. Related practices include dewatering and construction in waterways, which are discussed in Sections 6 and 7. The design details and notes for the BMPs identified in this section are provided in stand-alone Fact Sheets that also include guidance on applicability, design, maintenance, and final disposition. A key to effective stormwater management at construction sites is to understand how construction stormwater management requirements change over the course of a construction project, as summarized in Figure 7-2. Additionally, BMPs vary with regard to the functions they provide.

Table 7-2 provides a qualitative characterization of the roles that various BMPs provide with regard to serving erosion control functions, sediment control functions, or site/materials management roles. In particular, it is important to understand whether the primary role of the BMP is erosion control or sediment control. Effectively managed construction sites will provide a combination of BMPs that provide both functions.

Figure 7-2. Construction Stormwater Management

Table 7-2. Overview of Construction BMPs

Functions	Erosion Control	Sediment Control	Site/Material Management
Erosion Control BMPs			
Surface Roughening	Yes	No	No
Temporary/Permanent Seeding	Yes	No	No
Soil Binders	Yes	No	Moderate
Mulching	Yes	Moderate	No
Compost Blankets and Filter Berms	Yes	Moderate	No
Rolled Erosion Control Products	Yes	No	No
Temporary Slope Drains	Yes	No	No
Temporary Outlet Protection	Yes	Moderate	No
Rough Cut Street Control	Yes	Moderate	No
Earth Dikes / Drainage Swales	Yes	Moderate	No
Terracing	Yes	Moderate	No
Check Dams	Yes	Moderate	No
Streambank Stabilization	Yes	No	No
Wind Erosion / Dust Control	Yes	No	Moderate
Sediment Control BMPs			
Silt Fence	No	Yes	No
Sediment Control Log	Moderate	Yes	No
Straw Bale Barrier	No	Moderate	No
Brush Barrier	Moderate	Moderate	No
Rock Sock (perimeter control)	No	Yes	No
Inlet Protection (various forms)	No	Yes	No
Sediment Basins	No	Yes	No
Sediment Traps	No	Yes	No
Vegetative Buffers	Moderate	Yes	Yes
Chemical Treatment	Moderate	Yes	No
Materials Management			
Concrete Washout Area	No	No	Yes
Stockpile Management	Yes	Yes	Yes
Good Housekeeping (multiple practices)	No	No	Yes
Site Management and Other Specific Practices			
Construction Phasing	Moderate	Moderate	Yes
Protection of Existing Vegetation	Yes	Moderate	Yes
Construction Fence	No	No	Yes
Vehicle Tracking Control	Moderate	Yes	Yes
Stabilized Construction Roadway	Yes	Moderate	Yes
Stabilized Staging Area	Yes	Moderate	Yes
Street Sweeping / Vacuuming	No	Yes	Yes
Temporary Diversion Channel	Yes	No	No
Dewatering Operations	Moderate	Yes	Yes
Temporary Stream Crossing	Yes	Yes	No
Temporary Batch Plants	No	No	Yes
Paving and Grinding Operations	No	No	Yes

4.1 Erosion Control Measures

Erosion control measures are source controls used to limit erosion of soil. These are typically surface treatments that stabilize soil that has been exposed by excavation or grading, although some limit erosion by redirecting flows or reducing velocities of concentrated flow. Fact Sheets for the following erosion control (EC) practices are provided in this chapter:

- EC- 1 Surface Roughening (SR)
- EC-2 Temporary and Permanent Seeding (TS/PS)
- EC-3 Soil Binders (SB)
- EC-4 Mulching (MU)
- EC-5 Compost Blanket and Filter Berm (CB)
- EC-6 Rolled Erosion Control Products (RECP) (*includes erosion control blankets [ECBs] and turf reinforcement mats [TRMs]*)
- EC-7 Temporary Slope Drains (TSD)
- EC-8 Temporary Outlet Protection (TOP)
- EC-9 Rough Cut Street Control (RCS)
- EC-10 Earth Dikes and Drainage Swales (ED/DS)
- EC-11 Terracing (TER)
- EC-12 Check Dams (CD) (*also includes Reinforced Check Dams [RCD]*)
- EC-13 Streambank Stabilization (SS)
- EC-14 Wind Erosion / Dust Control (DC)

4.2 Sediment Control Measures

Sediment control measures limit transport of sediment off-site to downstream properties and receiving waters. Sediment controls are the second line of defense, capturing soil that has been eroded. Sediment controls generally rely on treatment processes that either provide filtration through a permeable media or that slow runoff to allow settling of suspended particles. A third treatment process that is used in some parts of the country includes advanced treatment systems employing chemical addition (flocculent) to promote coagulation and settling of sediment particles. UDFCD discourages use of chemical treatment as misuse of chemicals can be more detrimental than the sediment being removed. CDPHE does not currently allow use of chemicals. Sediment control (SC) BMPs included as Fact Sheets in this chapter are:

- SC-1 Silt Fence (SF)
- SC-2 Sediment Control Log (SCL)
- SC-3 Straw Bale Barrier (SBB)
- SC-4 Brush Barrier (BB)
- SC-5 Rock Sock (RS)
- SC-6 Inlet Protection (IP) (*multiple types*)
- SC-7 Sediment Basin (SB)
- SC-8 Sediment Trap (ST)
- SC-9 Vegetated Buffers (VB)
- SC-10 Chemical Treatment (CT) (*also known as Advanced Treatment Systems [ATS])*

4.3 Site Management

Site management is often ultimately the deciding factor in how effective BMPs are at a particular site. BMPs implemented at the site must not only be properly selected and installed, but also must be inspected, maintained and properly repaired for the duration of the construction project. In addition to general site management, there are a number of specific site management practices that affect construction site management. For example, effective construction scheduling (phasing and sequencing) helps minimize the duration of exposed soils. Protection of existing vegetation also minimizes exposed areas and can reduce the cost of final site stabilization. Stabilized construction entrances (vehicle tracking controls) and street sweeping are critical source control measures to minimize the amount of sediment that leaves a site. Additionally, there are several miscellaneous activities that must be carefully conducted to protect water quality such as dewatering operations, temporary batch plants, temporary stream crossings and other practices.

Resources for Construction Stormwater Management/Erosion and Sediment Control Training

Certified Professional in Erosion and Sediment Control Program (http://www.cpesc.org/)

Certified Inspector of Sediment and Erosion Control Program (http://www.cisecinc.org/)

Rocky Mountain Education Center (http://www.rrcc.edu/rmec/cetc.html)

International Erosion Control Association (http://www.ieca.org/)

Associated General Contractors of Colorado (www.agccolorado.org/)

As part of the construction kick-off meeting for the project (or for major phases of construction), an effective strategy is to include a training component related to construction site stormwater management. Such training should provide basic education to site personnel regarding the requirements of the state and local construction stormwater permits and the serious fines and penalties than can result from failure to comply with permit requirements. The individual or individuals responsible for inspection and maintenance of construction BMPs should have a practical understanding of how to maintain construction BMPs proactively in effective operating condition and to identify conditions where failure is eminent or has already occurred. In addition to site-specific training, several training courses are available in the metro Denver area regarding construction site stormwater management.

Site management (SM) practices addressed in Fact Sheets as part of this chapter include:

- SM-1 Construction Phasing/Sequencing (CP)
- SM-2 Protection of Existing Vegetation (PV)
- SM-3 Construction Fence (CF)
- SM-4 Vehicle Tracking Control (VTC) *(multiple types)*
- SM-5 Stabilized Construction Roadway (SCR)
- SM-6 Stabilized Staging Area (SSA)
- SM-7 Street Sweeping and Vacuuming (SS)
- SM-8 Temporary Diversion Channel (TDC)
- SM-9 Dewatering Operations (DW)
- SM-10 Temporary Stream Crossing (TSC) *(multiple types)*
- SM-11 Temporary Batch Plant (TBP)
- SM-12 Paving and Grinding Operations (PGO)

4.4 Materials Management

Materials management BMPs are source control practices intended to limit contact of runoff with pollutants commonly found at construction sites such as construction materials and equipment-related fluids. By intentionally controlling and managing areas where chemicals are handled, the likelihood of these materials being transported to waterways is reduced. Materials management (MM) BMPs provided as Fact Sheets in this chapter include:

- MM-1 Concrete Washout Area (CWA)
- MM-2 Stockpile Management (SP)
- MM-3 Good Housekeeping Practices (GH) (including *Spill Prevention and Control, Material Use, Material Delivery and Storage, Solid Waste Management, Hazardous Waste Management, Sanitary/Septic Waste Management, and Vehicle & Equipment Fueling, Maintenance and Cleaning*)

4.5 Proprietary BMPs

Many proprietary BMPs are available for construction site stormwater management. This manual does not provide a list of approved products; however, some local jurisdictions may require that proprietary products go through a formal approval process prior to use within their jurisdiction. Basic questions that local governments may want to consider asking when considering approval of proprietary construction BMPs include:

General

- Does the product provide equivalent or better function than the design details specified in this manual?
- What are the installation procedures?
- What are the maintenance requirements? Is special equipment required for maintenance?
- What are the consequences of failure of the product?
- Has the product been successfully implemented on other sites in the metropolitan Denver area?

Inlet Protection

- Does the inlet protection enable runoff to enter the inlet without excessive ponding in traffic areas?
- How does the BMP provide for overflow due to large storm events or blockages?
- How is the BMP secured to the street or curb? Will it result in damage to concrete or pavement? Is it secured in a manner that prevents short-circuiting or collapsing into the inlet?
- Does the BMP appear to be sturdy enough to withstand typical activities conducted at construction sites or traffic on public roadways?
- Is there potential for pollutant leaching from the BMP?

- For inlet inserts, is special equipment required to remove the insert? Is the insert material strong enough to withstand tearing and/or collapse into the inlet, even when maintenance is less than ideal?

Perimeter Controls

- How is the perimeter control installed (e.g., trenching, staking)? Perimeter controls that are not adequately secured may be subject to undercutting and washout.
- Is the material used in the perimeter control adequately durable for the life of the construction project?
- How are vehicle tracking and site access controlled where flexible perimeter controls allow vehicles to drive over the BMP?

Hydraulically Applied Products

- Does the product contain chemicals, pollutants, nutrients, or other materials that could adversely impact receiving waters or groundwater?
- Has the product been adequately field tested under local conditions to ensure that the service life is consistent with the manufacturer's representation?
- Does use of the product require special permits?

5.0 BMP Selection and Planning

Construction BMPs should be selected, designed, installed, and maintained based on site-specific conditions. BMPs should be selected based on the physical layout and site conditions that will exist during each stage of construction, because site conditions change through the various stages of construction. The number of stages that must be addressed in the SWMP depends on the type of construction activity and local jurisdiction requirements, but in general, three stages of erosion and sediment control plans can be considered. These stages include initial clearing and grading; utility, infrastructure and building construction; and final stabilization.

Effective construction site stormwater management planning involves the following:

- Collecting and analyzing site-specific information to identify needed erosion and sediment controls,
- Preparing a SWMP that specifies needed BMPs appropriate to each phase of construction, and
- Following the SWMP, maintaining BMPs and updating the SWMP as construction progresses.

This section focuses on important factors to consider in the development of a SWMP, including site-specific conditions, BMP functions, and other site-related plans.

5.1 Site Assessment

Early awareness of site-specific factors that make a site particularly prone to erosion problems can prevent serious problems later during the construction process. A site assessment should include attention to these factors, prior to selection of BMPs:

- **Slopes/Topography and Topographic Changes Due to Grading**: Slope length and steepness are two key factors in identifying the types and placement of both erosion and sediment control BMPs. Slopes will change throughout the phases of construction as grading is conducted. See Sections 5.2 and 5.3 for additional guidance.

- **Tributary Area/Catchment Size**: The overall size of sub-catchment areas prior to and following grading is a key factor in determining the types, sizes, spacing and other design requirements for sediment controls appropriate for each drainage area. The allowable tributary area for sediment controls varies, depending on the practice selected, as described in the BMP Fact Sheets.

- **Soils**: Regardless of soil type, all disturbed soils require erosion controls; however, NRCS soil maps and geotechnical reports for the development can be used to identify soil conditions where erosion may be particularly difficult to control. In such settings, additional layers of protection for both erosion and sediment controls may be needed and planned for proactively in the SWMP.

- **Vegetation**: Onsite vegetation that is to be left undisturbed must be clearly identified in the SWMP and/or the construction plans. Construction fence should be installed to avoid disturbance and compaction of these areas. This is particularly important for protection of mature trees, natural riparian buffers and wetlands, natural open space, or other areas specifically identified to be protected from compaction as part of Low Impact Development (LID) designs. Maintaining a vegetative buffer, in combination with other perimeter control BMPs, can be effective for minimizing transport of sediment off-site.

- **Drainage Infrastructure**: Understanding the hydrology of a site is important in the design of sediment controls. Offsite run-on as well as drainage patterns within the site should be thoroughly assessed. The configuration of hill slope areas and waterways, in the context of planned roads and buildings, will determine which erosion and sediment controls will be needed at each phase of construction.

- Sensitive Site Conditions: In cases where construction is occurring in areas of sensitive aquatic habitat, upstream of drinking water supplies, or near areas where threatened and endangered species are a concern, additional layers of protection may be specified by the local, state or federal government. These may include redundant BMPs or restrictions on times that construction activities are allowed.

5.2 Slope-Length and Runoff Considerations

Cut-and-fill slopes should be designed and constructed to minimize erosion. This requires consideration of the length and steepness of the slope, the soil type, upslope drainage area, groundwater conditions and other applicable factors. Slopes found to be eroding excessively will require additional slope stabilization until the problem is corrected. The following guidelines should assist site planners and plan reviewers in developing an adequate design:

Photograph 7-2. Diverting the upland slope drainage area may have avoided the rilling shown in this picture.

- Rough soil surfaces enhance infiltration and/or lengthen the travel path or runoff, reducing runoff velocity. See the Surface Roughening BMP Fact Sheet.

- Temporary diversion dikes should be constructed at the top of long or steep slopes. Diversion dikes or terraces reduce slope length within the disturbed area. See the Earth Dikes and Drainage Swales BMP Fact Sheet.

- Temporary diversion dikes should be provided whenever:

  $S^2L > 2.5$ for **undisturbed** tributary areas; Equation 7-1

  $S^2L > 1.0$ for disturbed tributary areas; Equation 7-2

  $S^2L > 0.25$ for paved tributary areas; Equation 7-3

  where:

  S = slope of the upstream tributary area (feet/foot)

  L = length of the upstream slope (feet)

  As an example, runoff from a developed area runs on to an area that will be disturbed. A diversion dike would be required if, for example, the length of the flow path was greater than 625 feet and the slope of the flow path was 2%.

- Concentrated stormwater (e.g., pipe outflow, channel, swale) should not be allowed to flow down cut or fill slopes unless contained within an adequately-sized temporary channel diversion, a permanent channel, or temporary slope drain. See the Temporary Slope Drain and Diversion Ditches/Channels BMP Fact Sheets.

- Wherever a slope face crosses a water seepage plane that endangers the stability of the slope, adequate drainage should be provided.

- Provide sediment basins or barriers (silt fence) at or near the toe of slopes to trap sediment or to reduce slope lengths. When flows are concentrated and conveyed down a slope using a slope drain or channel, energy dissipation measures will be required at the conveyance outlet at the toe of the slope. See the Sediment Control BMP Fact Sheets for several options for controlling sediment at the base of slopes.

5.3 Using the Revised Universal Soil Loss Equation

The Revised Universal Soil Loss Equation (RUSLE) is an erosion prediction method that has evolved over time, resulting from data collection and analysis efforts extending from the 1930s through the 1970s, ultimately published in *Agriculture Handbook 282* (Wischmeier and Smith, 1965), then *Agriculture Handbook 537* (Wischmeier and Smith, 1978) and *Agriculture Handbook 703* (Renard et al., 1997). Although originally developed for agricultural land use, it is also a useful method for estimating erosion potential on construction sites and adjusting BMPs to reduce the estimated erosion. The RUSLE is also incorporated into several modern erosion prediction models. The Modified Universal Soil Loss Equation (MUSLE) is similar to the RUSLE, but is differentiated by the fact that MUSLE is event-based while RUSLE is an annual method (with the option to calculate monthly or seasonal erosion). This section provides a brief overview of RUSLE and describes how it can be used to help select erosion control practices at construction sites.

$$A = RKLSCP \qquad \text{Equation 7-4}$$

where:

A = Computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. Typically, A is expressed in tons per acre per year.

R = Rainfall-runoff erosivity factor – the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K = Soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil.

L = Slope length factor – the ratio of soil loss from the field slope length to soil loss from a 72.6 ft length under identical conditions.

S = Slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9 percent slope under otherwise identical conditions.

C = Cover-management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in a bare condition. Values range from 0.01 to 1.

P = Erosion control practice factor – the ratio of soil loss with a certain conservation practice (erosion control BMP) to that of no practice. Values range from 0.8 to 1.2.

The slope length, *L,* and steepness factor, *S,* are commonly combined as one variable, *LS*. Values for *LS* are quantified relative to a 72.6 ft slope length with a 9 percent slope. A slope with these two values will have an *LS* factor of 1.

A detailed discussion of RUSLE factors is beyond the scope of this manual; however, *Agriculture Handbook 703* can be obtained at no charge from the USDA publications website and used to develop or

obtain values for the factors in the equation. Construction managers can use the RUSLE, either by hand or by using a variety of different software programs based on the equation, to evaluate how implementing various BMPs can help reduce surface erosion. Highly erosive sites or sites with sensitive receiving waters may benefit from more rigorous analysis using the RUSLE.

Although construction managers have no control over the *A* and *R* factors, factors *L, S, C* and *P* can be altered by implementing practices that reduce sediment loading. One technique to reduce the slope length and steepness is to terrace. For example, if a portion of a construction area has a slope length of 500 feet, it can be terraced into three or four equal sections to reduce the erosivity of the water coming down the slope. This factor can also be used to guide placement distances for silt fence, wattles and other practices that serve to break up the slope length. As another example, construction managers can vary cover management practices to decrease the *C* factor and reduce sediment loading. *C* values vary, depending on the type of cover implemented. Using the reference table for the *C* value, managers can select cover approaches to help reduce sediment loading. Finally, the practice factor *(P)* serves as an index of anticipated erosion reduction associated with various erosion control BMPs.

5.4 BMP Functions

Understanding the intended function of a BMP is critical to proper BMP selection. BMPs should be selected based on both the intended function of the BMP and consideration of whether the BMP can provide the desired function based on the site-specific conditions. It is also important to understand how BMP functions are related to maintenance. For example, when silt fence is initially installed, it provides a filtration function, but over time, the fabric can become clogged, leading to ponding and sedimentation behind the fence as the primary function rather than filtration.

Sediment control BMPs such as sediment basins can provide some settling of sediment from runoff, but must be combined with **erosion** controls throughout the site in order to be effective. Sediment basins, inlet protection, and other sediment control BMPs should not be solely relied upon as "end-of-pipe" treatment systems.

5.5 Consistency with Other Plans

Prior to selection of BMPs for the SWMP, it is important to cross-check other construction planning documents for consistency and/or opportunities for increased efficiencies and effectiveness. As an example, landscaping plans for a site should be consistent with final stabilization measures in the SWMP.

5.5.1 Drainage Plans

The SWMP should be prepared with due consideration of the final drainage plan for a development. As permanent drainage features are constructed, temporary sediment controls should be located and designed to both protect and complement these final drainage features. Temporary controls should be staged and removed at the appropriate time relative to the completion of permanent drainage features. Special care is necessary for permanent BMPs that rely on infiltration such as bioretention, permeable pavements, sand filters and others. These BMPs will clog if they are not adequately protected during construction (or constructed after tributary areas have been stabilized).

5.5.2 Post Construction Stormwater Management

Coordination of temporary and post-construction BMPs is important for several reasons. In some cases, post construction BMPs such as extended detention basins can be modified to serve as sedimentation basins during construction. In other cases, such as in the case of rain gardens or infiltration-oriented post-

construction BMPs, it is critically important to protect the post-construction facilities from sediment loading during construction. Also, as previously noted, if an area is targeted for preservation in an uncompacted, natural condition under a LID design, it is critical to keep heavy equipment and staging out of this area.

5.5.3 Air Quality Plans

Properly implemented erosion and sediment control BMPs are beneficial in minimizing wind erosion. For example, surface stabilization measures that help to reduce precipitation-induced erosion help to reduce windborne dust and sediment. Additional controls, such as road watering (to moisten roads but not to the extent that runoff results) and/or soil binders may be necessary to fully comply with fugitive dust regulations at a construction site. Contact the appropriate local agency for air quality requirements during construction.

5.6 Guidelines for Integrating Site Conditions and BMPs into a SWMP

The following guidelines are recommended when combining BMPs into an effective SWMP:

- **Determine the limits of clearing and grading**: If the entire site will not undergo excavation and grading, or excavation and grading will occur in stages, the boundaries of each cut-and-fill operation should be defined. Buffer strips of natural vegetation may be utilized as a control measure. Adequate protection of both tree limbs and root systems is important when specifying limits of construction activity. Use construction fence or other barriers to protect areas that should not be compacted or disturbed.

- **Define the layout of buildings and roads**: Typically, this will have been decided previously as a part of the general development plan. If building layout is not final, the road areas stabilized with pavement and the drainage features related to roads should be defined as they relate to the plan.

- **Determine permanent drainage features**: The location of permanent channels, storm sewers, roadside swales and stormwater quality controls such as ponds, wetlands, grassed-lined swales, buffer strips and areas of porous pavement, if known, should be defined.

- **Determine extent of temporary channel diversions and crossings**: If permanent channel improvements are a part of the plan, the route, sizing and lining needed for temporary channel diversions should be determined. Location and type of temporary channel crossings can be assessed.

- **Determine the boundaries of watersheds**: The size of drainage catchments will determine the types of sediment controls to be used. Areas located offsite that contribute runoff must be assessed. Measures to limit the size of upland drainage areas, such as diversion dikes, should be considered at this stage. Routing offsite "clean" runoff around areas of disturbance in stabilized conveyances reduces the burden on onsite measures and can reduce liability of the permittee—once offsite runoff enters the permitted construction area, the permittee is responsible for erosion and sediment transport resulting from the offsite runoff.

- **Select erosion controls**: All areas of exposed soil will require erosion control measures based on factors including the duration of exposure, soil erosivity, slope steepness, and length, and others.

- **Select sediment controls**: Select the controls needed for each stage of the construction project. Each stage will have different demands for the control of erosion and sedimentation. For example, over-lot grading will require controls that may require different BMPs than when individual homes are being

built and lots are disturbed after the streets and drainage systems are in place. Sediment basins are an essential part of the total plan when the tributary area exceeds one acre.

- **Determine sequencing of construction**: The schedule of construction will determine what areas must be disturbed at various stages throughout the development plan. The opportunity for phasing cut-and-fill operations to minimize the period of exposure of soils needs to be assessed and then incorporated into the SWMP.

- **Identify planned locations of topsoil stockpiles**: Areas for storing topsoil should be determined and proper measures to control erosion and sediment movement should be specified.

- **Identify planned location of temporary construction roads, vehicle tracking controls, portable toilets, waste disposal areas, and material storage areas**: These elements can be determined in the context of previously defined parts of the site construction management plan.

6.0 Construction Dewatering

Dewatering is typically necessary during construction activities that involve deep excavations, instream work, pumped surface diversions, and open trench operations in some cases. In Colorado, construction dewatering frequently requires a separate permit along with sample collection and the completion of Discharge Monitoring Reports (DMRs). When dewatering can be conducted without discharging surface runoff from the site, it may be possible to conduct such activities under the state Construction-phase Stormwater Permit. Some commonly used methods to handle the pumped water without surface discharge include land application to vegetated areas through a perforated discharge hose (i.e., the "sprinkler method") or dispersal from a water truck for dust control. Carefully check state and local permit requirements to determine when dewatering can be conducted without additional permitting.

Construction dewatering BMPs generally include practices to minimize turbidity in the pumped water. Representative practices that may help to reduce turbidity in various types of dewatering applications include:

- Using perimeter well points outside of the excavated area to draw down the water table rather than dewatering directly from the excavation;

- Placing a submersible pump in a perforated bucket filled with gravel for short-term pumping;

- Constructing a filtering sump pit for pumping groundwater below the excavation grade for multiple-day operations; or

- Using a flotation collar or other flotation device to pump from the surface of a sediment basin to avoid the silt that can accumulate on the bottom of the basin.

Guidance on BMPs for construction dewatering is provided on the Dewatering Operations Fact Sheet.

7.0 Construction in Waterways

Construction in waterways is often required for projects including bridge construction, utility construction, streambank stabilization and grade control, and temporary or permanent stream crossings. Construction in waterways requires a high standard of care in order to avoid and minimize damage to waterways, habitat, and aquatic life. In addition to the Construction Phase Permits already discussed, this work can also require a Clean Water Act Section 404 Permit from USACE, U.S. Fish and Wildlife

Service (USFWS) threatened and endangered species permitting, and/or other state and local permits. Some required permits may restrict construction to certain times of the year.

Many of the BMPs described in Section 4 of this chapter are used in waterway construction. This section provides guidance on factors to consider and plan for during construction in waterways, as well as guidance on specific BMPs that should be implemented, depending on site-specific conditions. Other UDFCD criteria and guidance that are closely related to in-stream work should also be referenced including:

- USDCM Volume 1 Major Drainage Chapter
- USDCM Volume 2 Revegetation Chapter
- USDCM Volume 2 Hydraulic Structures Chapter
- *Stormwater Management During Construction: Best Management Practices for Construction in Waterways Training Program Student Manual* (Altitude Training Associates 2008). This document is available for download on www.udfcd.org.

BMPs provided in this chapter that are commonly used when construction occurs in waterways include:

- EC-1 Surface Roughening (SR)
- EC-2 Temporary and Permanent Seeding (TS/PS)
- EC-3 Soil Binders (SB)
- EC-4 Mulching (MU)
- EC-6 Rolled Erosion Control Products (RECP)
- EC-10 Earth Dikes and Drainage Swale (ED/DS)
- EC-13 Streambank Stabilization (SS)
- SC-1 Silt Fence (SF)
- SM-1 Construction Phasing/Sequencing (CP)
- SM-8 Temporary Diversion Channel (TDC)
- SM-10 Dewatering Operations (DW)
- SM-11 Temporary Stream Crossing (TSC)

In addition to criteria specified for these BMPs, the following general principles should be followed:

- Construction vehicles should be kept out of a waterway to the maximum extent practicable.
- Where in-channel work is necessary, steps such as temporary channel diversions must be taken to stabilize the work area and control erosion during construction.
- When in-stream work has been completed, the channel must be stabilized using revegetation practices (often, including use of erosion control matting or turf reinforced mats), riprap, or other permanent stabilization measures as required by the SWMP.
- Where an actively-flowing watercourse must be crossed regularly by construction vehicles, a temporary crossing should be provided. Three primary methods are available: (1) a culvert crossing, (2) temporary bridge, and (3) a stream ford. See the Temporary Stream Crossing Fact Sheets.
- A permit is required for placement of fill in a waterway under Section 404 of the Clean Water Act.

The local office of the USACE should be contacted concerning the requirements for obtaining a 404 permit. In addition, a permit from USFWS may be needed if threatened or endangered species are of concern in the work area. Typically, the USFWS issues are addressed in conjunction with the 404 permit if one is required. A floodplain development permit and other local permits may also be required.

- When work takes place within a channel, a temporary water diversion to bypass the work area is typically required. See the Diversion Channel/Ditch BMP Fact Sheet for criteria and design details.
- To the extent practical, construction in a waterway should be sequenced to begin at the most downstream point and work progressively upstream installing required channel and grade control facilities.
- Complete work in small segments, exposing as little of the channel at a time as practical. Keep equipment operators contained in immediate work area and avoid excessive compacting of the soil surface because it inhibits revegetation.
- Where feasible, it is best to perform in-channel work between October 1 and March 31 in Colorado. This is the period when the chances of flash floods and flows higher than the 2-year flood peak flows are less likely.
- During the process of cut and fill, avoid letting side-cast or waste material enter waterways or placing it on unstable areas. Instead, efficiently move excavated material to areas needing fill or to a stockpile. For stream restoration/stabilization projects, consulting with a fluvial geomorphologist on stream stability issues may be prudent.

404 Permit Basics

Section 404 of the Federal Clean Water Act established a program to regulate the discharge of dredged and fill material into waters of the United States, including wetlands. Responsibility for administering and enforcing Section 404 is shared by the U.S. Army Corps of Engineers (USACE) and EPA. USACE administers the day-to-day program, including individual permit decisions and jurisdictional determinations; develops policy and guidance; and enforces Section 404 provisions. EPA develops and interprets environmental criteria used in evaluating permit applications, identifies activities that are exempt from permitting, reviews/comments on individual permit applications, enforces Section 404 provisions, and has authority to veto USACE permit decisions.

A Section 404 permit is typically required when the following activities are conducted in waters of the U.S., including wetlands:

- Construction of roads or paths
- Foundations or amenities for residential, commercial, or recreational developments
- Construction of ponds, dams, dikes or weirs
- Placement of riprap and channel protection
- Laying utility pipes or lines

When selecting BMPs for in-stream construction, a variety of factors should be considered such as:

- Hydrologic factors (tributary watershed size, length of the overland flow, roughness and slope characteristics, precipitation characteristics, imperviousness, etc.)
- Baseflow conditions
- Pollutants that may be delivered to the waterway from the surrounding area
- Extent of existing erosion, headcutting or bank sloughing
- Condition/type of vegetation and percent cover
- Sources of surface runoff
- Drainage pattern
- Historic events
- Flow regulation (ditch diversions, reservoir releases)

8.0 Considerations for Linear Construction Projects

Linear projects involving utilities, streets, highways, railways, and other transportation-related projects can pose some unique stormwater management challenges during construction. Section 8.1 identifies special considerations and approaches that may be beneficial to linear projects, and Section 8.2 provides criteria for trenching for underground utility lines.

8.1 General Considerations

General considerations for linear construction projects include:

- **Standard Details for Typical Activities**: Development of a set of standard BMP details for typical construction activities can promote consistent implementation of erosion and sediment control measures and more efficient SWMP preparation. For example, if a utility company frequently installs light poles, it may be beneficial to develop a standard detail showing the typical construction of a light pole and the associated BMPs. Typical details for construction activities can be used by contractors allowing them to know what BMPs must be used for specific construction activities. BMPs should be shown on the SWMP drawings when they are installed, or in some municipalities, it may be acceptable to reference the typical detail as an alternative to showing specific BMPs on the SWMP drawing. BMPs must be indicated on the site map if site-specific conditions vary from the conditions assumed for development of the typical construction activity BMP detail.

- **Construction Phasing**: By nature, linear construction activities are typically phased. Phasing often will be dictated by the extent of allowable traffic closures and typical requirements for closing trenches at the end of the workday in the right-of-way. For linear construction projects in the public right-of-way, stabilization often can be achieved rapidly as each segment or phase of the project is completed, often by paving or repairing and/or installing sod. For areas where revegetation is from seed, reaching final stabilization (and inactivating stormwater permit coverage) will be a lengthier process.

- **Weather and Climate**: Linear projects such as roadwork may need to consider seasonal weather patterns when scheduling construction. Bridgework over waterbodies should be planned during traditionally low water levels, October 1 to March 31 when possible. Utility projects should attempt to close trenches prior to inclement weather, if feasible, and at the end of each day when required by local requirements.

- **Space Constraints**: Select BMPs that work best under the space constraints of the project. Many utility and road construction projects in urban areas have BMPs that are located in active streets.

- **Durability**: Particularly in active traffic areas, durability of BMPs (i.e., ability to continue to function properly, even when run over by a vehicle) is an important consideration for BMP selection.

- **Potential for Ponding**: Creation of ponded water on roadways may also be a concern. It is important to keep in mind that inlet protection can function in two different ways: filtration and/or ponding. While both of these mechanisms can play a role in sediment removal, typically, inlet protection methods that encourage filtration and limit the amount of ponding are favorable, since ponding typically does not provide enough storage for significant residence time/settling and because ponding can impede travel in streets and highways. Ponding, which occurs to at least some degree with most types of inlet protection, can typically be addressed by selection of the appropriate type of inlet protection, frequent maintenance/sediment removal, and providing an overflow path that will not cause flooding in the event that excessive ponding occurs.

- **Temporary Access**: Unlike a typical residential or commercial development where there are access points that will be used throughout the duration of the project, for linear construction projects, it is often necessary to access the work area for limited periods of time at multiple locations throughout the corridor. For utility projects where access through vegetated areas is necessary at multiple locations, but generally only for a limited amount of time at each location, consider alternatives to standard geotextile and rock-lined vehicle tracking control pads such as construction mats or turf reinforced mats for temporary access to avoid disturbance to vegetation and soil that is typically associated with traditional vehicle tracking control pads.

- **Jurisdictional Considerations**: Linear projects are often multijurisdictional. In these cases, it is important to have upfront coordination with the municipalities that are involved to reduce the burden of permitting and SWMP preparation to the extent practical. For example, it may be possible to prepare a single SWMP that will satisfy the requirements of multiple municipalities rather than preparing separate SWMPs for work in each municipality.

- **Permitting Considerations**: Some municipalities require a stormwater permit for utility construction, maintenance and/or repair activities regardless of extent of the disturbed area. It is possible that even when coverage under the CDPHE Stormwater General Permit is not required (area of disturbance under 1.0 acre), coverage under the local jurisdiction is required. Check all local requirements prior to commencing work on linear construction projects.

8.2 Underground Utility Trenching Criteria

Specific criteria for trenching activities include:

- Minimize the length of trench open at one time to the extent practical. For most trenching projects, it should be feasible to phase construction so that no more than a few hundred feet of trench are open at any given time. Check local criteria, which may specify a maximum length of trench that may be open.

- Where consistent with safety and space considerations, place excavated material on the upgradient side of trenches.

- Trench dewatering devices must discharge in a manner that will not cause erosion or adversely affect flowing streams, wetlands, drainage systems, or off-site property. See the Dewatering Operations BMP Fact Sheet and Section 6 of this chapter for additional guidance.

- Provide storm sewer inlet protection whenever soil erosion from the excavated material has the potential to enter the storm drainage system. See Inlet Protection BMP Fact Sheet for specific guidance.

- Evaluate potential for sediment contributions to inlets or receiving waters that are not in the immediate vicinity of the work area and implement inlet protection and/or other BMPs as necessary. For example, if vehicles access the construction area to remove excavated material or to deliver materials, evaluate the potential for offsite sediment tracking and implement measures such as street sweeping, inlet protection, stabilized access to the construction area, and other BMPs to protect inlets or receiving waters that could be affected by tracked sediment. As another example, perimeter controls on the upgradient side of stockpiles and inlet protection on the opposite side of the crown of the street may be necessary if stockpile height or tracking from accessing stockpiles has the potential to contribute sediment to the opposite side of the street.

9.0 References

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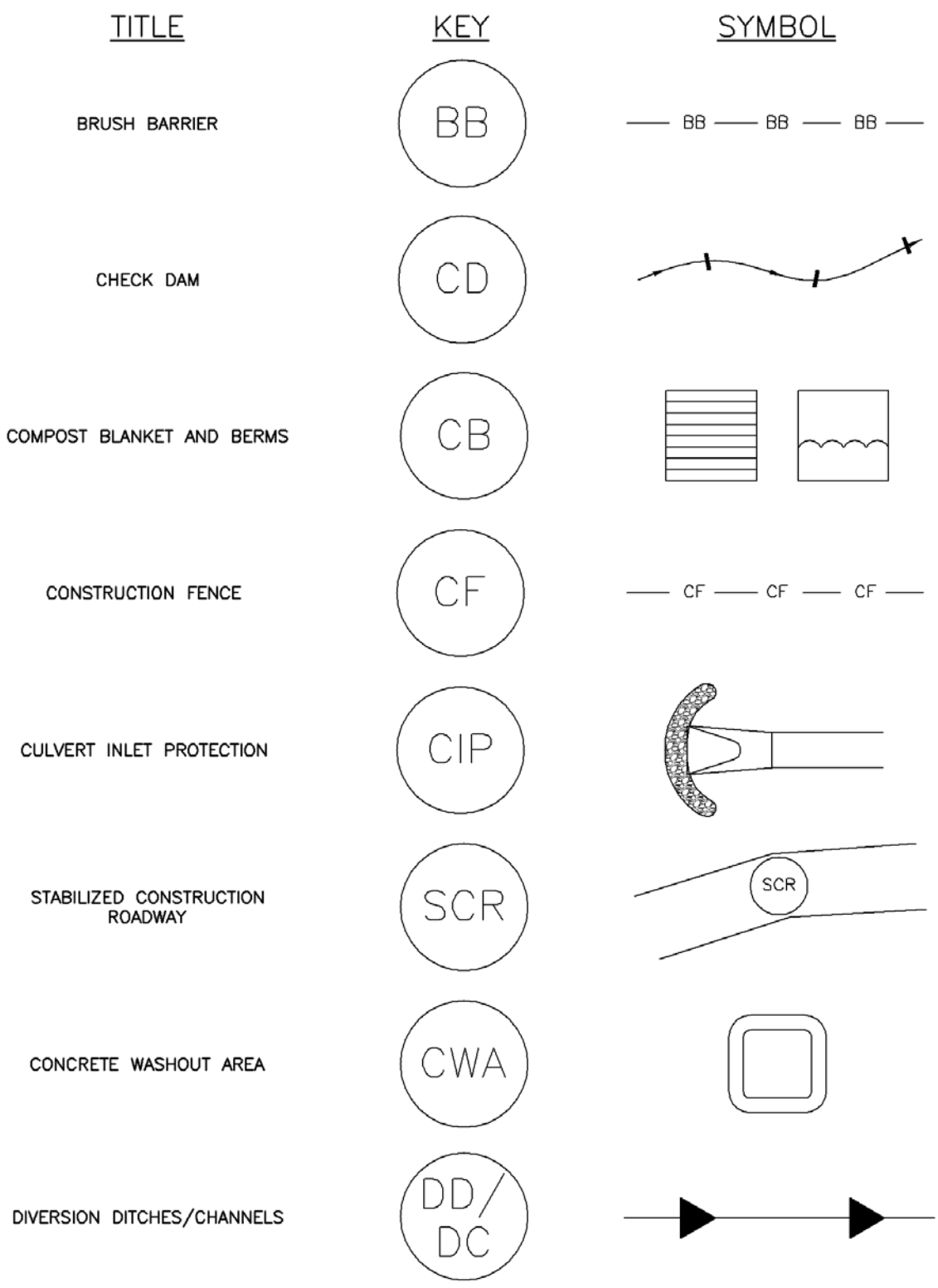
Construction BMP Plan Symbols



Construction BMP Plan Symbols

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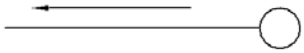
DEWATERING OPERATIONS	DW	
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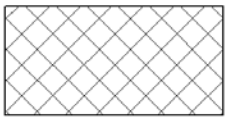
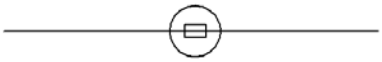
EROSION CONTROL BLANKET	ECB TRM	
INLET PROTECTION	IP	
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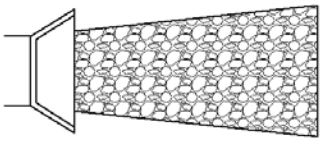
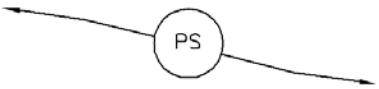
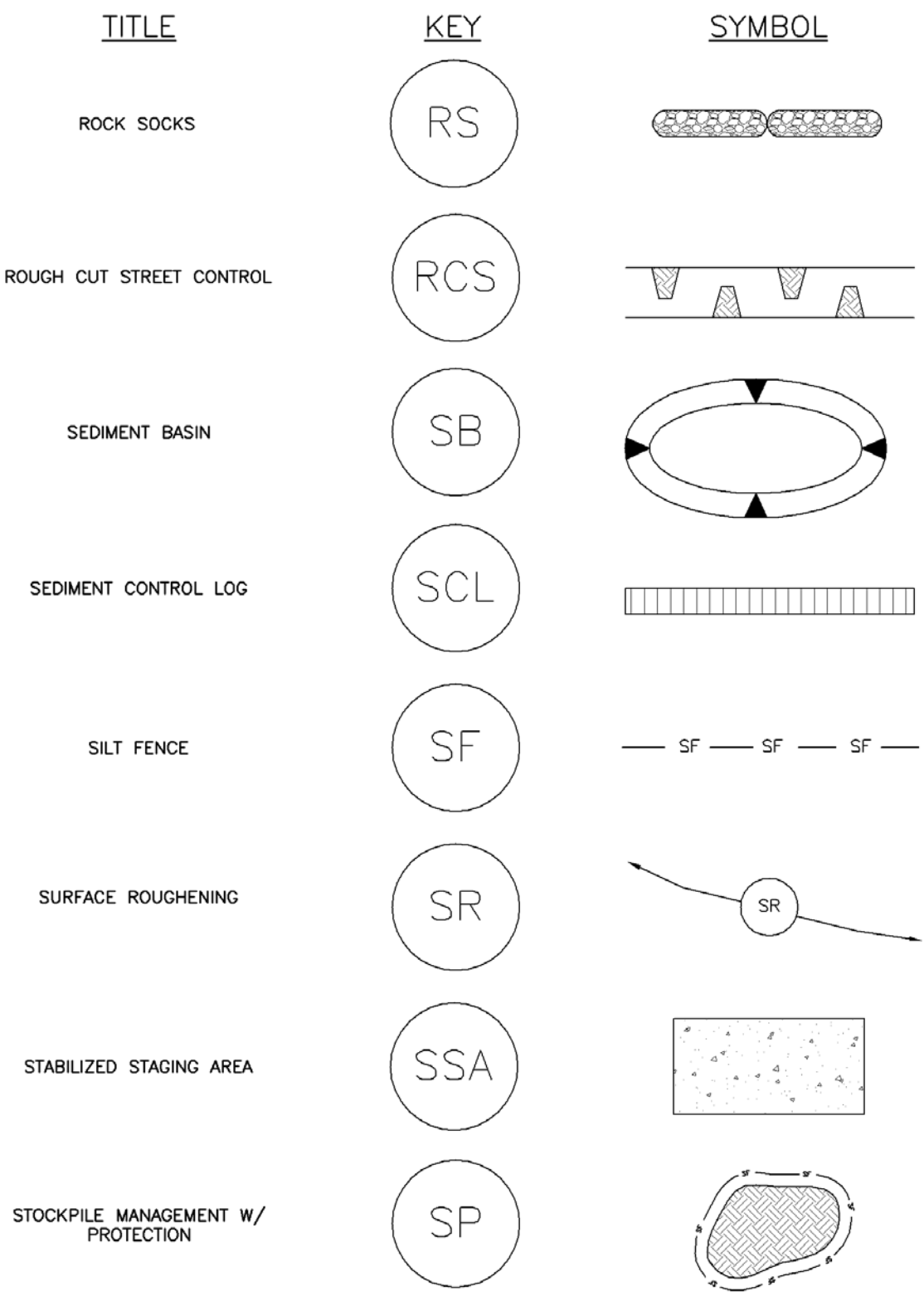
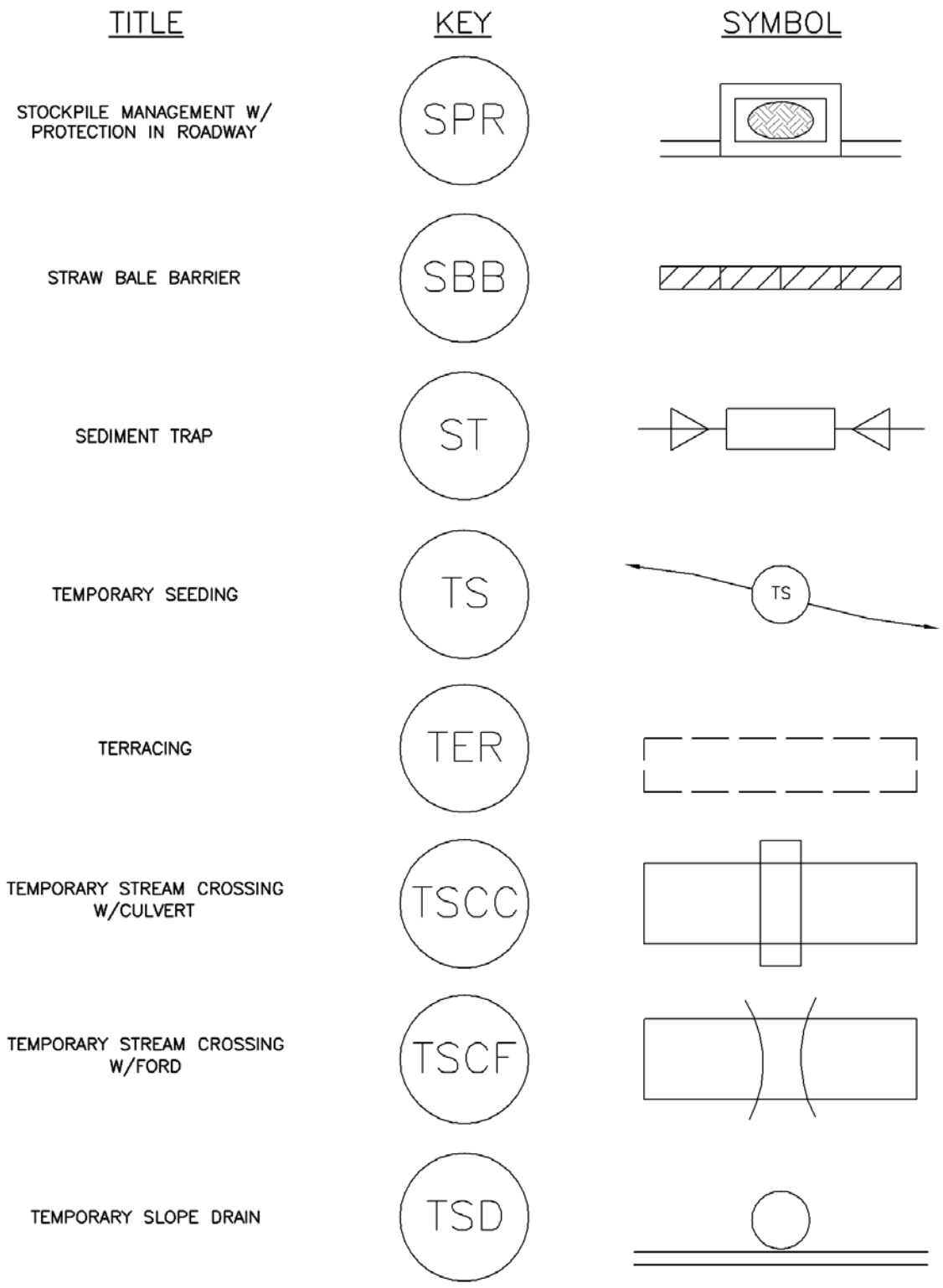
OUTLET PROTECTION	OP	
PERMANENT SEEDING	PS	
REINFORCED CHECK DAM	RCD	

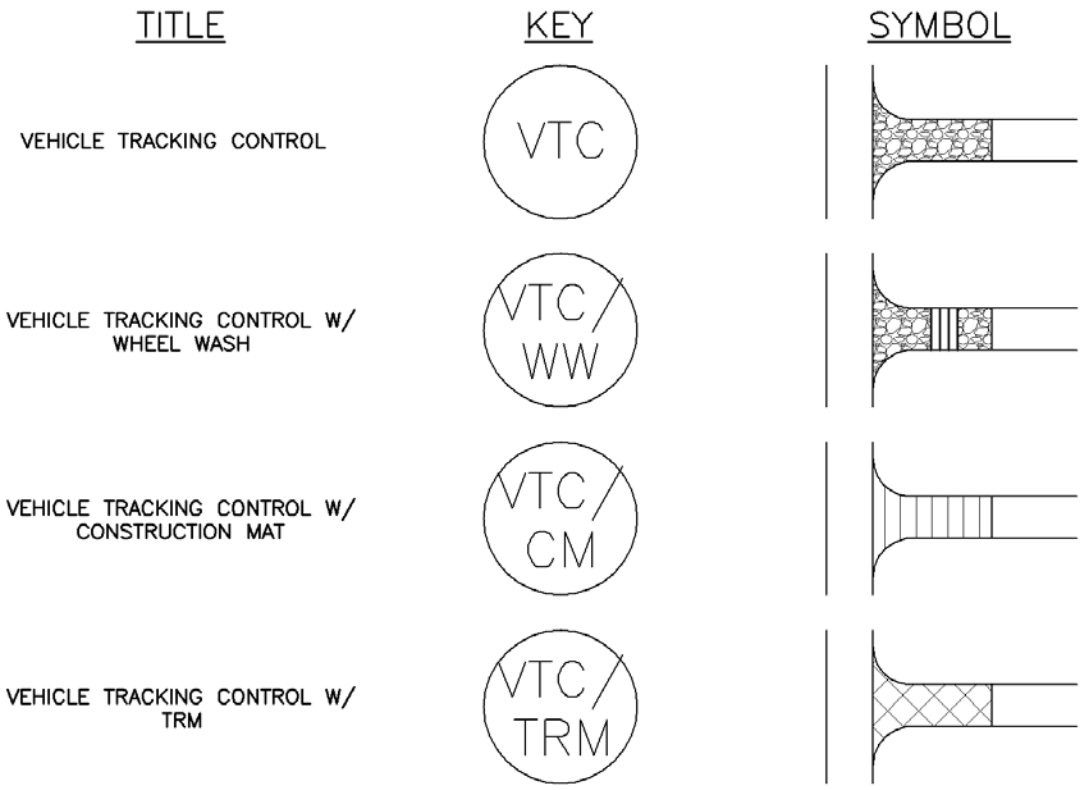
Construction BMP Plan Symbols



Construction BMP Plan Symbols



Construction BMP Plan Symbols



Surface Roughening (SR) EC-1

Description

Surface roughening is an erosion control practice that involves tracking, scarifying, imprinting, or tilling a disturbed area to provide temporary stabilization of disturbed areas. Surface roughening creates variations in the soil surface that help to minimize wind and water erosion. Depending on the technique used, surface roughening may also help establish conditions favorable to establishment of vegetation.

Photograph SR-1. Surface roughening via imprinting for temporary stabilization.

Appropriate Uses

Surface roughening can be used to provide temporary stabilization of disturbed areas, such as when revegetation cannot be immediately established due to seasonal planting limitations. Surface roughening is not a stand-alone BMP, and should be used in conjunction with other erosion and sediment controls.

Surface roughening is often implemented in conjunction with grading and is typically performed using heavy construction equipment to track the surface. Be aware that tracking with heavy equipment will also compact soils, which is not desirable in areas that will be revegetated. Scarifying, tilling, or ripping are better surface roughening techniques in locations where revegetation is planned. Roughening is not effective in very sandy soils and cannot be effectively performed in rocky soil.

Design and Installation

Typical design details for surfacing roughening on steep and mild slopes are provided in Details SR-1 and SR-2, respectively.

Surface roughening should be performed either after final grading or to temporarily stabilize an area during active construction that may be inactive for a short time period. Surface roughening should create depressions 2 to 6 inches deep and approximately 6 inches apart. The surface of exposed soil can be roughened by a number of techniques and equipment. Horizontal grooves (running parallel to the contours of the land) can be made using tracks from equipment treads, stair-step grading, ripping, or tilling.

Fill slopes can be constructed with a roughened surface. Cut slopes that have been smooth graded can be roughened as a subsequent operation. Roughening should follow along the contours of the slope. The tracks left by truck mounted equipment working perpendicular to the contour can leave acceptable horizontal depressions; however, the equipment will also compact the soil.

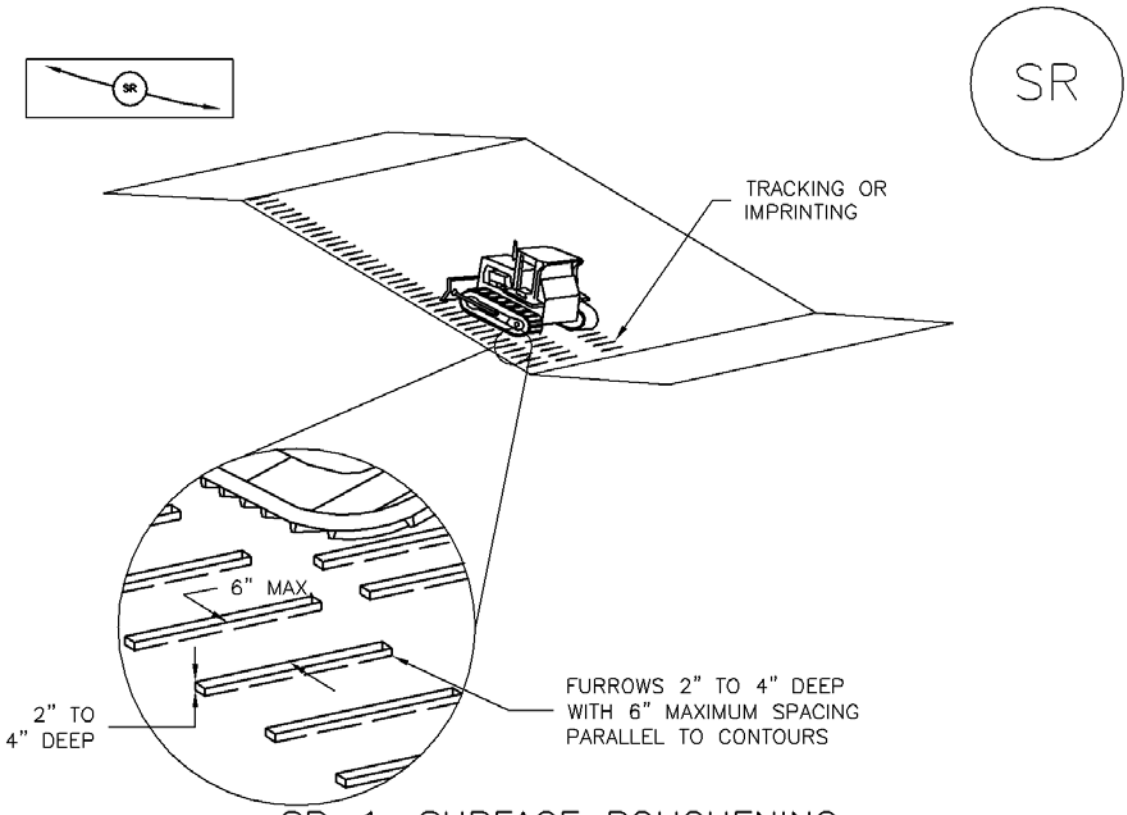
Surface Roughening	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

Maintenance and Removal

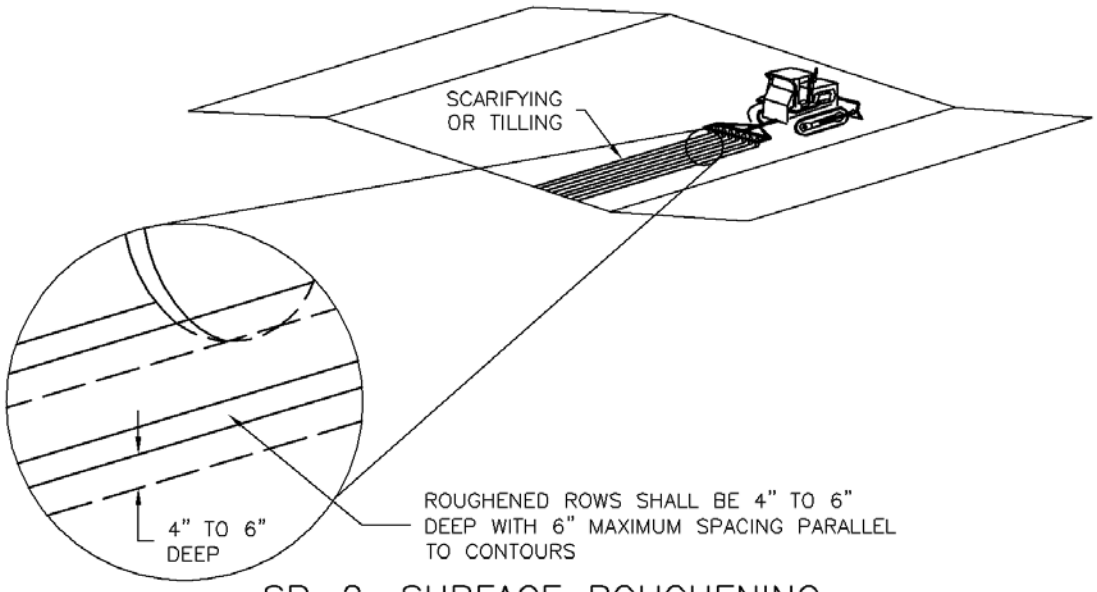
Care should be taken not to drive vehicles or equipment over areas that have been surface roughened. Tire tracks will smooth the roughened surface and may cause runoff to collect into rills and gullies.

Because surface roughening is only a temporary control, additional treatments may be necessary to maintain the soil surface in a roughened condition.

Areas should be inspected for signs of erosion. Surface roughening is a temporary measure, and will not provide long-term erosion control.



SR–1. SURFACE ROUGHENING
FOR STEEP SLOPES (3:1 OR STEEPER)



SR–2. SURFACE ROUGHENING
FOR LOW SLOPES (LESS THAN 3:1)

SURFACE ROUGHENING INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION(S) OF SURFACE ROUGHENING.

2. SURFACE ROUGHENING SHALL BE PROVIDED PROMPTLY AFTER COMPLETION OF FINISHED GRADING (FOR AREAS NOT RECEIVING TOPSOIL) OR PRIOR TO TOPSOIL PLACEMENT OR ANY FORECASTED RAIN EVENT.

3. AREAS WHERE BUILDING FOUNDATIONS, PAVEMENT, OR SOD WILL BE PLACED WITHOUT DELAY IN THE CONSTRUCTION SEQUENCE, SURFACE ROUGHENING IS NOT REQUIRED.

4. DISTURBED SURFACES SHALL BE ROUGHENED USING RIPPING OR TILLING EQUIPMENT ON THE CONTOUR OR TRACKING UP AND DOWN A SLOPE USING EQUIPMENT TREADS.

5. A FARMING DISK SHALL NOT BE USED FOR SURFACE ROUGHENING.

SURFACE ROUGHENING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACE UPON DISCOVERY OF THE FAILURE.

4. VEHICLES AND EQUIPMENT SHALL NOT BE DRIVEN OVER AREAS THAT HAVE BEEN SURFACE ROUGHENED.

5. IN NON–TURF GRASS FINISHED AREAS, SEEDING AND MULCHING SHALL TAKE PLACE DIRECTLY OVER SURFACE ROUGHENED AREAS WITHOUT FIRST SMOOTHING OUT THE SURFACE.

6. IN AREAS NOT SEEDED AND MULCHED AFTER SURFACE ROUGHENING, SURFACES SHALL BE RE–ROUGHENED AS NECESSARY TO MAINTAIN GROOVE DEPTH AND SMOOTH OVER RILL EROSION.

(DETAILS ADAPTED FROM TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Temporary and Permanent Seeding (TS/PS) EC-2

Description

Temporary seeding can be used to stabilize disturbed areas that will be inactive for an extended period. Permanent seeding should be used to stabilize areas at final grade that will not be otherwise stabilized. Effective seeding includes preparation of a seedbed, selection of an appropriate seed mixture, proper planting techniques, and protection of the seeded area with mulch, geotextiles, or other appropriate measures.

Photograph TS/PS -1. Equipment used to drill seed. Photo courtesy of Douglas County.

Appropriate Uses

When the soil surface is disturbed and will remain inactive for an extended period (typically 30 days or longer), proactive stabilization measures should be implemented. If the inactive period is short-lived (on the order of two weeks), techniques such as surface roughening may be appropriate. For longer periods of inactivity, temporary seeding and mulching can provide effective erosion control. Permanent seeding should be used on finished areas that have not been otherwise stabilized.

Typically, local governments have their own seed mixes and timelines for seeding. Check jurisdictional requirements for seeding and temporary stabilization.

Design and Installation

Effective seeding requires proper seedbed preparation, selection of an appropriate seed mixture, use of appropriate seeding equipment to ensure proper coverage and density, and protection with mulch or fabric until plants are established.

The USDCM Volume 2 *Revegetation* Chapter contains detailed seed mix, soil preparations, and seeding and mulching recommendations that may be referenced to supplement this Fact Sheet.

Drill seeding is the preferred seeding method. Hydroseeding is not recommended except in areas where steep slopes prevent use of drill seeding equipment, and even in these instances it is preferable to hand seed and mulch. Some jurisdictions do not allow hydroseeding or hydromulching.

Seedbed Preparation

Prior to seeding, ensure that areas to be revegetated have soil conditions capable of supporting vegetation. Overlot grading can result in loss of topsoil, resulting in poor quality subsoils at the ground surface that have low nutrient value, little organic matter content, few soil microorganisms, rooting restrictions, and conditions less conducive to infiltration of precipitation. As a result, it is typically necessary to provide stockpiled topsoil, compost, or other

Temporary and Permanent Seeding	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

soil amendments and rototill them into the soil to a depth of 6 inches or more.

Topsoil should be salvaged during grading operations for use and spread on areas to be revegetated later. Topsoil should be viewed as an important resource to be utilized for vegetation establishment, due to its water-holding capacity, structure, texture, organic matter content, biological activity, and nutrient content. The rooting depth of most native grasses in the semi-arid Denver metropolitan area is 6 to 18 inches. At a minimum, the upper 6 inches of topsoil should be stripped, stockpiled, and ultimately respread across areas that will be revegetated.

Where topsoil is not available, subsoils should be amended to provide an appropriate plant-growth medium. Organic matter, such as well digested compost, can be added to improve soil characteristics conducive to plant growth. Other treatments can be used to adjust soil pH conditions when needed. Soil testing, which is typically inexpensive, should be completed to determine and optimize the types and amounts of amendments that are required.

If the disturbed ground surface is compacted, rip or rototill the surface prior to placing topsoil. If adding compost to the existing soil surface, rototilling is necessary. Surface roughening will assist in placement of a stable topsoil layer on steeper slopes, and allow infiltration and root penetration to greater depth.

Prior to seeding, the soil surface should be rough and the seedbed should be firm, but neither too loose nor compacted. The upper layer of soil should be in a condition suitable for seeding at the proper depth and conducive to plant growth. Seed-to-soil contact is the key to good germination.

Seed Mix for Temporary Vegetation

To provide temporary vegetative cover on disturbed areas which will not be paved, built upon, or fully landscaped or worked for an extended period (typically 30 days or more), plant an annual grass appropriate for the time of planting and mulch the planted areas. Annual grasses suitable for the Denver metropolitan area are listed in Table TS/PS-1. These are to be considered only as general recommendations when specific design guidance for a particular site is not available. Local governments typically specify seed mixes appropriate for their jurisdiction.

Seed Mix for Permanent Revegetation

To provide vegetative cover on disturbed areas that have reached final grade, a perennial grass mix should be established. Permanent seeding should be performed promptly (typically within 14 days) after reaching final grade. Each site will have different characteristics and a landscape professional or the local jurisdiction should be contacted to determine the most suitable seed mix for a specific site. In lieu of a specific recommendation, one of the perennial grass mixes appropriate for site conditions and growth season listed in Table TS/PS-2 can be used. The pure live seed (PLS) rates of application recommended in these tables are considered to be absolute minimum rates for seed applied using proper drill-seeding equipment.

If desired for wildlife habitat or landscape diversity, shrubs such as rubber rabbitbrush (*Chrysothamnus nauseosus*), fourwing saltbush (*Atriplex canescens*) and skunkbrush sumac (*Rhus trilobata*) could be added to the upland seedmixes at 0.25, 0.5 and 1 pound PLS/acre, respectively. In riparian zones, planting root stock of such species as American plum (*Prunus americana*), woods rose (*Rosa woodsii*), plains cottonwood (*Populus sargentii*), and willow (*Populus spp.*) may be considered. On non-topsoiled upland sites, a legume such as Ladak alfalfa at 1 pound PLS/acre can be included as a source of nitrogen for perennial grasses.

Seeding dates for the highest success probability of perennial species along the Front Range are generally in the spring from April through early May and in the fall after the first of September until the ground freezes. If the area is irrigated, seeding may occur in summer months, as well. See Table TS/PS-3 for appropriate seeding dates.

Table TS/PS-1. Minimum Drill Seeding Rates for Various Temporary Annual Grasses

Species[a] (Common name)	Growth Season[b]	Pounds of Pure Live Seed (PLS)/acre[c]	Planting Depth (inches)
1. Oats	Cool	35 - 50	1 - 2
2. Spring wheat	Cool	25 - 35	1 - 2
3. Spring barley	Cool	25 - 35	1 - 2
4. Annual ryegrass	Cool	10 - 15	½
5. Millet	Warm	3 - 15	½ - ¾
6. Sudangrass	Warm	5–10	½ - ¾
7. Sorghum	Warm	5–10	½ - ¾
8. Winter wheat	Cool	20–35	1 - 2
9. Winter barley	Cool	20–35	1 - 2
10. Winter rye	Cool	20–35	1 - 2
11. Triticale	Cool	25–40	1 - 2

[a] Successful seeding of annual grass resulting in adequate plant growth will usually produce enough dead-plant residue to provide protection from wind and water erosion for an additional year. This assumes that the cover is not disturbed or mowed closer than 8 inches.

Hydraulic seeding may be substituted for drilling only where slopes are steeper than 3:1 or where access limitations exist. When hydraulic seeding is used, hydraulic mulching should be applied as a separate operation, when practical, to prevent the seeds from being encapsulated in the mulch.

[b] See Table TS/PS-3 for seeding dates. Irrigation, if consistently applied, may extend the use of cool season species during the summer months.

[c] Seeding rates should be doubled if seed is broadcast, or increased by 50 percent if done using a Brillion Drill or by hydraulic seeding.

Table TS/PS-2. Minimum Drill Seeding Rates for Perennial Grasses

Common[a] Name	Botanical Name	Growth Season[b]	Growth Form	Seeds/ Pound	Pounds of PLS/acre
Alakali Soil Seed Mix					
Alkali sacaton	*Sporobolus airoides*	Cool	Bunch	1,750,000	0.25
Basin wildrye	*Elymus cinereus*	Cool	Bunch	165,000	2.5
Sodar streambank wheatgrass	*Agropyron riparium 'Sodar'*	Cool	Sod	170,000	2.5
Jose tall wheatgrass	*Agropyron elongatum 'Jose'*	Cool	Bunch	79,000	7.0
Arriba western wheatgrass	*Agropyron smithii 'Arriba'*	Cool	Sod	110,000	5.5
Total					**17.75**
Fertile Loamy Soil Seed Mix					
Ephriam crested wheatgrass	*Agropyron cristatum 'Ephriam'*	Cool	Sod	175,000	2.0
Dural hard fescue	*Festuca ovina 'duriuscula'*	Cool	Bunch	565,000	1.0
Lincoln smooth brome	*Bromus inermis leyss 'Lincoln'*	Cool	Sod	130,000	3.0
Sodar streambank wheatgrass	*Agropyron riparium 'Sodar'*	Cool	Sod	170,000	2.5
Arriba western wheatgrass	*Agropyron smithii 'Arriba'*	Cool	Sod	110,000	7.0
Total					**15.5**
High Water Table Soil Seed Mix					
Meadow foxtail	*Alopecurus pratensis*	Cool	Sod	900,000	0.5
Redtop	*Agrostis alba*	Warm	Open sod	5,000,000	0.25
Reed canarygrass	*Phalaris arundinacea*	Cool	Sod	68,000	0.5
Lincoln smooth brome	*Bromus inermis leyss 'Lincoln'*	Cool	Sod	130,000	3.0
Pathfinder switchgrass	*Panicum virgatum 'Pathfinder'*	Warm	Sod	389,000	1.0
Alkar tall wheatgrass	*Agropyron elongatum 'Alkar'*	Cool	Bunch	79,000	5.5
Total					**10.75**
Transition Turf Seed Mix[c]					
Ruebens Canadian bluegrass	*Poa compressa 'Ruebens'*	Cool	Sod	2,500,000	0.5
Dural hard fescue	*Festuca ovina 'duriuscula'*	Cool	Bunch	565,000	1.0
Citation perennial ryegrass	*Lolium perenne 'Citation'*	Cool	Sod	247,000	3.0
Lincoln smooth brome	*Bromus inermis leyss 'Lincoln'*	Cool	Sod	130,000	3.0
Total					**7.5**

Table TS/PS-2. Minimum Drill Seeding Rates for Perennial Grasses (cont.)

Common Name	Botanical Name	Growth Season[b]	Growth Form	Seeds/ Pound	Pounds of PLS/acre
Sandy Soil Seed Mix					
Blue grama	*Bouteloua gracilis*	Warm	Sod-forming bunchgrass	825,000	0.5
Camper little bluestem	*Schizachyrium scoparium 'Camper'*	Warm	Bunch	240,000	1.0
Prairie sandreed	*Calamovilfa longifolia*	Warm	Open sod	274,000	1.0
Sand dropseed	*Sporobolus cryptandrus*	Cool	Bunch	5,298,000	0.25
Vaughn sideoats grama	*Bouteloua curtipendula 'Vaughn'*	Warm	Sod	191,000	2.0
Arriba western wheatgrass	*Agropyron smithii 'Arriba'*	Cool	Sod	110,000	5.5
Total					**10.25**
Heavy Clay, Rocky Foothill Seed Mix					
Ephriam crested wheatgrass[d]	*Agropyron cristatum 'Ephriam'*	Cool	Sod	175,000	1.5
Oahe Intermediate wheatgrass	*Agropyron intermedium 'Oahe'*	Cool	Sod	115,000	5.5
Vaughn sideoats grama[e]	*Bouteloua curtipendula 'Vaughn'*	Warm	Sod	191,000	2.0
Lincoln smooth brome	*Bromus inermis leyss 'Lincoln'*	Cool	Sod	130,000	3.0
Arriba western wheatgrass	*Agropyron smithii 'Arriba'*	Cool	Sod	110,000	5.5
Total					**17.5**

[a] All of the above seeding mixes and rates are based on drill seeding followed by crimped straw mulch. These rates should be doubled if seed is broadcast and should be increased by 50 percent if the seeding is done using a Brillion Drill or is applied through hydraulic seeding. Hydraulic seeding may be substituted for drilling only where slopes are steeper than 3:1. If hydraulic seeding is used, hydraulic mulching should be done as a separate operation.

[b] See Table TS/PS-3 for seeding dates.

[c] If site is to be irrigated, the transition turf seed rates should be doubled.

[d] Crested wheatgrass should not be used on slopes steeper than 6H to 1V.

[e] Can substitute 0.5 lbs PLS of blue grama for the 2.0 lbs PLS of Vaughn sideoats grama.

Table TS/PS-3. Seeding Dates for Annual and Perennial Grasses

	Annual Grasses (Numbers in table reference species in Table TS/PS-1)		Perennial Grasses	
Seeding Dates	**Warm**	**Cool**	**Warm**	**Cool**
January 1–March 15			✓	✓
March 16–April 30	4	1,2,3	✓	✓
May 1–May 15	4		✓	
May 16–June 30	4,5,6,7			
July 1–July 15	5,6,7			
July 16–August 31				
September 1–September 30		8,9,10,11		
October 1–December 31			✓	✓

Mulch

Cover seeded areas with mulch or an appropriate rolled erosion control product to promote establishment of vegetation. Anchor mulch by crimping, netting or use of a non-toxic tackifier. See the Mulching BMP Fact Sheet for additional guidance.

Maintenance and Removal

Monitor and observe seeded areas to identify areas of poor growth or areas that fail to germinate. Reseed and mulch these areas, as needed.

An area that has been permanently seeded should have a good stand of vegetation within one growing season if irrigated and within three growing seasons without irrigation in Colorado. Reseed portions of the site that fail to germinate or remain bare after the first growing season.

Seeded areas may require irrigation, particularly during extended dry periods. Targeted weed control may also be necessary.

Protect seeded areas from construction equipment and vehicle access.

Soil Binders (SB) EC-3

Description

Soil binders include a broad range of treatments that can be applied to exposed soils for temporary stabilization to reduce wind and water erosion. Soil binders may be applied alone or as tackifiers in conjunction with mulching and seeding applications.

Acknowledgement: This BMP Fact Sheet has been adapted from the 2003 California Stormwater Quality Association (CASQA) Stormwater BMP Handbook: Construction (www.cabmphandbooks.com).

Photograph SB-1. Tackifier being applied to provide temporary soil stabilization. Photo courtesy of Douglas County.

Appropriate Uses

Soil binders can be used for short-term, temporary stabilization of soils on both mild and steep slopes. Soil binders are often used in areas where work has temporarily stopped, but is expected to resume before revegetation can become established. Binders are also useful on stockpiled soils or where temporary or permanent seeding has occurred.

Prior to selecting a soil binder, check with the state and local jurisdiction to ensure that the chemicals used in the soil binders are allowed. The water quality impacts of some types of soil binders are relatively unknown and may not be allowed due to concerns about potential environmental impacts. Soil binders must be environmentally benign (non-toxic to plant and animal life), easy to apply, easy to maintain, economical, and should not stain paved or painted surfaces.

Soil binders should not be used in vehicle or pedestrian high traffic areas, due to loss in effectiveness under these conditions.

Site soil type will dictate appropriate soil binders to be used. Be aware that soil binders may not function effectively on silt or clay soils or highly compacted areas. Check manufacturer's recommendations for appropriateness with regard to soil conditions. Some binders may not be suitable for areas with existing vegetation.

Design and Installation

Properties of common soil binders used for erosion control are provided in Table SB-1. Design and installation guidance below are provided for general reference. Follow the manufacturer's instructions for application rates and procedures.

Soil Binders	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	Moderate

Table SB-1. Properties of Soil Binders for Erosion Control (Source: CASQA 2003)

Evaluation Criteria	Binder Type			
	Plant Material Based (short lived)	**Plant Material Based (long lived)**	**Polymeric Emulsion Blends**	**Cementitious-Based Binders**
Resistance to Leaching	High	High	Low to Moderate	Moderate
Resistance to Abrasion	Moderate	Low	Moderate to High	Moderate to High
Longevity	Short to Medium	Medium	Medium to Long	Medium
Minimum Curing Time before Rain	9 to 18 hours	19 to 24 hours	0 to 24 hours	4 to 8 hours
Compatibility with Existing Vegetation	Good	Poor	Poor	Poor
Mode of Degradation	Biodegradable	Biodegradable	Photodegradable/ Chemically Degradable	Photodegradable/ Chemically Degradable
Specialized Application Equipment	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher
Liquid/Powder	Powder	Liquid	Liquid/Powder	Powder
Surface Crusting	Yes, but dissolves on rewetting	Yes	Yes, but dissolves on rewetting	Yes
Clean Up	Water	Water	Water	Water
Erosion Control Application Rate	Varies	Varies	Varies	4,000 to 12,000 lbs/acre Typ.

Factors to consider when selecting a soil binder generally include:

- **Suitability to situation**: Consider where the soil binder will be applied, if it needs a high resistance to leaching or abrasion, and whether it needs to be compatible with existing vegetation. Determine the length of time soil stabilization will be needed, and if the soil binder will be placed in an area where it will degrade rapidly. In general, slope steepness is not a discriminating factor.

- **Soil types and surface materials**: Fines and moisture content are key properties of surface materials. Consider a soil binder's ability to penetrate, likelihood of leaching, and ability to form a surface crust on the surface materials.

- **Frequency of application**: The frequency of application can be affected by subgrade conditions, surface type, climate, and maintenance schedule. Frequent applications could lead to high costs. Application frequency may be minimized if the soil binder has good penetration, low evaporation, and good longevity. Consider also that frequent application will require frequent equipment clean up.

An overview of major categories of soil binders, corresponding to the types included in Table SB-1 follows.

Plant-Material Based (Short Lived) Binders

- **Guar**: A non-toxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersant agents for easy field mixing. It should be mixed with water at the rate of 11 to 15 lbs per 1,000 gallons. Recommended minimum application rates are provided in Table SB-2.

Table SB-2. Application Rates for Guar Soil Stabilizer

	Slope (H:V)				
	Flat	4:1	3:1	2:1	1:1
Application Rate (lb/acre)	40	45	50	60	70

- **Psyllium**: Composed of the finely ground muciloid coating of plantago seeds that is applied as a wet slurry to the surface of the soil. It dries to form a firm but rewettable membrane that binds soil particles together but permits germination and growth of seed. Psyllium requires 12 to 18 hours drying time. Application rates should be from 80 to 200 lbs/acre, with enough water in solution to allow for a uniform slurry flow.

- **Starch**: Non-ionic, cold-water soluble (pre-gelatinized) granular cornstarch. The material is mixed with water and applied at the rate of 150 lb/acre. Approximate drying time is 9 to 12 hours.

Plant-Material Based (Long Lived) Binders

- **Pitch and Rosin Emulsion**: Generally, a non-ionic pitch and rosin emulsion has a minimum solids content of 48 percent. The rosin should be a minimum of 26 percent of the total solids content. The soil stabilizer should be a non-corrosive, water dilutable emulsion that upon application cures to a water insoluble binding and cementing agent. For soil erosion control applications, the emulsion is diluted and should be applied as follows:

    - For clayey soil: 5 parts water to 1 part emulsion

- For sandy soil: 10 parts water to 1 part emulsion

Application can be by water truck or hydraulic seeder with the emulsion and product mixture applied at the rate specified by the manufacturer.

Polymeric Emulsion Blend Binders

- **Acrylic Copolymers and Polymers**: Polymeric soil stabilizers should consist of a liquid or solid polymer or copolymer with an acrylic base that contains a minimum of 55 percent solids. The polymeric compound should be handled and mixed in a manner that will not cause foaming or should contain an anti-foaming agent. The polymeric emulsion should not exceed its shelf life or expiration date; manufacturers should provide the expiration date. Polymeric soil stabilizer should be readily miscible in water, non-injurious to seed or animal life, non-flammable, should provide surface soil stabilization for various soil types without inhibiting water infiltration, and should not re-emulsify when cured. The applied compound should air cure within a maximum of 36 to 48 hours. Liquid copolymer should be diluted at a rate of 10 parts water to 1 part polymer and the mixture applied to soil at a rate of 1,175 gallons/acre.

- **Liquid Polymers of Methacrylates and Acrylates**: This material consists of a tackifier/sealer that is a liquid polymer of methacrylates and acrylates. It is an aqueous 100 percent acrylic emulsion blend of 40 percent solids by volume that is free from styrene, acetate, vinyl, ethoxylated surfactants or silicates. For soil stabilization applications, it is diluted with water in accordance with manufacturer's recommendations, and applied with a hydraulic seeder at the rate of 20 gallons/acre. Drying time is 12 to 18 hours after application.

- **Copolymers of Sodium Acrylates and Acrylamides**: These materials are non-toxic, dry powders that are copolymers of sodium acrylate and acrylamide. They are mixed with water and applied to the soil surface for erosion control at rates that are determined by slope gradient, as summarized in Table SB-3.

Table SB-3. Application Rates for Copolymers of Sodium Acrylates and Acrylamides

	Slope (H:V)		
	Flat to 5:1	5:1 to 3:1	2:2 to 1:1
Application Rate (lb/acre)	3.0-5.0	5.0-10.0	10.0-20.0

- **Polyacrylamide and Copolymer of Acrylamide**: Linear copolymer polyacrylamide is packaged as a dry flowable solid. When used as a stand-alone stabilizer, it is diluted at a rate of 11 lb/1,000 gal. of water and applied at the rate of 5.0 lb/acre.

- **Hydrocolloid Polymers**: Hydrocolloid Polymers are various combinations of dry flowable polyacrylamides, copolymers, and hydrocolloid polymers that are mixed with water and applied to the soil surface at rates of 55 to 60 lb/acre. Drying times are 0 to 4 hours.

Cementitious-Based Binders

- **Gypsum**: This formulated gypsum based product readily mixes with water and mulch to form a thin protective crust on the soil surface. It is composed of high purity gypsum that is ground, calcined and processed into calcium sulfate hemihydrate with a minimum purity of 86 percent. It is mixed in a hydraulic seeder and applied at rates 4,000 to 12,000 lb/acre. Drying time is 4 to 8 hours.

Installation

After selecting an appropriate soil binder, the untreated soil surface must be prepared before applying the soil binder. The untreated soil surface must contain sufficient moisture to assist the agent in achieving uniform distribution. In general, the following steps should be followed:

- Follow manufacturer's written recommendations for application rates, pre-wetting of application area, and cleaning of equipment after use.
- Prior to application, roughen embankment and fill areas.
- Consider the drying time for the selected soil binder and apply with sufficient time before anticipated rainfall. Soil binders should not be applied during or immediately before rainfall.
- Avoid over spray onto roads, sidewalks, drainage channels, sound walls, existing vegetation, etc.
- Soil binders should not be applied to frozen soil, areas with standing water, under freezing or rainy conditions, or when the temperature is below 40°F during the curing period.
- More than one treatment is often necessary, although the second treatment may be diluted or have a lower application rate.
- Generally, soil binders require a minimum curing time of 24 hours before they are fully effective. Refer to manufacturer's instructions for specific cure time.
- For liquid agents:
    - Crown or slope ground to avoid ponding.
    - Uniformly pre-wet ground at 0.03 to 0.3 gal/yd^2 or according to manufacturer's recommendations.
    - Apply solution under pressure. Overlap solution 6 to 12 in.
    - Allow treated area to cure for the time recommended by the manufacturer, typically at least 24 hours.
    - Apply second treatment before first treatment becomes ineffective, using 50 percent application rate.
    - In low humidity, reactivate chemicals by re-wetting with water at 0.1 to 0.2 gal/yd^2.

Maintenance and Removal

Soil binders tend to break down due to natural weathering. Weathering rates depend on a variety of site-specific and product characteristics. Consult the manufacturer for recommended reapplication rates and reapply the selected soil binder as needed to maintain effectiveness.

Soil binders can fail after heavy rainfall events and may require reapplication. In particular, soil binders will generally experience spot failures during heavy rainfall events. If runoff penetrates the soil at the top of a slope treated with a soil binder, it is likely that the runoff will undercut the stabilized soil layer and discharge at a point further down slope.

Areas where erosion is evident should be repaired and soil binder or other stabilization reapplied, as needed. Care should be exercised to minimize the damage to protected areas while making repairs.

Most binders biodegrade after exposure to sun, oxidation, heat and biological organisms; therefore, removal of the soil binder is not typically required.

Description

Mulching consists of evenly applying straw, hay, shredded wood mulch, rock, bark or compost to disturbed soils and securing the mulch by crimping, tackifiers, netting or other measures. Mulching helps reduce erosion by protecting bare soil from rainfall impact, increasing infiltration, and reducing runoff. Although often applied in conjunction with temporary or permanent seeding, it can also be used for temporary stabilization of areas that cannot be reseeded due to seasonal constraints.

Mulch can be applied either using standard mechanical dry application methods or using hydromulching equipment that hydraulically applies a slurry of water, wood fiber mulch, and often a tackifier.

Photograph MU-1. An area that was recently seeded, mulched, and crimped.

Appropriate Uses

Use mulch in conjunction with seeding to help protect the seedbed and stabilize the soil. Mulch can also be used as a temporary cover on low to mild slopes to help temporarily stabilize disturbed areas where growing season constraints prevent effective reseeding. Disturbed areas should be properly mulched and tacked, or seeded, mulched and tacked promptly after final grade is reached (typically within no longer than 14 days) on portions of the site not otherwise permanently stabilized.

Standard dry mulching is encouraged in most jurisdictions; however, hydromulching may not be allowed in certain jurisdictions or may not be allowed near waterways.

Do not apply mulch during windy conditions.

Design and Installation

Prior to mulching, surface-roughen areas by rolling with a crimping or punching type roller or by track walking. Track walking should only be used where other methods are impractical because track walking with heavy equipment typically compacts the soil.

A variety of mulches can be used effectively at construction sites. Consider the following:

Mulch	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

- Clean, weed-free and seed-free cereal grain straw should be applied evenly at a rate of 2 tons per acre and must be tacked or fastened by a method suitable for the condition of the site. Straw mulch must be anchored (and not merely placed) on the surface. This can be accomplished mechanically by crimping or with the aid of tackifiers or nets. Anchoring with a crimping implement is preferred, and is the recommended method for areas flatter than 3:1. Mechanical crimpers must be capable of tucking the long mulch fibers into the soil to a depth of 3 inches without cutting them. An agricultural disk, while not an ideal substitute, may work if the disk blades are dull or blunted and set vertically; however, the frame may have to be weighted to afford proper soil penetration.

- Grass hay may be used in place of straw; however, because hay is comprised of the entire plant including seed, mulching with hay may seed the site with non-native grass species which might in turn out-compete the native seed. Alternatively, native species of grass hay may be purchased, but can be difficult to find and are more expensive than straw. Purchasing and utilizing a certified weed-free straw is an easier and less costly mulching method. When using grass hay, follow the same guidelines as for straw (provided above).

- On small areas sheltered from the wind and heavy runoff, spraying a tackifier on the mulch is satisfactory for holding it in place. For steep slopes and special situations where greater control is needed, erosion control blankets anchored with stakes should be used instead of mulch.

- Hydraulic mulching consists of wood cellulose fibers mixed with water and a tackifying agent and should be applied at a rate of no less than 1,500 pounds per acre (1,425 lbs of fibers mixed with at least 75 lbs of tackifier) with a hydraulic mulcher. For steeper slopes, up to 2000 pounds per acre may be required for effective hydroseeding. Hydromulch typically requires up to 24 hours to dry; therefore, it should not be applied immediately prior to inclement weather. Application to roads, waterways and existing vegetation should be avoided.

- Erosion control mats, blankets, or nets are recommended to help stabilize steep slopes (generally 3:1 and steeper) and waterways. Depending on the product, these may be used alone or in conjunction with grass or straw mulch. Normally, use of these products will be restricted to relatively small areas. Biodegradable mats made of straw and jute, straw-coconut, coconut fiber, or excelsior can be used instead of mulch. (See the ECM/TRM BMP for more information.)

- Some tackifiers or binders may be used to anchor mulch. Check with the local jurisdiction for allowed tackifiers. Manufacturer's recommendations should be followed at all times. (See the Soil Binder BMP for more information on general types of tackifiers.)

- Rock can also be used as mulch. It provides protection of exposed soils to wind and water erosion and allows infiltration of precipitation. An aggregate base course can be spread on disturbed areas for temporary or permanent stabilization. The rock mulch layer should be thick enough to provide full coverage of exposed soil on the area it is applied.

Maintenance and Removal

After mulching, the bare ground surface should not be more than 10 percent exposed. Reapply mulch, as needed, to cover bare areas.

Compost Blanket and Filter Berm (CB) EC-5

Description

A compost blanket is a layer of compost uniformly applied to the soil in disturbed areas to control erosion, facilitate revegetation, and retain sediment resulting from sheet-flow runoff.

A compost filter berm is a dike of compost or a compost product that is placed perpendicular to runoff to control erosion in disturbed areas and retain sediment. Compost berms can be placed at regular intervals to help reduce the formation of rill and gully erosion when a compost blanket is stabilizing a slope.

Photograph CB-1. Application of a compost blanket to a disturbed area. Photo courtesy of Caltrans.

Appropriate Uses

Compost blankets can be used as an alternative to erosion control blankets and mulching to help stabilize disturbed areas where sheet flow conditions are present. Compost blankets should not be used in areas of concentrated flows. Compost provides an excellent source of nutrients for plant growth, and should be considered for use in areas that will be permanently vegetated.

Design and Installation

See Detail CB-1 for design details and notes.

Do not place compost in areas where it can easily be transported into drainage pathways or waterways. When using a compost blanket on a slope, berms should be installed periodically to reduce the potential for concentrated flow and rilling. Seeding should be completed before an area is composted or incorporated into the compost.

Compost quality is an important consideration when selecting compost blankets or berms. Representative compost quality factors include pH, salinity, moisture content, organic matter content, stability (maturity), and physical contaminants. The compost should meet all local, state, and federal quality requirements. Biosolids compost must meet the Standards for Class A biosolids outlined in 40 CFR Part 503. The U.S. Composting Council (USCC) certifies compost products under its Seal of Testing Assurance (STA) Program. Compost producers whose products have been certified through the STA Program provide customers with a standard product label that allows comparison between compost products. Only STA certified, Class I compost should be used.

Compost Blankets and Berms	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

Maintenance and Removal

When rills or gullies develop in an area that has been composted, fill and cover the area with additional compost and install berms as necessary to help reduce erosion.

Weed control can be a maintenance challenge in areas using compost blankets. A weed control strategy may be necessary, including measures such as mechanical removal and spot application of targeted herbicides by licensed applicators.

For compost berms, accumulated sediments should be removed from behind the berm when the sediments reach approximately one third the height of the berm. Areas that have been washed away should be replaced. If the berm has experienced significant or repeated washouts, a compost berm may not be the appropriate BMP for this area.

Compost blankets and berms biodegrade and do not typically require removal following site stabilization.

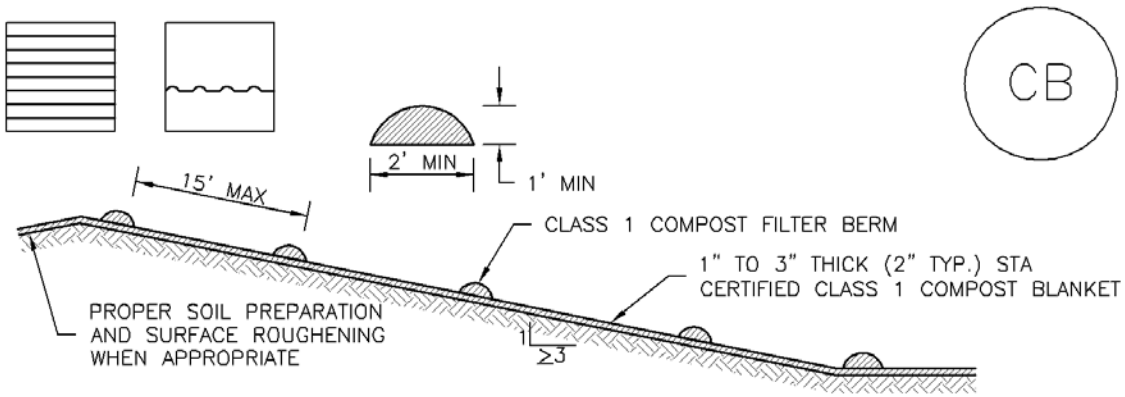


TABLE CB–1. CLASS 1 COMPOST	
PARAMETERS	CHARACTERISTIC
MINIMUM STABILITY INDICATOR	STABLE TO VERY STABLE
SOLUBLE SALTS	MAXIMUM 5 mmhos/cm
PH	6.0 – 8.0
AG INDEX	> 10
MATURITY INDICATOR EXPRESSED AS PERCENTAGE OF GERMINATION/VIGOR	80+/80+
MATURITY INDICATOR EXPRESSED AS AMMONIA N/ NITRATE N RATIO	< 4
MATURITY INDEX AS CARBON TO NITROGEN RATIO	20:1
TESTED FOR CLOPYRALID	YES/NEGATIVE RESULT
MOISTURE CONTENT	30–60%
ORGANIC MATTER CONTENT	25–45% OF DRY WEIGHT
PARTICLE SIZE DISTRIBUTION	3" (75mm) 100% PASSING
PRIMARY, SECONDARY NUTRIENTS; TRACE ELEMENTS	MUST BE REPORTED
TESTING AND TEST REPORT SUBMITTAL REQUIREMENTS	STA + CLOPYRALID
ORGANIC MATTER PER CUBIC YARD	MUST REPORT
CHEMICAL CONTAMINANTS	COMPLY WITH US EPA CLASS A STANDARD, 40 CFR 503.1 TABLES 1 & 3 LEVELS
MINIMUM MANUFACTURING/PRODUCTION REQUIREMENT	FULLY PERMITTED UNDER COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT, HAZARDOUS MATERIALS AND WASTE MANAGEMENT DIVISION
RISK FACTOR RELATING TO PLANT GERMINATION AND HEALTH	LOW

CB–1. COMPOST BLANKET AND COMPOST FILTER BERM

COMPOST FILTER BERM AND COMPOST BLANKET INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   –LOCATION OF COMPOST FILTER BERM(S).
   –LENGTH OF COMPOST FILTER BERM(S).

2. COMPOST BERMS AND BLANKETS MAY BE USED IN PLACE OF STRAW MULCH OR GEOTEXTILE FABRIC IN AREAS WHERE ACCESS TO LANDSCAPING IS DIFFICULT DUE TO LANDSCAPING OR OTHER OBJECTS OR IN AREAS WHERE A SMOOTH TURF GRASS FINISH IS DESIRED.

3. FILTER BERMS SHALL RUN PARALLEL TO THE CONTOUR.

4. FILTER BERMS SHALL BE A MINIMUM OF 1 FEET HIGH AND 2 FEET WIDE.

5. FILTER BERMS SHALL BE APPLIED BY PNEUMATIC BLOWER OR BY HAND.

6. FILTER BERMS SHALL ONLY BE UTILIZED IN AREAS WHERE SHEET FLOW CONDITIONS PREVAIL AND NOT IN AREAS OF CONCENTRATED FLOW.

7. COMPOST BLANKETS SHALL BE APPLIED AT A DEPTH OF 1 –3 INCHES (TYPICALLY 2 INCHES). FOR AREAS WITH EXISTING VEGETATION THAT ARE TO BE SUPPLEMENTED BY COMPOST, A THIN 0.5–INCH LAYER MAY BE USED.

8. SEEDING SHALL BE PERFORMED PRIOR TO THE APPLICATION OF COMPOST. ALTERNATIVELY, SEED MAY BE COMBINED WITH COMPOST AND BLOWN WITH THE PNEUMATIC BLOWER.

9. WHEN TURF GRASS FINISH IS NOT DESIRED, SURFACE ROUGHENING ON SLOPES SHALL TAKE PLACE PRIOR TO COMPOST APPLICATION.

10. COMPOST SHALL BE A CLASS 1 COMPOST AS DEFINED BY TABLE CB–1.

COMPOST FILTER BERM MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. COMPOST BERMS AND BLANKETS SHALL BE REAPPLIED OR REGRADED AS NECESSARY IF RILLING IN THE COMPOST SURFACE OCCURS.

(DETAILS ADAPTED FROM ARAPAHOE COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Rolled Erosion Control Products (RECP) EC-6

Description

Photograph RECP-1. Erosion control blanket protecting the slope from erosion and providing favorable conditions for revegetation.

Rolled Erosion Control Products (RECPs) include a variety of temporary or permanently installed manufactured products designed to control erosion and enhance vegetation establishment and survivability, particularly on slopes and in channels. For applications where natural vegetation alone will provide sufficient permanent erosion protection, temporary products such as netting, open weave textiles and a variety of erosion control blankets (ECBs) made of biodegradable natural materials (e.g., straw, coconut fiber) can be used. For applications where natural vegetation alone will not be sustainable under expected flow conditions, permanent rolled erosion control products such as turf reinforcement mats (TRMs) can be used. In particular, turf reinforcement mats are designed for discharges that exert velocities and sheer stresses that exceed the typical limits of mature natural vegetation.

Appropriate Uses

RECPs can be used to control erosion in conjunction with revegetation efforts, providing seedbed protection from wind and water erosion. These products are often used on disturbed areas on steep slopes, in areas with highly erosive soils, or as part of drainageway stabilization. In order to select the appropriate RECP for site conditions, it is important to have a general understanding of the general types of these products, their expected longevity, and general characteristics.

The Erosion Control Technology Council (ECTC 2005) characterizes rolled erosion control products according to these categories:

- **Mulch control netting**: A planar woven natural fiber or extruded geosynthetic mesh used as a temporary degradable rolled erosion control product to anchor loose fiber mulches.
- **Open weave textile**: A temporary degradable rolled erosion control product composed of processed natural or polymer yarns woven into a matrix, used to provide erosion control and facilitate vegetation establishment.
- **Erosion control blanket (ECB)**: A temporary degradable rolled erosion control product composed of processed natural or polymer fibers which are mechanically, structurally or chemically bound together to form a continuous matrix to provide erosion control and facilitate vegetation establishment. ECBs can be further differentiated into rapidly degrading single-net and double-net types or slowly degrading types.

Rolled Erosion Control Products	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

- **Turf Reinforcement Mat (TRM)**: A rolled erosion control product composed of non-degradable synthetic fibers, filaments, nets, wire mesh, and/or other elements, processed into a permanent, three-dimensional matrix of sufficient thickness. TRMs, which may be supplemented with degradable components, are designed to impart immediate erosion protection, enhance vegetation establishment and provide long-term functionality by permanently reinforcing vegetation during and after maturation. Note: TRMs are typically used in hydraulic applications, such as high flow ditches and channels, steep slopes, stream banks, and shorelines, where erosive forces may exceed the limits of natural, unreinforced vegetation or in areas where limited vegetation establishment is anticipated.

Tables RECP-1 and RECP-2 provide guidelines for selecting rolled erosion control products appropriate to site conditions and desired longevity. Table RECP-1 is for conditions where natural vegetation alone will provide permanent erosion control, whereas Table RECP-2 is for conditions where vegetation alone will not be adequately stable to provide long-term erosion protection due to flow or other conditions.

Table RECP-1. ECTC Standard Specification for Temporary Rolled Erosion Control Products
(Adapted from Erosion Control Technology Council 2005)

Product Description	Slope Applications*		Channel Applications*	Minimum Tensile Strength[1]	Expected Longevity
	Maximum Gradient	C Factor[2,5]	Max. Shear Stress[3,4,6]		
Mulch Control Nets	5:1 (H:V)	≤0.10 @ 5:1	0.25 lbs/ft^2 (12 Pa)	5 lbs/ft (0.073 kN/m)	Up to 12 months
Netless Rolled Erosion Control Blankets	4:1 (H:V)	≤0.10 @ 4:1	0.5 lbs/ft^2 (24 Pa)	5 lbs/ft (0.073 kN/m)	
Single-net Erosion Control Blankets & Open Weave Textiles	3:1 (H:V)	≤0.15 @ 3:1	1.5 lbs/ft^2 (72 Pa)	50 lbs/ft (0.73 kN/m)	
Double-net Erosion Control Blankets	2:1 (H:V)	≤0.20 @ 2:1	1.75 lbs/ft^2 (84 Pa)	75 lbs/ft (1.09 kN/m)	
Mulch Control Nets	5:1 (H:V)	≤0.10 @ 5:1	0.25 lbs/ft^2 (12 Pa)	25 lbs/ft (0.36 kN/m)	24 months
Erosion Control Blankets & Open Weave Textiles (slowly degrading)	1.5:1 (H:V)	≤0.25 @ 1.5:1	2.00 lbs/ft^2 (96 Pa)	100 lbs/ft (1.45 kN/m)	24 months
Erosion Control Blankets & Open Weave Textiles	1:1 (H:V)	≤0.25 @ 1:1	2.25 lbs/ft^2 (108 Pa)	125 lbs/ft (1.82 kN/m)	36 months

* C Factor and shear stress for mulch control nettings must be obtained with netting used in conjunction with pre-applied mulch material. (*See Section 5.3 of Chapter 7 Construction BMPs for more information on the C Factor*.)

[1] Minimum Average Roll Values, Machine direction using ECTC Mod. ASTM D 5035.

[2] C Factor calculated as ratio of soil loss from RECP protected slope (tested at specified or greater gradient, H:V) to ratio of soil loss from unprotected (control) plot in large-scale testing.

[3] Required minimum shear stress RECP (unvegetated) can sustain without physical damage or excess erosion (> 12.7 mm (0.5 in) soil loss) during a 30-minute flow event in large-scale testing.

[4] The permissible shear stress levels established for each performance category are based on historical experience with products characterized by Manning's roughness coefficients in the range of 0.01 - 0.05.

[5] Acceptable large-scale test methods may include ASTM D 6459, or other independent testing deemed acceptable by the engineer.

[6] Per the engineer's discretion. Recommended acceptable large-scale testing protocol may include ASTM D 6460, or other independent testing deemed acceptable by the engineer.

Table RECP-2. ECTC Standard Specification for Permanent[1] Rolled Erosion Control Products
(Adapted from: Erosion Control Technology Council 2005)

Product Type	Slope Applications	Channel Applications	
TRMs with a minimum thickness of 0.25 inches (6.35 mm) per ASTM D 6525 and UV stability of 80% per ASTM D 4355 (500 hours exposure).	Maximum Gradient	Maximum Shear Stress[4,5]	Minimum Tensile Strength[2,3]
	0.5:1 (H:V)	6.0 lbs/ft^2 (288 Pa)	125 lbs/ft (1.82 kN/m)
	0.5:1 (H:V)	8.0 lbs/ft^2 (384 Pa)	150 lbs/ft (2.19 kN/m)
	0.5:1 (H:V)	10.0 lbs/ft^2 (480 Pa)	175 lbs/ft (2.55 kN/m)

[1] For TRMs containing degradable components, all property values must be obtained on the non-degradable portion of the matting alone.

[2] Minimum Average Roll Values, machine direction only for tensile strength determination using ASTM D 6818 (Supersedes Mod. ASTM D 5035 for RECPs)

[3] Field conditions with high loading and/or high survivability requirements may warrant the use of a TRM with a tensile strength of 44 kN/m (3,000 lb/ft) or greater.

[4] Required minimum shear stress TRM (fully vegetated) can sustain without physical damage or excess erosion (> 12.7 mm (0.5 in.) soil loss) during a 30-minute flow event in large scale testing.

[5] Acceptable large-scale testing protocols may include ASTM D 6460, or other independent testing deemed acceptable by the engineer.

Design and Installation

RECPs should be installed according to manufacturer's specifications and guidelines. Regardless of the type of product used, it is important to ensure no gaps or voids exist under the material and that all corners of the material are secured using stakes and trenching. Continuous contact between the product and the soil is necessary to avoid failure. Never use metal stakes to secure temporary erosion control products. Often wooden stakes are used to anchor RECPs; however, wood stakes may present installation and maintenance challenges and generally take a long time to biodegrade. Some local jurisdictions have had favorable experiences using biodegradable stakes.

This BMP Fact Sheet provides design details for several commonly used ECB applications, including:

ECB-1 Pipe Outlet to Drainageway

ECB-2 Small Ditch or Drainageway

ECB-3 Outside of Drainageway

Staking patterns are also provided in the design details according to these factors:

- ECB type
- Slope or channel type

For other types of RECPs including TRMs, these design details are intended to serve as general guidelines for design and installation; however, engineers should adhere to manufacturer's installation recommendations.

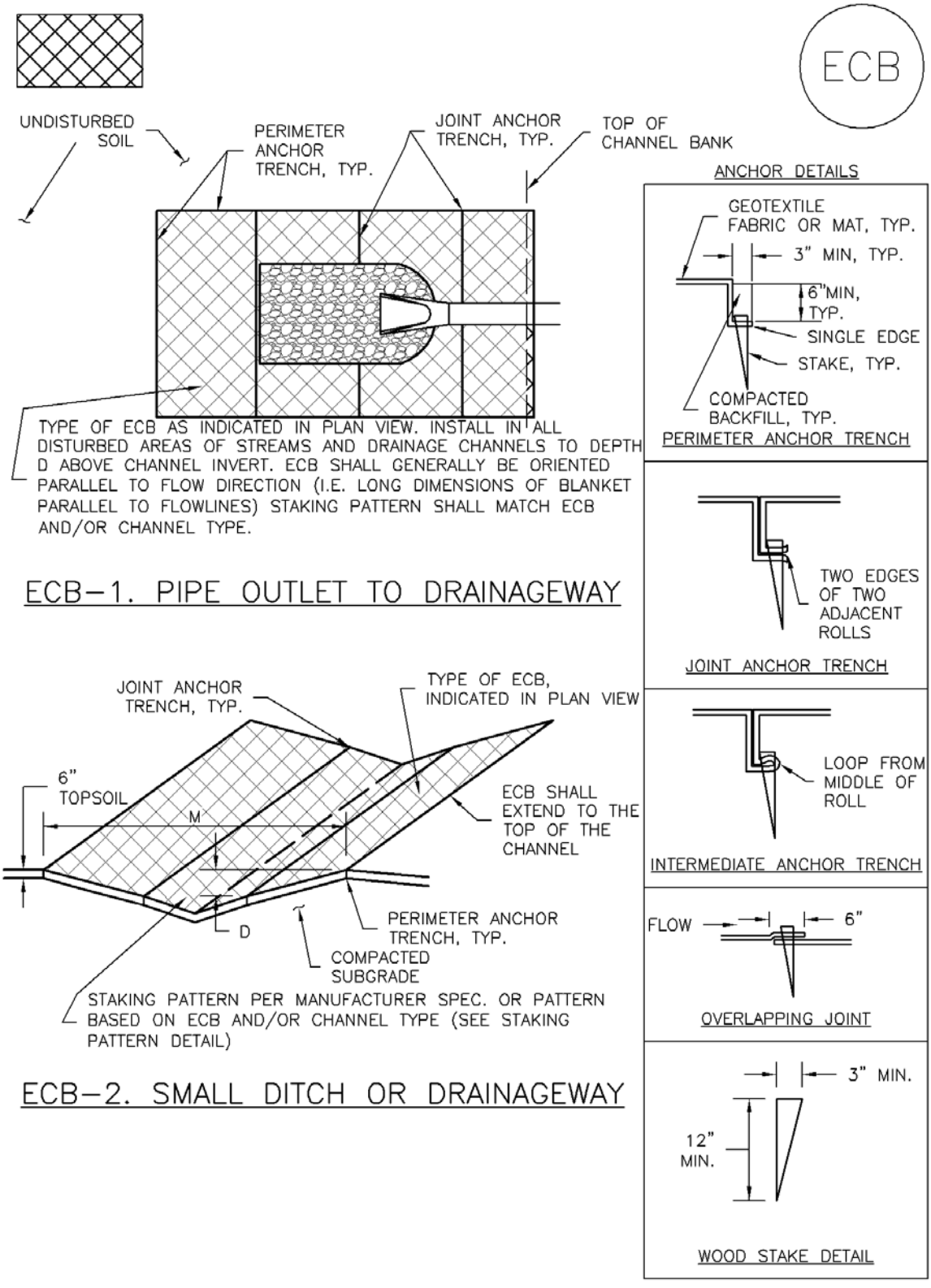
Maintenance and Removal

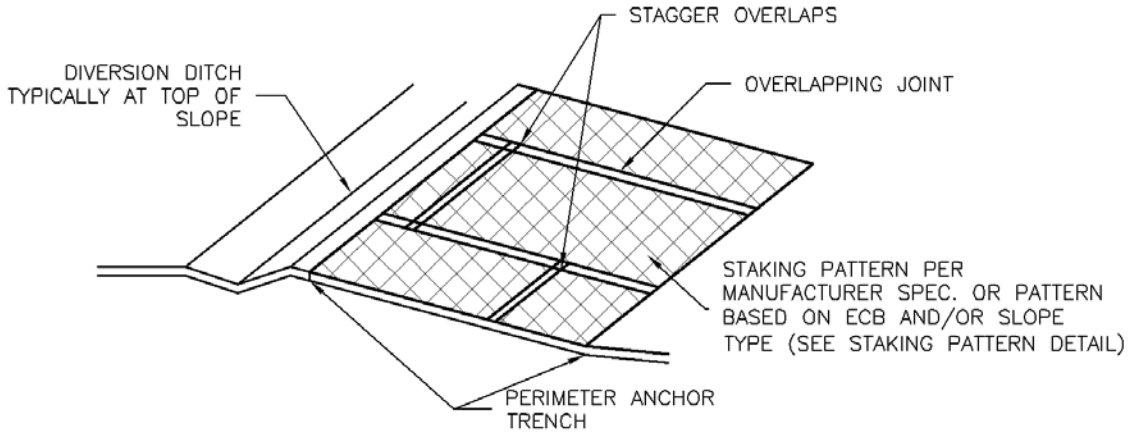
Inspection of erosion control blankets and other RECPs includes:

- Check for general signs of erosion, including voids beneath the mat. If voids are apparent, fill the void with suitable soil and replace the erosion control blanket, following the appropriate staking pattern.
- Check for damaged or loose stakes and secure loose portions of the blanket.

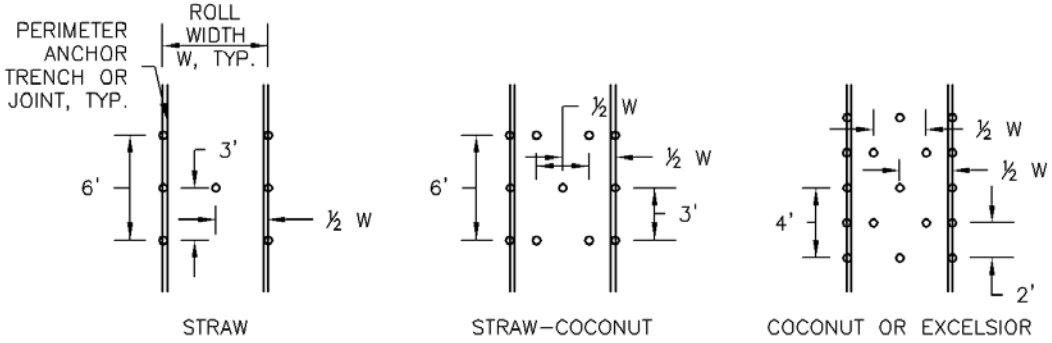
Erosion control blankets and other RECPs that are biodegradable typically do not need to be removed after construction. If they must be removed, then an alternate soil stabilization method should be installed promptly following removal.

Turf reinforcement mats, although generally resistant to biodegradation, are typically left in place as a dense vegetated cover grows in through the mat matrix. The turf reinforcement mat provides long-term stability and helps the established vegetation resist erosive forces.

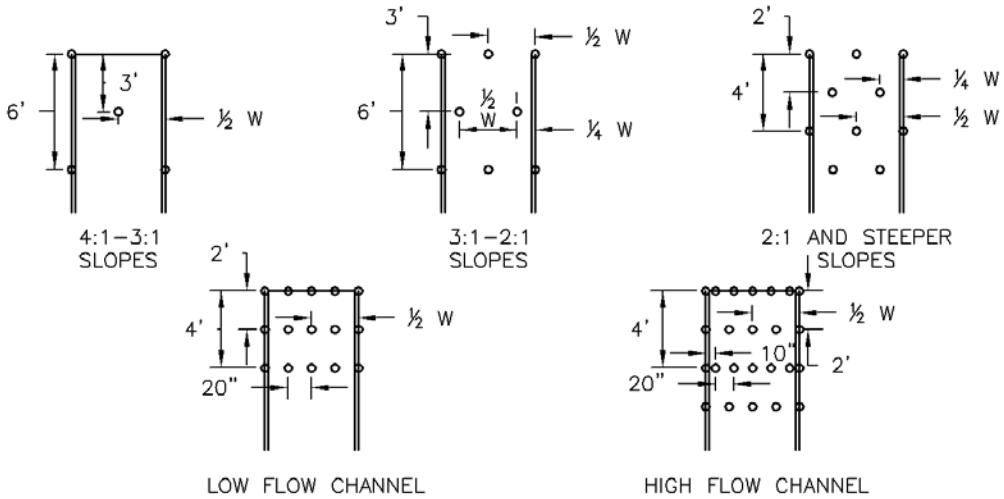

ECB
UNDISTURBED SOIL
PERIMETER ANCHOR TRENCH, TYP.
JOINT ANCHOR TRENCH, TYP.
TOP OF CHANNEL BANK
TYPE OF ECB AS INDICATED IN PLAN VIEW. INSTALL IN ALL DISTURBED AREAS OF STREAMS AND DRAINAGE CHANNELS TO DEPTH D ABOVE CHANNEL INVERT. ECB SHALL GENERALLY BE ORIENTED PARALLEL TO FLOW DIRECTION (I.E. LONG DIMENSIONS OF BLANKET PARALLEL TO FLOWLINES) STAKING PATTERN SHALL MATCH ECB AND/OR CHANNEL TYPE.
ECB–1. PIPE OUTLET TO DRAINAGEWAY
JOINT ANCHOR TRENCH, TYP.
TYPE OF ECB, INDICATED IN PLAN VIEW
6" TOPSOIL
M
ECB SHALL EXTEND TO THE TOP OF THE CHANNEL
D
PERIMETER ANCHOR TRENCH, TYP.
COMPACTED SUBGRADE
STAKING PATTERN PER MANUFACTURER SPEC. OR PATTERN BASED ON ECB AND/OR CHANNEL TYPE (SEE STAKING PATTERN DETAIL)
ECB–2. SMALL DITCH OR DRAINAGEWAY
ANCHOR DETAILS
GEOTEXTILE FABRIC OR MAT, TYP.
3" MIN, TYP.
6" MIN, TYP.
SINGLE EDGE STAKE, TYP.
COMPACTED BACKFILL, TYP.
PERIMETER ANCHOR TRENCH
TWO EDGES OF TWO ADJACENT ROLLS
JOINT ANCHOR TRENCH
LOOP FROM MIDDLE OF ROLL
INTERMEDIATE ANCHOR TRENCH
FLOW
6"
OVERLAPPING JOINT
3" MIN.
12" MIN.
WOOD STAKE DETAIL



ECB–3. OUTSIDE OF DRAINAGEWAY



STAKING PATTERNS BY ECB TYPE



STAKING PATTERNS BY SLOPE OR CHANNEL TYPE

EROSION CONTROL BLANKET INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATION OF ECB.
   - –TYPE OF ECB (STRAW, STRAW–COCONUT, COCONUT, OR EXCELSIOR).
   - –AREA, A, IN SQUARE YARDS OF EACH TYPE OF ECB.

2. 100% NATURAL AND BIODEGRADABLE MATERIALS ARE PREFERRED FOR RECPs, ALTHOUGH SOME JURISDICTIONS MAY ALLOW OTHER MATERIALS IN SOME APPLICATIONS.

3. IN AREAS WHERE ECBs ARE SHOWN ON THE PLANS, THE PERMITTEE SHALL PLACE TOPSOIL AND PERFORM FINAL GRADING, SURFACE PREPARATION, AND SEEDING AND MULCHING. SUBGRADE SHALL BE SMOOTH AND MOIST PRIOR TO ECB INSTALLATION AND THE ECB SHALL BE IN FULL CONTACT WITH SUBGRADE. NO GAPS OR VOIDS SHALL EXIST UNDER THE BLANKET.

4. PERIMETER ANCHOR TRENCH SHALL BE USED ALONG THE OUTSIDE PERIMETER OF ALL BLANKET AREAS.

5. JOINT ANCHOR TRENCH SHALL BE USED TO JOIN ROLLS OF ECBs TOGETHER (LONGITUDINALLY AND TRANSVERSELY) FOR ALL ECBs EXCEPT STRAW WHICH MAY USE AN OVERLAPPING JOINT.

6. INTERMEDIATE ANCHOR TRENCH SHALL BE USED AT SPACING OF ONE–HALF ROLL LENGTH FOR COCONUT AND EXCELSIOR ECBs.

7. OVERLAPPING JOINT DETAIL SHALL BE USED TO JOIN ROLLS OF ECBs TOGETHER FOR ECBs ON SLOPES.

8. MATERIAL SPECIFICATIONS OF ECBs SHALL CONFORM TO TABLE ECB–1.

9. ANY AREAS OF SEEDING AND MULCHING DISTURBED IN THE PROCESS OF INSTALLING ECBS SHALL BE RESEEDED AND MULCHED.

10. DETAILS ON DESIGN PLANS FOR MAJOR DRAINAGEWAY STABILIZATION WILL GOVERN IF DIFFERENT FROM THOSE SHOWN HERE.

TABLE ECB–1. ECB MATERIAL SPECIFICATIONS

TYPE	COCONUT CONTENT	STRAW CONTENT	EXCELSIOR CONTENT	RECOMMENDED NETTING**
STRAW*	–	100%	–	DOUBLE/ NATURAL
STRAW–COCONUT	30% MIN	70% MAX	–	DOUBLE/ NATURAL
COCONUT	100%	–	–	DOUBLE/ NATURAL
EXCELSIOR	–	–	100%	DOUBLE/ NATURAL

*STRAW ECBs MAY ONLY BE USED OUTSIDE OF STREAMS AND DRAINAGE CHANNEL.
**ALTERNATE NETTING MAY BE ACCEPTABLE IN SOME JURISDICTIONS

EROSION CONTROL BLANKET MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ECBs SHALL BE LEFT IN PLACE TO EVENTUALLY BIODEGRADE, UNLESS REQUESTED TO BE REMOVED BY THE LOCAL JURISDICTION.

5. ANY ECB PULLED OUT, TORN, OR OTHERWISE DAMAGED SHALL BE REPAIRED OR REINSTALLED. ANY SUBGRADE AREAS BELOW THE GEOTEXTILE THAT HAVE ERODED TO CREATED A VOID UNDER THE BLANKET, OR THAT REMAIN DEVOID OF GRASS SHALL BE REPAIRED, RESEEDED AND MULCHED AND THE ECB REINSTALLED.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO AND TOWN OF PARKER COLORADO, NOT AVAILABLE IN AUTOCAD)

Temporary Slope Drains (TSD) EC-7

Description

A temporary slope drain is a pipe or culvert used to convey water down a slope where there is a high potential for erosion. A drainage channel or swale at the top of the slope typically directs upgradient runoff to the pipe entrance for conveyance down the slope. The pipe outlet must be equipped with outlet protection.

Photograph TSD-1. A temporary slope drain installed to convey runoff down a slope during construction. Photo courtesy of the City of Aurora.

Appropriate Uses

Use on long, steep slopes when there is a high potential of flow concentration or rill development.

Design and Installation

Effective use of temporary slope drains involves design of an effective collection system to direct flows to the pipe, proper sizing and anchoring of the pipe, and outlet protection. Upgradient of the temporary slope drain, a temporary drainage ditch or swale should be constructed to collect surface runoff from the drainage area and convey it to the drain entrance. The temporary slope drain must be sized to safely convey the desired flow volume. At a minimum, it should be sized to convey the 2-year, 24-hour storm.

Temporary slope drains may be constructed of flexible or rigid pipe, riprap, or heavy (30 mil) plastic lining. When piping is used, it must be properly anchored by burying it with adequate cover or by using an anchor system to secure it to the ground.

The discharge from the slope drain must be directed to a stabilized outlet, temporary or permanent channel, and/or sedimentation basin.

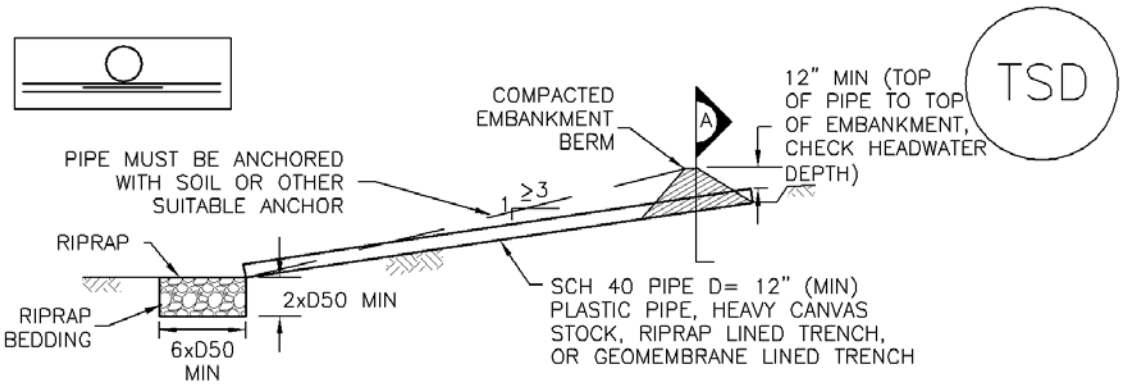
See Detail TSD-1 for additional sizing and design information.

Temporary Slope Drains	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

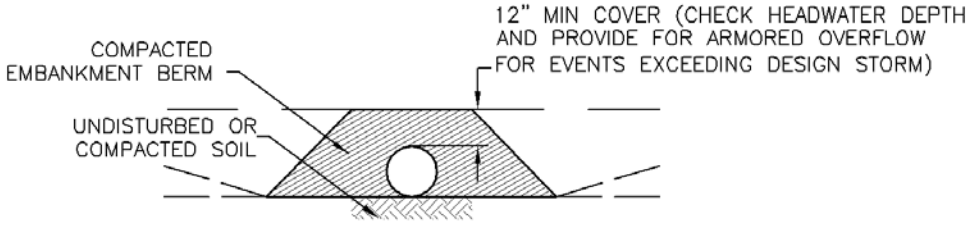
Maintenance and Removal

Inspect the entrance for sediment accumulation and remove, as needed. Clogging as a result of sediment deposition at the entrance can lead to ponding upstream causing flooding or overtopping of the slope drain. Inspect the downstream outlet for signs of erosion and stabilize, as needed. It may also be necessary to remove accumulated sediment at the outfall. Inspect pipe anchors to ensure that they are secure. If the pipe is secured by ground cover, ensure erosion has not compromised the depth of cover.

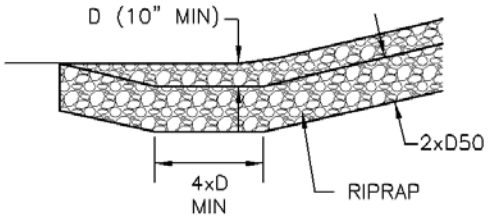
Slope drains should be removed when no longer needed or just prior to installation of permanent slope stabilization measures that cannot be installed with the slope drain in place. When slope drains are removed, the disturbed areas should be covered with topsoil, seeded, mulched or otherwise stabilized as required by the local jurisdiction.



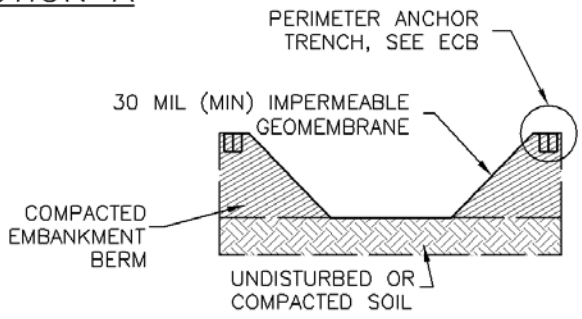
TEMPORARY SLOPE DRAIN PROFILE



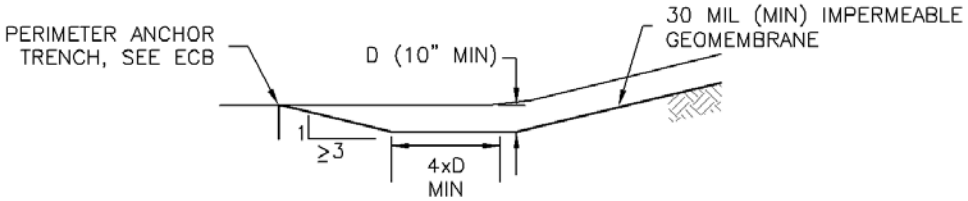
SECTION A



TERMINATION OF RIPRAP LINED SLOPE DRAIN



GEOMEMBRANE LINED SLOPE DRAIN



TERMINATION OF GEOMEMBRANE LINED SLOPE DRAIN

TSD–1. TEMPORARY SLOPE DRAIN PROFILE

SLOPE DRAIN INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION AND LENGTH OF SLOPE DRAIN
   –PIPE DIAMETER, D, AND RIPRAP SIZE, D50.

2. SLOPE DRAIN SHALL BE DESIGNED TO CONVEY PEAK RUNOFF FOR 2–YEAR 24–HOUR STORM AT A MINIMUM. FOR LONGER DURATION PROJECTS, LARGER MAY BE APPROPRIATE.

3. SLOPE DRAIN DIMENSIONS SHALL BE CONSIDERED MINIMUM DIMENSIONS; CONTRACTOR MAY ELECT TO INSTALL LARGER FACILITIES.

4. SLOPE DRAINS INDICATED SHALL BE INSTALLED PRIOR TO UPGRADIENT LAND–DISTURBING ACTIVITIES.

5. CHECK HEADWATER DEPTHS FOR TEMPORARY AND PERMANENT SLOPE DRAINS. DETAILS SHOW MINIMUM COVER; INCREASE AS NECESSARY FOR DESIGN HEADWATER DEPTH.

6. RIPRAP PAD SHALL BE PLACED AT SLOPE DRAIN OUTFALL.

7. ANCHOR PIPE BY COVERING WITH SOIL OR AN ALTERNATE SUITABLE ANCHOR MATERIAL.

SLOPE DRAIN MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. INSPECT INLET AND OUTLET POINTS AFTER STORMS FOR CLOGGING OR EVIDENCE OF OVERTOPPING. BREACHES IN PIPE OR OTHER CONVEYANCE SHALL BE REPAIRED AS SOON AS PRACTICABLE IF OBSERVED.

5. INSPECT RIPRAP PAD AT OUTLET FOR SIGNS OF EROSION. IF SIGNS OF EROSION EXIST, ADDITIONAL ARMORING SHALL BE INSTALLED.

6. TEMPORARY SLOPE DRAINS ARE TO REMAIN IN PLACE UNTIL NO LONGER NEEDED, BUT SHALL BE REMOVED PRIOR TO THE END OF CONSTRUCTION. WHEN SLOPE DRAINS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOP SOIL, SEEDED, MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND THE CITY OF COLORADO SPRINGS, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Temporary Outlet Protection (TOP) EC-8

Description

Outlet protection helps to reduce erosion immediately downstream of a pipe, culvert, slope drain, rundown or other conveyance with concentrated, high-velocity flows. Typical outlet protection consists of riprap or rock aprons at the conveyance outlet.

Photograph TOP-1. Riprap outlet protection.

Appropriate Uses

Outlet protection should be used when a conveyance discharges onto a disturbed area where there is potential for accelerated erosion due to concentrated flow. Outlet protection should be provided where the velocity at the culvert outlet exceeds the maximum permissible velocity of the material in the receiving channel.

Note**:** This Fact Sheet and detail are for temporary outlet protection, outlets that are intended to be used for less than 2 years. For permanent, long-term outlet protection, see the *Major Drainage* chapter of Volume 1.

Design and Installation

Design outlet protection to handle runoff from the largest drainage area that may be contributing runoff during construction (the drainage area may change as a result of grading). Key in rock, around the entire perimeter of the apron, to a minimum depth of 6 inches for stability. Extend riprap to the height of the culvert or the normal flow depth of the downstream channel, whichever is less. Additional erosion control measures such as vegetative lining, turf reinforcement mat and/or other channel lining methods may be required downstream of the outlet protection if the channel is susceptible to erosion. See Design Detail OP-1 for additional information.

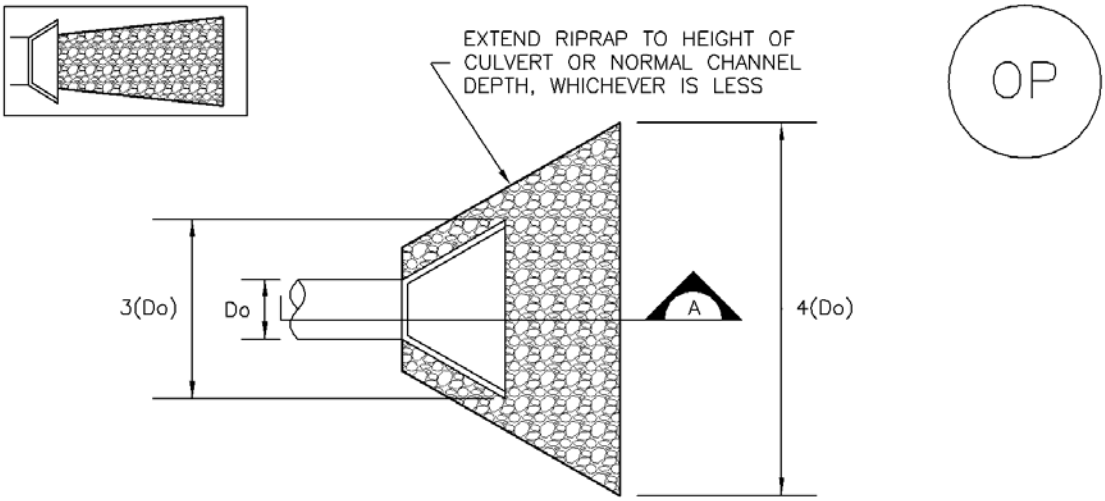
Maintenance and Removal

Inspect apron for damage and displaced rocks. If rocks are missing or significantly displaced, repair or replace as necessary. If rocks are continuously missing or displaced, consider increasing the size of the riprap or deeper keying of the perimeter.

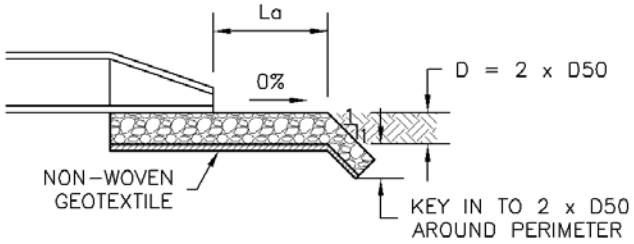
Remove sediment accumulated at the outlet before the outlet protection becomes buried and ineffective. When sediment accumulation is noted, check that upgradient BMPs, including inlet protection, are in effective operating condition.

Outlet protection may be removed once the pipe is no longer draining an upstream area, or once the downstream area has been sufficiently stabilized. If the drainage pipe is permanent, outlet protection can be left in place; however, permanent outlet protection should be designed and constructed in accordance with the requirements of the *Major Drainage* chapter of Volume 2.

Outlet Protection	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No



TEMPORARY OUTLET PROTECTION PLAN



SECTION A

TABLE OP-1. TEMPORARY OUTLET PROTECTION SIZING TABLE			
PIPE DIAMETER, Do (INCHES)	DISCHARGE, Q (CFS)	APRON LENGTH, La (FT)	RIPRAP D50 DIAMETER MIN (INCHES)
8	2.5 5	5 10	4 6
12	5 10	10 13	4 6
18	10 20 30 40	10 16 23 26	6 9 12 16
24	30 40 50 60	16 26 26 30	9 9 12 16

OP-1. TEMPORARY OUTLET PROTECTION

TEMPORARY OUTLET PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   –LOCATION OF OUTLET PROTECTION.
   –DIMENSIONS OF OUTLET PROTECTION.

2. DETAIL IS INTENDED FOR PIPES WITH SLOPE ≤ 10%. ADDITIONAL EVALUATION OF RIPRAP SIZING AND OUTLET PROTECTION DIMENSIONS REQUIRED FOR STEEPER SLOPES.

3. TEMPORARY OUTLET PROTECTION INFORMATION IS FOR OUTLETS INTENDED TO BE UTILIZED LESS THAN 2 YEARS.

TEMPORARY OUTLET PROTECTION INSPECTION AND MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM AURORA, COLORADO AND PREVIOUS VERSION OF VOLUME 3, NOT AVAILABLE IN AUTOCAD)

Rough Cut Street Control (RCS) EC-9

Description

Rough cut street controls are rock or earthen berms placed along dirt roadways that are under construction or used for construction access. These temporary berms intercept sheet flow and divert runoff from the roadway, and control erosion by minimizing concentration of flow and reducing runoff velocity.

Photograph RCS-1. Rough cut street controls.

Appropriate Uses

Appropriate uses include:

- Temporary dirt construction roadways that have not received roadbase.
- Roadways under construction that will not be paved within 14 days of final grading, and that have not yet received roadbase.

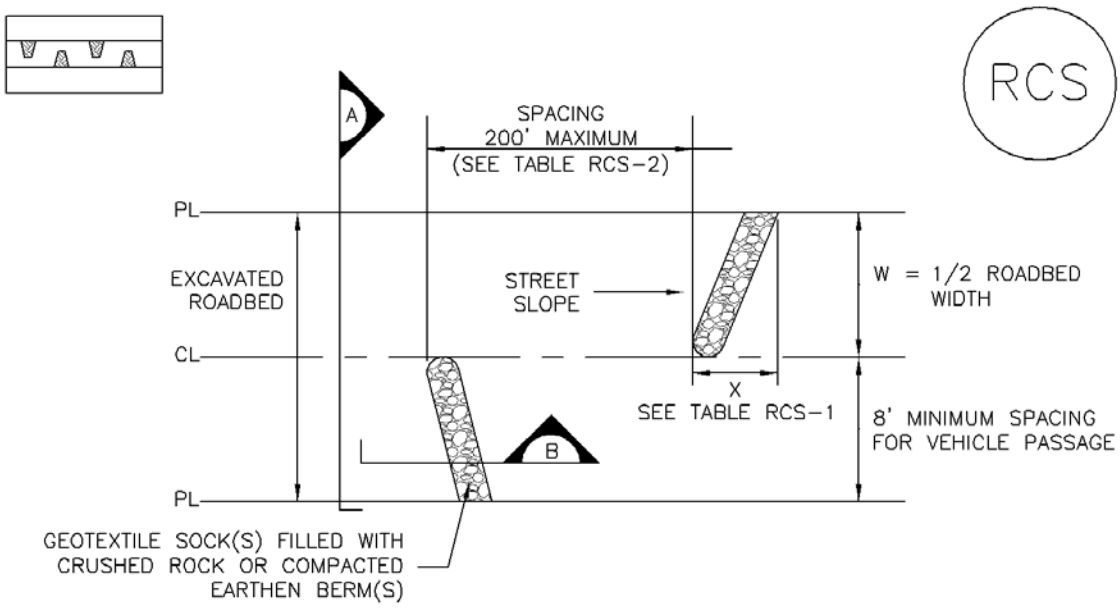
Design and Installation

Rough cut street controls are designed to redirect sheet flow off the dirt roadway to prevent water from concentrating and eroding the soil. These controls consist of runoff barriers that are constructed at intervals along the road. These barriers are installed perpendicular to the longitudinal slope from the outer edge of the roadside swale to the crown of the road. The barriers are positioned alternately from the right and left side of the road to allow construction traffic to pass in the lane not barred. If construction traffic is expected to be congested and a vehicle tracking control has been constructed, rough-cut street controls may be omitted for 400 feet from the entrance. Runoff from the controls should be directed to another stormwater BMP such as a roadside swale with check dams once removed from the roadway. See Detail RCS-1 for additional information.

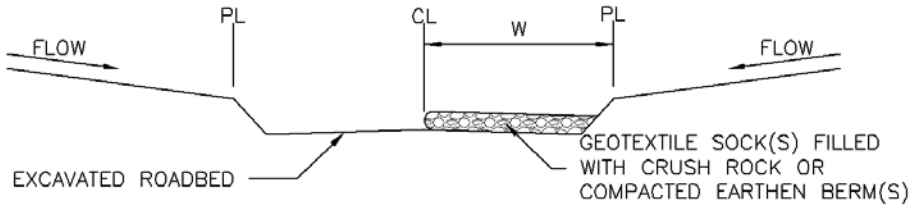
Maintenance and Removal

Inspect street controls for erosion and stability. If rills are forming in the roadway or cutting through the control berms, place the street controls at shorter intervals. If earthen berms are used, periodic recompaction may be necessary. When rock berms are used, repair and/or replace as necessary when damaged. Street controls may be removed 14 days prior to road surfacing and paving.

Rough Cut Street Control	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No



ROUGH CUT STREET CONTROL PLAN



SECTION A

SECTION B

TABLE RCS-1

W (FT)	X (FT)
20-30	5
31-40	7
41-50	9
51-60	10.5
61-70	12

TABLE RCS-2

LONGITUDINAL STREET SLOPE (%)	SPACING (FT)
<2 2	NOT TYPICALLY NEEDED 200
3 4	200 150
5 6	100 50
7 8	25 25

RCS-1. ROUGH CUT STREET CONTROL

ROUGH CUT STREET CONTROL INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   –LOCATION OF ROUGH CUT STREET CONTROL MEASURES.

2. ROUGH CUT STREET CONTROL SHALL BE INSTALLED AFTER A ROAD HAS BEEN CUT IN, AND WILL NOT BE PAVED FOR MORE THAN 14 DAYS OR FOR TEMPORARY CONSTRUCTION ROADS THAT HAVE NOT RECEIVED ROAD BASE.

ROUGH CUT STREET CONTROL INSPECTION AND MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

(DETAILS ADAPTED FROM AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Earth Dikes and Drainage Swales (ED/DS) EC-10

Description

Earth dikes and drainage swales are temporary storm conveyance channels constructed either to divert runoff around slopes or to convey runoff to additional sediment control BMPs prior to discharge of runoff from a site. Drainage swales may be lined or unlined, but if an unlined swale is used, it must be well compacted and capable of resisting erosive velocities.

Photograph ED/DS-1. Example of an earth dike used to divert flows at a construction site. Photo courtesy of CDOT.

Appropriate Uses

Earth dikes and drainage swales are typically used to control the flow path of runoff at a construction site by diverting runoff around areas prone to erosion, such as steep slopes. Earth dikes and drainage swales may also be constructed as temporary conveyance features. This will direct runoff to additional sediment control treatment BMPs, such as sediment traps or basins.

Design and Installation

When earth dikes are used to divert water for slope protection, the earth dike typically consists of a horizontal ridge of soil placed perpendicular to the slope and angled slightly to provide drainage along the contour. The dike is used in conjunction with a swale or a small channel upslope of the berm to convey the diverted water. Temporary diversion dikes can be constructed by excavation of a V-shaped trench or ditch and placement of the fill on the downslope side of the cut. There are two types of placement for temporary slope diversion dikes:

- A dike located at the top of a slope to divert upland runoff away from the disturbed area and convey it in a temporary or permanent channel.
- A diversion dike located at the base or mid-slope of a disturbed area to intercept runoff and reduce the effective slope length.

Depending on the project, either an earth dike or drainage swale may be more appropriate. If there is a need for cut on the project, then an excavated drainage swale may be better suited. When the project is primarily fill, then a conveyance constructed using a berm may be the better option.

All dikes or swales receiving runoff from a disturbed area should direct stormwater to a sediment control BMP such as a sediment trap or basin.

Earth Dikes and Drainage Swales	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

EC-10 Earth Dikes and Drainage Swales (ED/DS)

Unlined dikes or swales should only be used for intercepting sheet flow runoff and are not intended for diversion of concentrated flows.

Details with notes are provided for several design variations, including:

ED-1. Unlined Earth Dike formed by Berm

DS-1. Unlined Excavated Swale

DS-2. Unlined Swale Formed by Cut and Fill

DS-3. ECB-lined Swale

DS-4. Synthetic-lined Swale

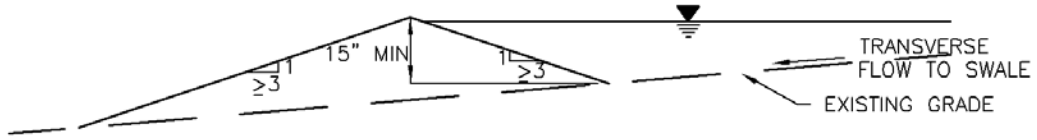
DS-5. Riprap-lined Swale

The details also include guidance on permissible velocities for cohesive channels if unlined approaches will be used.

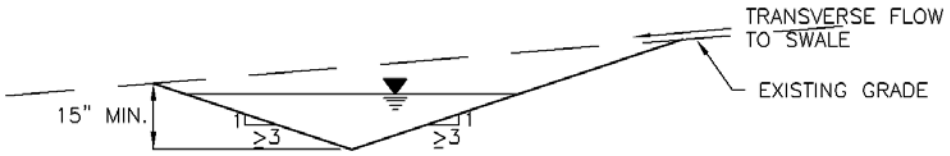
Maintenance and Removal

Inspect earth dikes for stability, compaction, and signs of erosion and repair. Inspect side slopes for erosion and damage to erosion control fabric. Stabilize slopes and repair fabric as necessary. If there is reoccurring extensive damage, consider installing rock check dams or lining the channel with riprap.

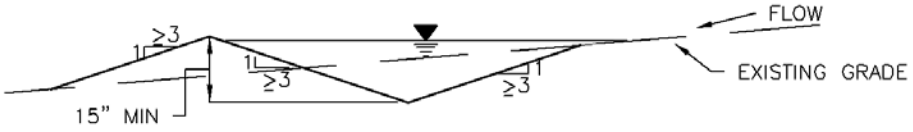
If drainage swales are not permanent, remove dikes and fill channels when the upstream area is stabilized. Stabilize the fill or disturbed area immediately following removal by revegetation or other permanent stabilization method approved by the local jurisdiction.



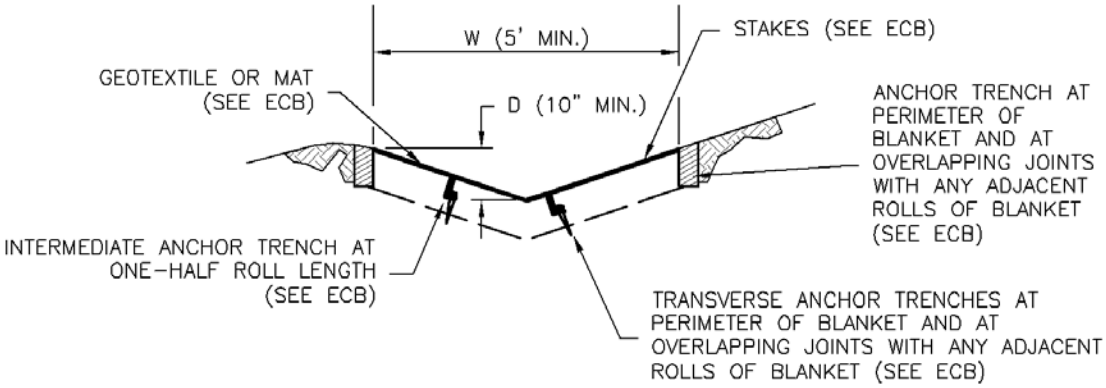
ED–1. COMPACTED UNLINED EARTH DIKE FORMED BY BERM



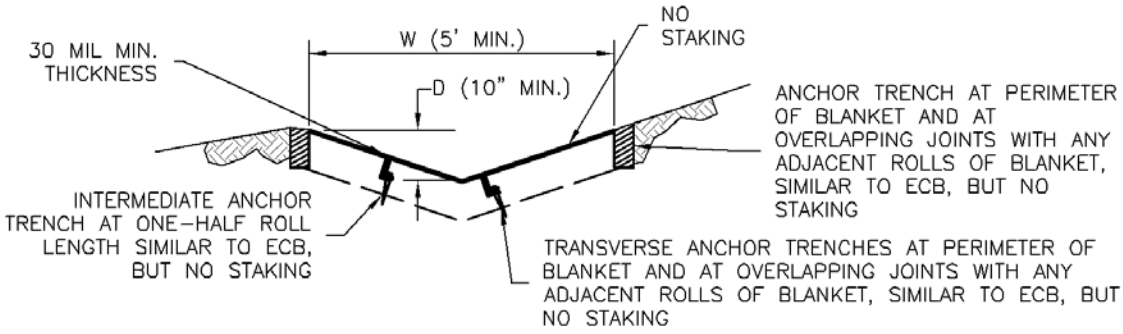
DS–1. COMPACTED UNLINED EXCAVATED SWALE



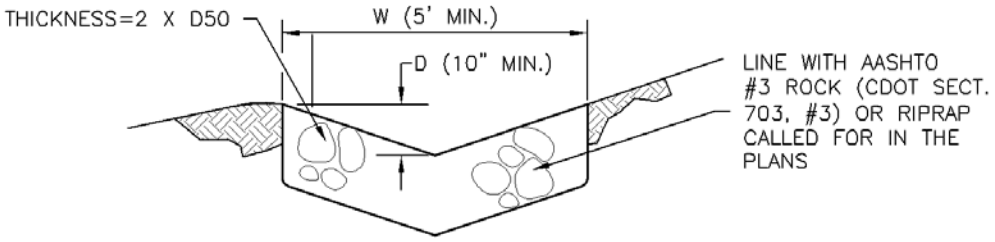
DS–2. COMPACTED UNLINED SWALE FORMED BY CUT AND FILL



DS–3. ECB LINED SWALE (CUT AND FILL OR BERM)



DS-4. SYNTHETIC LINED SWALE



DS-5. RIPRAP LINED SWALE

EARTH DIKE AND DRAINAGE SWALE INSTALLATION NOTES

1. SEE SITE PLAN FOR:
   - LOCATION OF DIVERSION SWALE
   - TYPE OF SWALE (UNLINED, COMPACTED AND/OR LINED).
   - LENGTH OF EACH SWALE.
   - DEPTH, D, AND WIDTH, W DIMENSIONS.
   - FOR ECB/TRM LINED DITCH, SEE ECB DETAIL.
   - FOR RIPRAP LINED DITCH, SIZE OF RIPRAP, D50.

2. SEE DRAINAGE PLANS FOR DETAILS OF PERMANENT CONVEYANCE FACILITIES AND/OR DIVERSION SWALES EXCEEDING 2-YEAR FLOW RATE OR 10 CFS.

3. EARTH DIKES AND SWALES INDICATED ON SWMP PLAN SHALL BE INSTALLED PRIOR TO LAND-DISTURBING ACTIVITIES IN PROXIMITY.

4. EMBANKMENT IS TO BE COMPACTED TO 90% OF MAXIMUM DENSITY AND WITHIN 2% OF OPTIMUM MOISTURE CONTENT ACCORDING TO ASTM D698.

5. SWALES ARE TO DRAIN TO A SEDIMENT CONTROL BMP.

6. FOR LINED DITCHES, INSTALLATION OF ECB/TRM SHALL CONFORM TO THE REQUIREMENTS OF THE ECB DETAIL.

7. WHEN CONSTRUCTION TRAFFIC MUST CROSS A DIVERSION SWALE, INSTALL A TEMPORARY CULVERT WITH A MINIMUM DIAMETER OF 12 INCHES.

EARTH DIKE AND DRAINAGE SWALE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SWALES SHALL REMAIN IN PLACE UNTIL THE END OF CONSTRUCTION; IF APPROVED BY LOCAL JURISDICTION, SWALES MAY BE LEFT IN PLACE.

5. WHEN A SWALE IS REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND THE CITY OF COLORADO SPRINGS, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Terracing (TER) EC-11

Description

Terracing involves grading steep slopes into a series of relatively flat sections, or terraces, separated at intervals by steep slope segments. Terraces shorten the uninterrupted flow lengths on steep slopes, helping to reduce the development of rills and gullies. Retaining walls, gabions, cribbing, deadman anchors, rock-filled slope mattresses, and other types of soil retention systems can be used in terracing.

Photograph TER-1. Use of a terrace to reduce erosion by controlling slope length on a long, steep slope. Photo courtesy of Douglas County.

Appropriate Uses

Terracing techniques are most typically used to control erosion on slopes that are steeper than 4:1.

Design and Installation

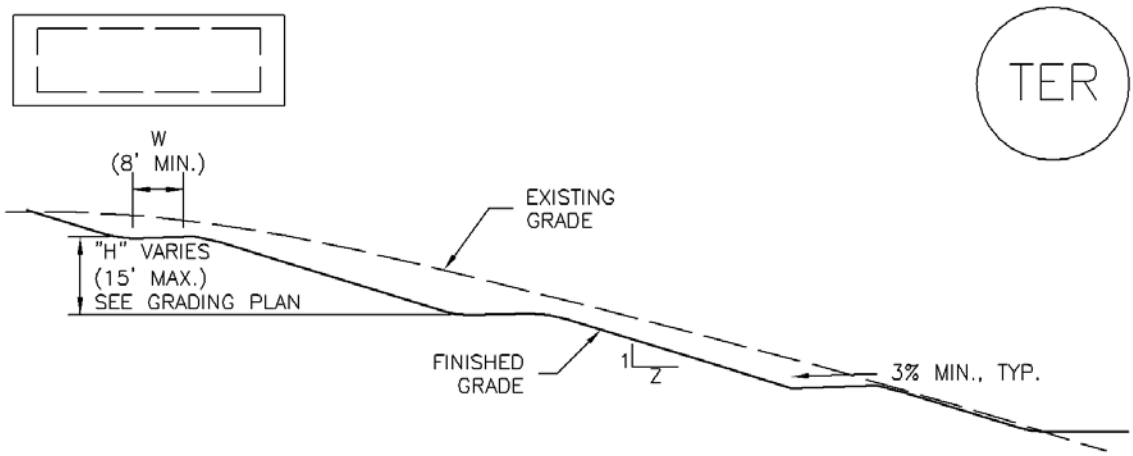
Design details with notes are provided in Detail TER-1.

The type, number, and spacing of terraces will depend on the slope, slope length, and other factors. The Revised Universal Soil Loss Equation (RUSLE) may be helpful in determining spacing of terraces on slopes. Terracing should be used in combination with other stabilization measures that provide cover for exposed soils such as mulching, seeding, surface roughening, or other measures.

Maintenance and Removal

Repair rill erosion on slopes and remove accumulated sediment, as needed. Terracing may be temporary or permanent. If terracing is temporary, the slope should be topsoiled, seeded, and mulched when the slope is graded to its final configuration and terraces are removed. Due to the steepness of the slope, once terraces are graded, erosion control blankets or other stabilization measures are typically required. If terraces are permanent, vegetation should be established on slopes and terraces as soon as practical.

Terracing	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No



TER–1. TERRACING

TERRACING INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF TERRACING
   –WIDTH (W), AND SLOPE (Z).

2. TERRACING IS TYPICALLY NOT REQUIRED FOR SLOPES OF 4:1 OR FLATTER.

3. GRADE TERRACES TO DRAIN BACK TO SLOPE AT A MINIMUM OF 3% GRADE.

TERRACING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. RILL EROSION OCCURRING ON TERRACED SLOPES SHALL BE REPAIRED, RESEEDED, MULCHED OR STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

5. TERRACING MAY NEED TO BE RE–GRADED TO RETURN THE SLOPE TO THE FINAL DESIGN GRADE. THE SLOPE SHALL THEN BE COVERED WITH TOPSOIL, SEEDED AND MULCHED, OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Check Dams (CD) EC-12

Description

Check dams are temporary grade control structures placed in drainage channels to limit the erosivity of stormwater by reducing flow velocity. Check dams are typically constructed from rock, gravel bags, sand bags, or sometimes, proprietary devices. Reinforced check dams are typically constructed from rock and wire gabion. Although the primary function of check dams is to reduce the velocity of concentrated flows, a secondary benefit is sediment trapping upstream of the structure.

Photograph CD-1. Rock check dams in a roadside ditch. Photo courtesy of WWE.

Appropriate Uses

Use as a grade control for temporary drainage ditches or swales until final soil stabilization measures are established upstream and downstream. Check dams can be used on mild or moderately steep slopes. Check dams may be used under the following conditions:

- As temporary grade control facilities along waterways until final stabilization is established.
- Along permanent swales that need protection prior to installation of a non-erodible lining.
- Along temporary channels, ditches or swales that need protection where construction of a non-erodible lining is not practicable.
- Reinforced check dams should be used in areas subject to high flow velocities.

Design and Installation

Place check dams at regularly spaced intervals along the drainage swale or ditch. Check dams heights should allow for pools to develop upstream of each check dam, extending to the downstream toe of the check dam immediately upstream.

When rock is used for the check dam, place rock mechanically or by hand. Do not dump rocks into the drainage channel. Where multiple check dams are used, the top of the lower dam should be at the same elevation as the toe of the upper dam.

When reinforced check dams are used, install erosion control fabric under and around the check dam to prevent erosion on the upstream and downstream sides. Each section of the dam should be keyed in to reduce the potential for washout or undermining. A rock apron upstream and downstream of the dam may be necessary to further control erosion.

Check Dams	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

Design details with notes are provided for the following types of check dams:

- Rock Check Dams (CD-1)
- Reinforced Check Dams (CD-2)

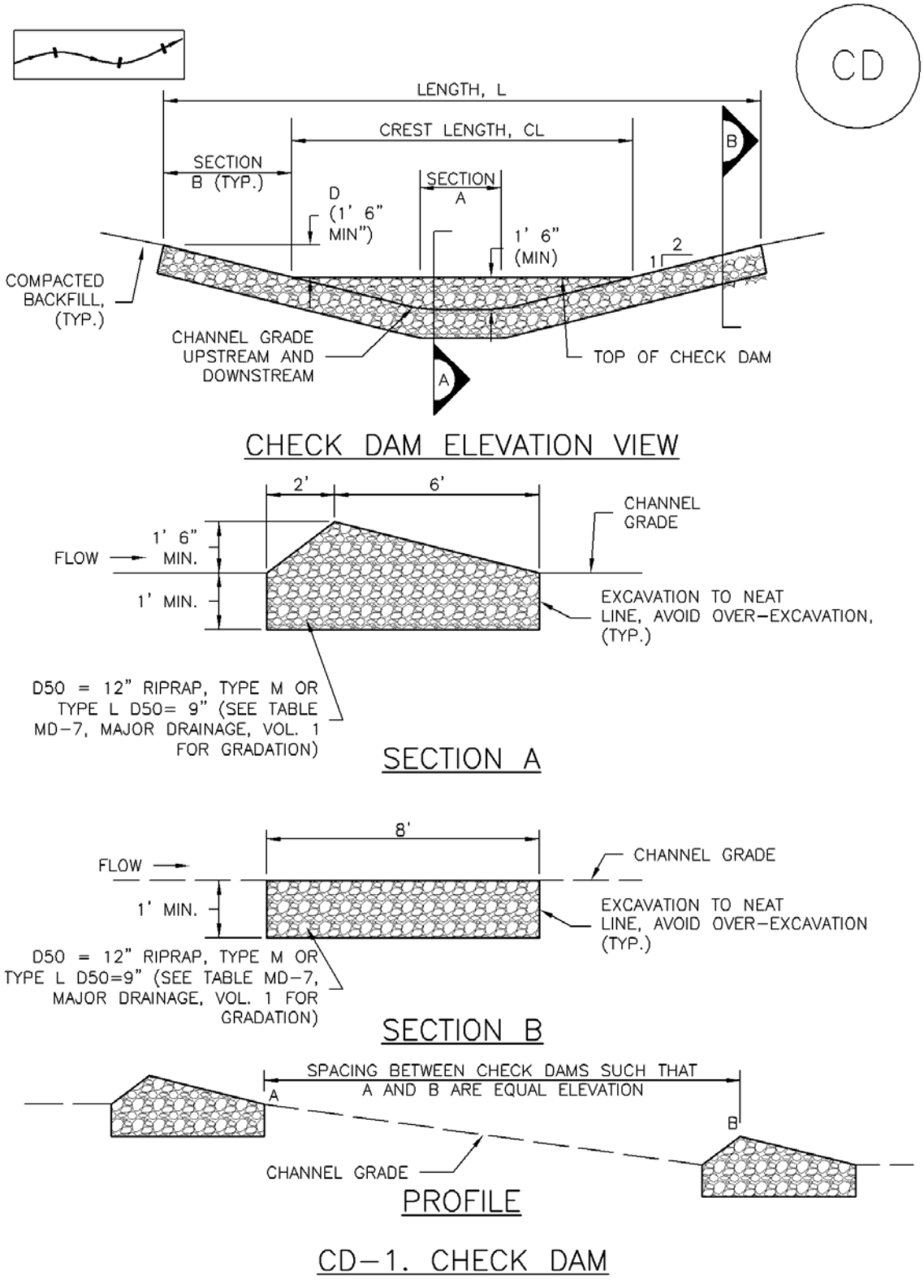
Sediment control logs may also be used as check dams; however, silt fence is not appropriate for use as a check dam. Many jurisdictions also prohibit or discourage use of straw bales for this purpose.

Maintenance and Removal

Replace missing rocks causing voids in the check dam. If gravel bags or sandbags are used, replace or repair torn or displaced bags.

Remove accumulated sediment, as needed to maintain BMP effectiveness, typically before the sediment depth upstream of the check dam is within ½ of the crest height. Remove accumulated sediment prior to mulching, seeding, or chemical soil stabilization. Removed sediment can be incorporated into the earthwork with approval from the Project Engineer, or disposed of at an alternate location in accordance with the standard specifications.

Check dams constructed in permanent swales should be removed when perennial grasses have become established, or immediately prior to installation of a non-erodible lining. All of the rock and accumulated sediment should be removed, and the area seeded and mulched, or otherwise stabilized.



CD-1. CHECK DAM

CHECK DAM INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF CHECK DAMS.
   –CHECK DAM TYPE (CHECK DAM OR REINFORCED CHECK DAM).
   –LENGTH (L), CREST LENGTH (CL), AND DEPTH (D).

2. CHECK DAMS INDICATED ON INITIAL SWMP SHALL BE INSTALLED AFTER CONSTRUCTION FENCE, BUT PRIOR TO ANY UPSTREAM LAND DISTURBING ACTIVITIES.

3. RIPRAP UTILIZED FOR CHECK DAMS SHOULD BE OF APPROPRIATE SIZE FOR THE APPLICATION. TYPICAL TYPES OF RIPRAP USED FOR CHECK DAMS ARE TYPE M (D50 12") OR TYPE L (D50 9").

4. RIPRAP PAD SHALL BE TRENCHED INTO THE GROUND A MINIMUM OF 1'.

5. THE ENDS OF THE CHECK DAM SHALL BE A MINIMUM OF 1' 6" HIGHER THAN THE CENTER OF THE CHECK DAM.

CHECK DAM MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

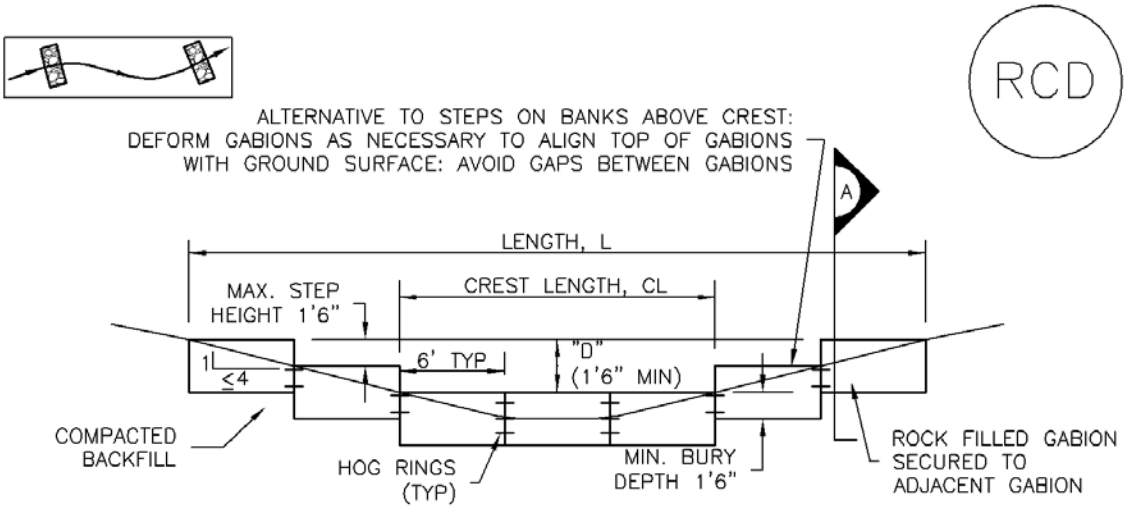
4. SEDIMENT ACCUMULATED UPSTREAM OF THE CHECK DAMS SHALL BE REMOVED WHEN THE SEDIMENT DEPTH IS WITHIN ½ OF THE HEIGHT OF THE CREST.

5. CHECK DAMS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

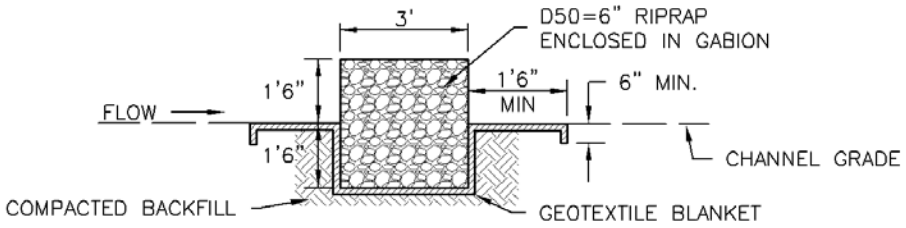
6. WHEN CHECK DAMS ARE REMOVED, EXCAVATIONS SHALL BE FILLED WITH SUITABLE COMPACTED BACKFILL. DISTURBED AREA SHALL BE SEEDED AND MULCHED AND COVERED WITH GEOTEXTILE OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.



REINFORCED CHECK DAM ELEVATION VIEW



SECTION A

REINFORCED CHECK DAM INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATIONS OF CHECK DAMS.
   - –CHECK DAM TYPE (CHECK DAM OR REINFORCED CHECK DAM).
   - –LENGTH (L), CREST LENGTH (CL), AND DEPTH (D).

2. CHECK DAMS INDICATED ON THE SWMP SHALL BE INSTALLED PRIOR TO AN UPSTREAM LAND–DISTURBING ACTIVITIES.

3. REINFORCED CHECK DAMS, GABIONS SHALL HAVE GALVANIZED TWISTED WIRE NETTING WITH A MAXIMUM OPENING DIMENSION OF 4½" AND A MINIMUM WIRE THICKNESS OF 0.10". WIRE "HOG RINGS" AT 4" SPACING OR OTHER APPROVED MEANS SHALL BE USED AT ALL GABION SEAMS AND TO SECURE THE GABION TO THE ADJACENT SECTION.

4. THE CHECK DAM SHALL BE TRENCHED INTO THE GROUND A MINIMUM OF 1' 6".

5. GEOTEXTILE BLANKET SHALL BE PLACED IN THE REINFORCED CHECK DAM TRENCH EXTENDING A MINIMUM OF 1' 6" ON BOTH THE UPSTREAM AND DOWNSTREAM SIDES OF THE REINFORCED CHECK DAM.

CD–2. REINFORCED CHECK DAM

REINFORCED CHECK DAM MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF REINFORCED CHECK DAMS SHALL BE REMOVED AS NEEDED TO MAINTAIN THE EFFECTIVENESS OF BMP, TYPICALLY WHEN THE UPSTREAM SEDIMENT DEPTH IS WITHIN ½ THE HEIGHT OF THE CREST.

5. REPAIR OR REPLACE REINFORCED CHECK DAMS WHEN THERE ARE SIGNS OF DAMAGE SUCH AS HOLES IN THE GABION OR UNDERCUTTING.

6. REINFORCED CHECK DAMS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

7. WHEN REINFORCED CHECK DAMS ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED, AND COVERED WITH A GEOTEXTILE BLANKET, OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Streambank Stabilization (SS) EC-13

Description

Streambank stabilization involves a combination of erosion and sediment control practices to protect streams, banks, and in-stream habitat from accelerated erosion. BMPs associated with streambank stabilization may include protection of existing vegetation, check dams/grade control, temporary and permanent seeding, outlet protection, rolled erosion control products, temporary diversions, dewatering operations and bioengineering practices such as brush layering, live staking and fascines.

Photograph SS-1. Streambank stabilization using geotextiles following installation of a permanent in-stream grade control structure.

Appropriate Uses

Streambank stabilization may be a construction activity in and of itself, or it may be in conjunction with a broader construction project that discharges to a waterway that is susceptible to accelerated erosion due to increases in the rate and volume of stormwater runoff. Depending on the health of the stream, water quality sampling and testing may be advisable prior to and/or during construction to evaluate health and stability of the stream and potential effects from adjacent construction activities.

Design and Installation

Streambank stabilization consists of protecting the stream in a variety of ways to minimize negative effects to the stream environment. The following lists the minimum requirements necessary for construction streambank stabilization:

- Protect existing vegetation along the stream bank in accordance with the Vegetated Buffers and Protection of Existing Vegetation Fact Sheets. Preserving a riparian buffer along the streambank will help to remove sediment and decrease runoff rates from the disturbed area.
- Outside the riparian buffer, provide sediment control in the form of a silt fence or equivalent sediment control practice along the entire length of the stream that will receive runoff from the area of disturbance. In some cases, a double-layered perimeter control may be justified adjacent to sensitive receiving waters and wetlands to provide additional protection.
- Stabilize all areas that will be draining to the stream. Use rolled erosion control products, temporary or permanent seeding, or other appropriate measures.
- Ensure all point discharges entering the stream are adequately armored with a velocity dissipation device and appropriate outlet protection.

Streambank Stabilization	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

See individual design details and notes for the various BMPs referenced in this practice. Additional information on bioengineering techniques for stream stabilization can be

found in the *Major Drainage* chapter of Volume 1 and additional guidance on BMPs for working in waterways can be found in UDFCD's *Best Management Practices for Construction in Waterways Training Manual*.

Maintenance and Removal

Inspect BMPs protecting the stream for damage on a daily basis. Maintain, repair, or replace damaged BMPs following the guidance provided in individual BMP Fact Sheets for practices that are implemented. Some streambank stabilization BMPs are intended to remain in place as vegetation matures (e.g. erosion control blankets protecting seeded stream banks and turf reinforcement mats).

For BMPs that are not to remain in place as a part of final stabilization such as silt fence and other temporary measures, BMPs should be removed when all land disturbing activities have ceased and areas have been permanently stabilized.

Wind Erosion/Dust Control (DC) EC-14

Description

Wind erosion and dust control BMPs help to keep soil particles from entering the air as a result of land disturbing construction activities. These BMPs include a variety of practices generally focused on either graded disturbed areas or construction roadways. For graded areas, practices such as seeding and mulching, use of soil binders, site watering, or other practices that provide prompt surface cover should be used. For construction roadways, road watering and stabilized surfaces should be considered.

Photograph DC-1. Water truck used for dust suppression. Photo courtesy of Douglas County.

Appropriate Uses

Dust control measures should be used on any site where dust poses a problem to air quality. Dust control is important to control for the health of construction workers and surrounding waterbodies.

Design and Installation

The following construction BMPs can be used for dust control:

- An irrigation/sprinkler system can be used to wet the top layer of disturbed soil to help keep dry soil particles from becoming airborne.
- Seeding and mulching can be used to stabilize disturbed surfaces and reduce dust emissions.
- Protecting existing vegetation can help to slow wind velocities across the ground surface, thereby limiting the likelihood of soil particles to become airborne.
- Spray-on soil binders form a bond between soil particles keeping them grounded. Chemical treatments may require additional permitting requirements. Potential impacts to surrounding waterways and habitat must be considered prior to use.
- Placing rock on construction roadways and entrances will help keep dust to a minimum across the construction site.
- Wind fences can be installed on site to reduce wind speeds. Install fences perpendicular to the prevailing wind direction for maximum effectiveness.

Wind Erosion Control/ Dust Control	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	Moderate

Maintenance and Removal

When using an irrigation/sprinkler control system to aid in dust control, be careful not to overwater. Overwatering will cause construction vehicles to track mud off-site.

Concrete Washout Area (CWA) MM-1

Description

Concrete waste management involves designating and properly managing a specific area of the construction site as a concrete washout area. A concrete washout area can be created using one of several approaches designed to receive wash water from washing of tools and concrete mixer chutes, liquid concrete waste from dump trucks, mobile batch mixers, or pump trucks. Three basic approaches are available: excavation of a pit in the ground, use of an above ground storage area, or use of prefabricated haul-away concrete washout containers. Surface discharges of concrete washout water from construction sites are prohibited.

Photograph CWA-1. Example of concrete washout area. Note gravel tracking pad for access and sign.

Appropriate Uses

Concrete washout areas must be designated on all sites that will generate concrete wash water or liquid concrete waste from onsite concrete mixing or concrete delivery.

Because pH is a pollutant of concern for washout activities, when unlined pits are used for concrete washout, the soil must have adequate buffering capacity to result in protection of state groundwater standards; otherwise, a liner/containment must be used. The following management practices are recommended to prevent an impact from unlined pits to groundwater:

- The use of the washout site should be temporary (less than 1 year), and
- The washout site should be not be located in an area where shallow groundwater may be present, such as near natural drainages, springs, or wetlands.

Design and Installation

Concrete washout activities must be conducted in a manner that does not contribute pollutants to surface waters or stormwater runoff. Concrete washout areas may be lined or unlined excavated pits in the ground, commercially manufactured prefabricated washout containers, or aboveground holding areas constructed of berms, sandbags or straw bales with a plastic liner.

Although unlined washout areas may be used, lined pits may be required to protect groundwater under certain conditions.

Do not locate an unlined washout area within 400 feet of any natural drainage pathway or waterbody or within 1,000 feet of any wells or drinking water sources. Even for lined concrete washouts, it is advisable to locate the facility away from waterbodies and drainage paths. If site constraints make these

Concrete Washout Area	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

setbacks infeasible or if highly permeable soils exist in the area, then the pit must be installed with an impermeable liner (16 mil minimum thickness) or surface storage alternatives using prefabricated concrete washout devices or a lined aboveground storage area should be used.

Design details with notes are provided in Detail CWA-1 for pits and CWA-2 for aboveground storage areas. Pre-fabricated concrete washout container information can be obtained from vendors.

Maintenance and Removal

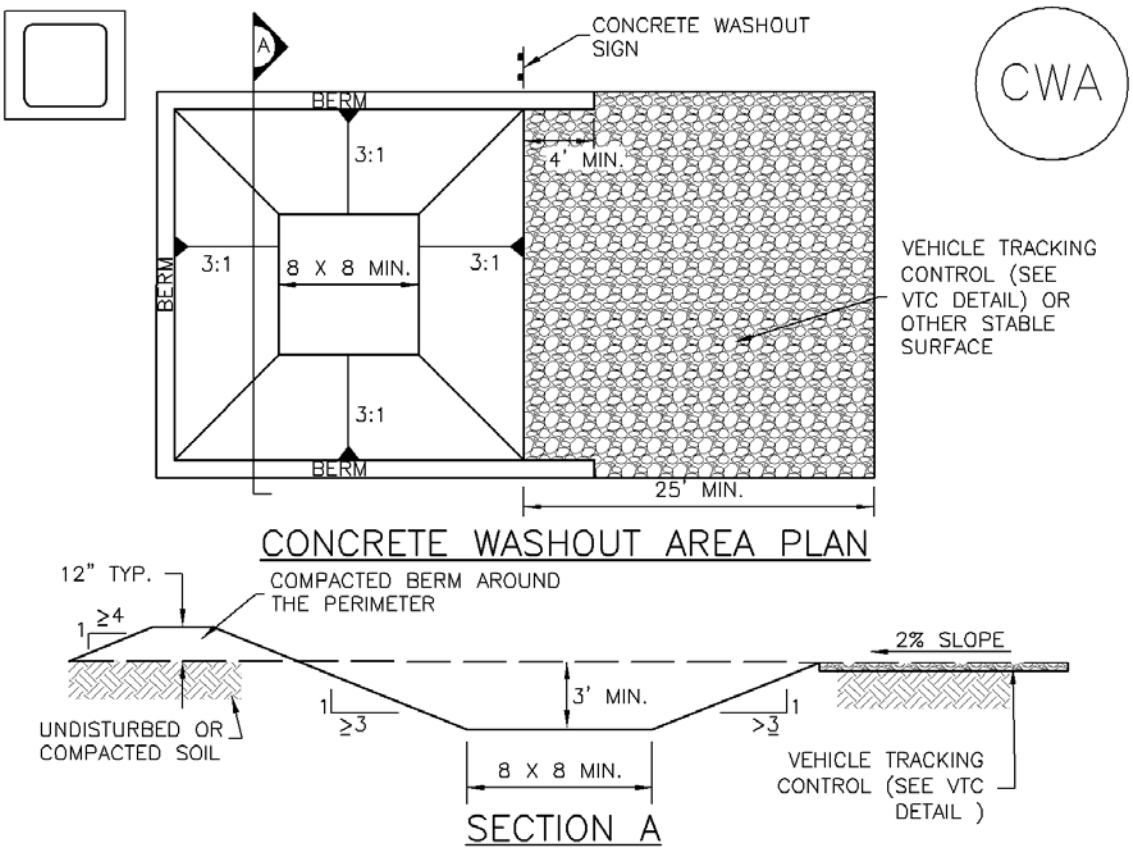
A key consideration for concrete washout areas is to ensure that adequate signage is in place identifying the location of the washout area. Part of inspecting and maintaining washout areas is ensuring that adequate signage is provided and in good repair and that the washout area is being used, as opposed to washout in non-designated areas of the site.

Remove concrete waste in the washout area, as needed to maintain BMP function (typically when filled to about two-thirds of its capacity). Collect concrete waste and deliver offsite to a designated disposal location.

Upon termination of use of the washout site, accumulated solid waste, including concrete waste and any contaminated soils, must be removed from the site to prevent on-site disposal of solid waste. If the wash water is allowed to evaporate and the concrete hardens, it may be recycled.

Photograph CWA-2. Prefabricated concrete washout. Photo courtesy of CDOT.

Photograph CWA-3. Earthen concrete washout. Photo courtesy of CDOT.



CWA–1. CONCRETE WASHOUT AREA

CWA INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –CWA INSTALLATION LOCATION.

2. DO NOT LOCATE AN UNLINED CWA WITHIN 400' OF ANY NATURAL DRAINAGE PATHWAY OR WATERBODY. DO NOT LOCATE WITHIN 1,000' OF ANY WELLS OR DRINKING WATER SOURCES. IF SITE CONSTRAINTS MAKE THIS INFEASIBLE, OR IF HIGHLY PERMEABLE SOILS EXIST ON SITE, THE CWA MUST BE INSTALLED WITH AN IMPERMEABLE LINER (16 MIL MIN. THICKNESS) OR SURFACE STORAGE ALTERNATIVES USING PREFABRICATED CONCRETE WASHOUT DEVICES OR A LINED ABOVE GROUND STORAGE ARE SHOULD BE USED.

3. THE CWA SHALL BE INSTALLED PRIOR TO CONCRETE PLACEMENT ON SITE.

4. CWA SHALL INCLUDE A FLAT SUBSURFACE PIT THAT IS AT LEAST 8' BY 8' SLOPES LEADING OUT OF THE SUBSURFACE PIT SHALL BE 3:1 OR FLATTER. THE PIT SHALL BE AT LEAST 3' DEEP.

5. BERM SURROUNDING SIDES AND BACK OF THE CWA SHALL HAVE MINIMUM HEIGHT OF 1'.

6. VEHICLE TRACKING PAD SHALL BE SLOPED 2% TOWARDS THE CWA.

7. SIGNS SHALL BE PLACED AT THE CONSTRUCTION ENTRANCE, AT THE CWA, AND ELSEWHERE AS NECESSARY TO CLEARLY INDICATE THE LOCATION OF THE CWA TO OPERATORS OF CONCRETE TRUCKS AND PUMP RIGS.

8. USE EXCAVATED MATERIAL FOR PERIMETER BERM CONSTRUCTION.

CWA MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. THE CWA SHALL BE REPAIRED, CLEANED, OR ENLARGED AS NECESSARY TO MAINTAIN CAPACITY FOR CONCRETE WASTE. CONCRETE MATERIALS, ACCUMULATED IN PIT, SHALL BE REMOVED ONCE THE MATERIALS HAVE REACHED A DEPTH OF 2'.

5. CONCRETE WASHOUT WATER, WASTED PIECES OF CONCRETE AND ALL OTHER DEBRIS IN THE SUBSURFACE PIT SHALL BE TRANSPORTED FROM THE JOB SITE IN A WATER–TIGHT CONTAINER AND DISPOSED OF PROPERLY.

6. THE CWA SHALL REMAIN IN PLACE UNTIL ALL CONCRETE FOR THE PROJECT IS PLACED.

7. WHEN THE CWA IS REMOVED, COVER THE DISTURBED AREA WITH TOP SOIL, SEED AND MULCH OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND THE CITY OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD).

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Stockpile Management (SP) MM-2

Description

Stockpile management includes measures to minimize erosion and sediment transport from soil stockpiles.

Appropriate Uses

Stockpile management should be used when soils or other erodible materials are stored at the construction site. Special attention should be given to stockpiles in close proximity to natural or manmade storm systems.

Photograph SP-1. A topsoil stockpile that has been partially revegetated and is protected by silt fence perimeter control.

Design and Installation

Locate stockpiles away from all drainage system components including storm sewer inlets. Where practical, choose stockpile locations that that will remain undisturbed for the longest period of time as the phases of construction progress. Place sediment control BMPs around the perimeter of the stockpile, such as sediment control logs, rock socks, silt fence, straw bales and sand bags. See Detail SP-1 for guidance on proper establishment of perimeter controls around a stockpile. For stockpiles in active use, provide a stabilized designated access point on the upgradient side of the stockpile.

Stabilize the stockpile surface with surface roughening, temporary seeding and mulching, erosion control blankets, or soil binders. Soils stockpiled for an extended period (typically for more than 60 days) should be seeded and mulched with a temporary grass cover once the stockpile is placed (typically within 14 days). Use of mulch only or a soil binder is acceptable if the stockpile will be in place for a more limited time period (typically 30-60 days). Timeframes for stabilization of stockpiles noted in this fact sheet are "typical" guidelines. Check permit requirements for specific federal, state, and/or local requirements that may be more prescriptive.

Stockpiles should not be placed in streets or paved areas unless no other practical alternative exists. See the Stabilized Staging Area Fact Sheet for guidance when staging in roadways is unavoidable due to space or right-of-way constraints. For paved areas, rock socks must be used for perimeter control and all inlets with the potential to receive sediment from the stockpile (even from vehicle tracking) must be protected.

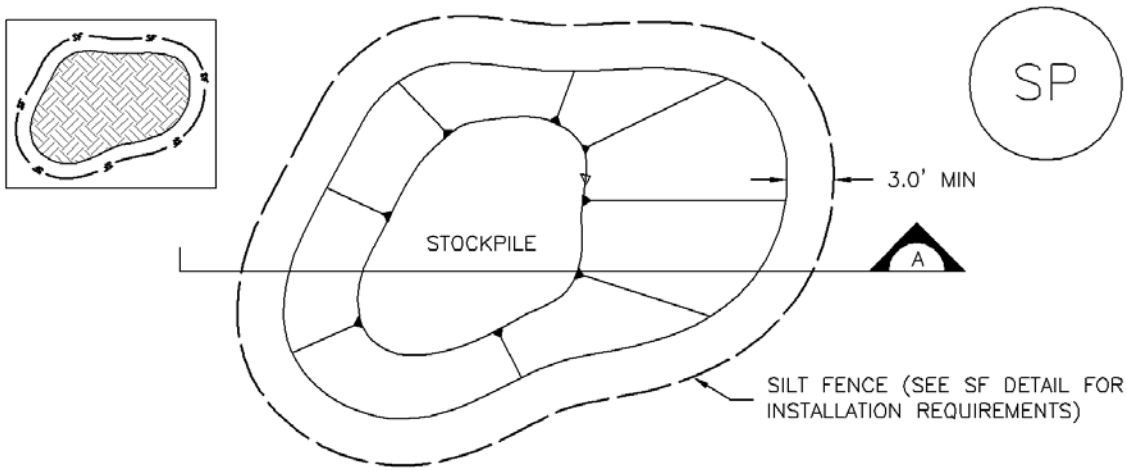
Maintenance and Removal

Inspect perimeter controls and inlet protection in accordance with their respective BMP Fact Sheets. Where seeding, mulch and/or soil binders are used, reseeding or reapplication of soil binder may be necessary.

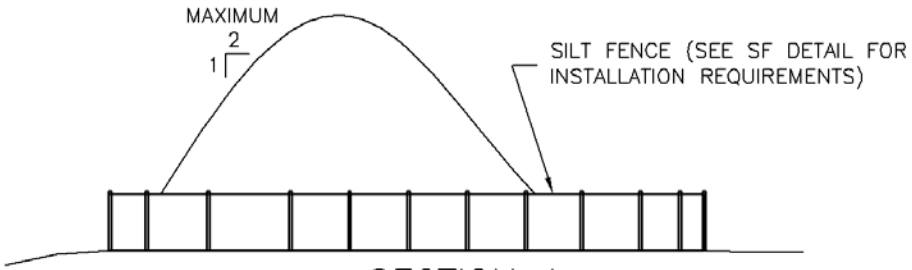
When temporary removal of a perimeter BMP is necessary to access a stockpile, ensure BMPs are reinstalled in accordance with their respective design detail section.

Stockpile Management	
Functions	
Erosion Control	Yes
Sediment Control	Yes
Site/Material Management	Yes

When the stockpile is no longer needed, properly dispose of excess materials and revegetate or otherwise stabilize the ground surface where the stockpile was located.



STOCKPILE PROTECTION PLAN



SECTION A

SP–1. STOCKPILE PROTECTION

STOCKPILE PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF STOCKPILES.
   –TYPE OF STOCKPILE PROTECTION.

2. INSTALL PERIMETER CONTROLS IN ACCORDANCE WITH THEIR RESPECTIVE DESIGN DETAILS. SILT FENCE IS SHOWN IN THE STOCKPILE PROTECTION DETAILS; HOWEVER, OTHER TYPES OF PERIMETER CONTROLS INCLUDING SEDIMENT CONTROL LOGS OR ROCK SOCKS MAY BE SUITABLE IN SOME CIRCUMSTANCES. CONSIDERATIONS FOR DETERMINING THE APPROPRIATE TYPE OF PERIMETER CONTROL FOR A STOCKPILE INCLUDE WHETHER THE STOCKPILE IS LOCATED ON A PERVIOUS OR IMPERVIOUS SURFACE, THE RELATIVE HEIGHTS OF THE PERIMETER CONTROL AND STOCKPILE, THE ABILITY OF THE PERIMETER CONTROL TO CONTAIN THE STOCKPILE WITHOUT FAILING IN THE EVENT THAT MATERIAL FROM THE STOCKPILE SHIFTS OR SLUMPS AGAINST THE PERIMETER, AND OTHER FACTORS.

3. STABILIZE THE STOCKPILE SURFACE WITH SURFACE ROUGHENING, TEMPORARY SEEDING AND MULCHING, EROSION CONTROL BLANKETS, OR SOIL BINDERS. SOILS STOCKPILED FOR AN EXTENDED PERIOD (TYPICALLY FOR MORE THAN 60 DAYS) SHOULD BE SEEDED AND MULCHED WITH A TEMPORARY GRASS COVER ONCE THE STOCKPILE IS PLACED (TYPICALLY WITHIN 14 DAYS). USE OF MULCH ONLY OR A SOIL BINDER IS ACCEPTABLE IF THE STOCKPILE WILL BE IN PLACE FOR A MORE LIMITED TIME PERIOD (TYPICALLY 30–60 DAYS).

4. FOR TEMPORARY STOCKPILES ON THE INTERIOR PORTION OF A CONSTRUCTION SITE, WHERE OTHER DOWNGRADIENT CONTROLS, INCLUDING PERIMETER CONTROL, ARE IN PLACE, STOCKPILE PERIMETER CONTROLS MAY NOT BE REQUIRED.

STOCKPILE PROTECTION MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

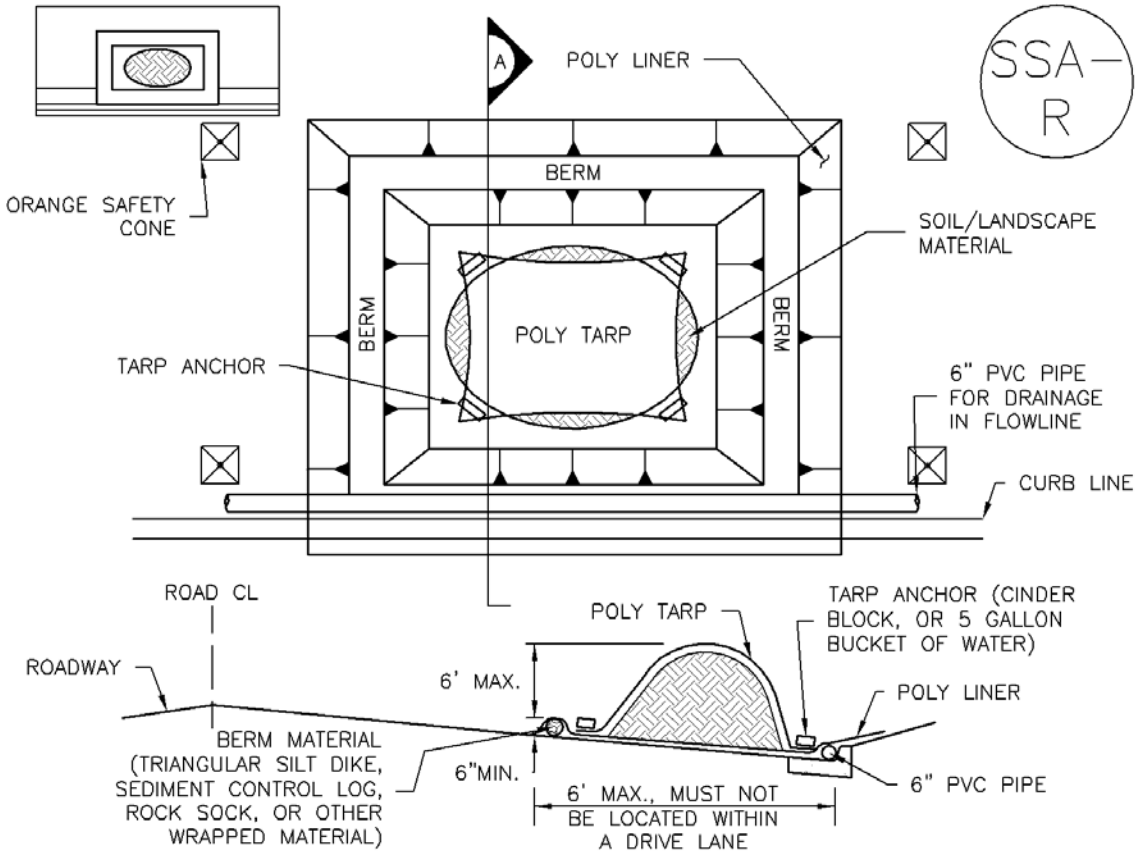
STOCKPILE PROTECTION MAINTENANCE NOTES

4. IF PERIMETER PROTECTION MUST BE MOVED TO ACCESS SOIL STOCKPILE, REPLACE PERIMETER CONTROLS BY THE END OF THE WORKDAY.

5. STOCKPILE PERIMETER CONTROLS CAN BE REMOVED ONCE ALL THE MATERIAL FROM THE STOCKPILE HAS BEEN USED.

(DETAILS ADAPTED FROM PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.



SP–2. MATERIALS STAGING IN ROADWAY

MATERIALS STAGING IN ROADWAYS INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   –LOCATION OF MATERIAL STAGING AREA(S).
   –CONTRACTOR MAY ADJUST LOCATION AND SIZE OF STAGING AREA WITH APPROVAL FROM THE LOCAL JURISDICTION.

2. FEATURE MUST BE INSTALLED PRIOR TO EXCAVATION, EARTHWORK OR DELIVERY OF MATERIALS.

3. MATERIALS MUST BE STATIONED ON THE POLY LINER. ANY INCIDENTAL MATERIALS DEPOSITED ON PAVED SECTION OR ALONG CURB LINE MUST BE CLEANED UP PROMPTLY.

4. POLY LINER AND TARP COVER SHOULD BE OF SIGNIFICANT THICKNESS TO PREVENT DAMAGE OR LOSS OF INTEGRITY.

5. SAND BAGS MAY BE SUBSTITUTED TO ANCHOR THE COVER TARP OR PROVIDE BERMING UNDER THE BASE LINER.

6. FEATURE IS NOT INTENDED FOR USE WITH WET MATERIAL THAT WILL BE DRAINING AND/OR SPREADING OUT ON THE POLY LINER OR FOR DEMOLITION MATERIALS.

7. THIS FEATURE CAN BE USED FOR:
   –UTILITY REPAIRS.
   –WHEN OTHER STAGING LOCATIONS AND OPTIONS ARE LIMITED.
   –OTHER LIMITED APPLICATION AND SHORT DURATION STAGING.

MATERIALS STAGING IN ROADWAY MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. INSPECT PVC PIPE ALONG CURB LINE FOR CLOGGING AND DEBRIS. REMOVE OBSTRUCTIONS PROMPTLY.

5. CLEAN MATERIAL FROM PAVED SURFACES BY SWEEPING OR VACUUMING.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM AURORA, COLORADO)

Good Housekeeping Practices (GH) MM-3

Description

Implement construction site good housekeeping practices to prevent pollution associated with solid, liquid and hazardous construction-related materials and wastes. Stormwater Management Plans (SWMPs) should clearly specify BMPs including these good housekeeping practices:

- Provide for waste management.
- Establish proper building material staging areas.
- Designate paint and concrete washout areas.
- Establish proper equipment/vehicle fueling and maintenance practices.
- Control equipment/vehicle washing and allowable non-stormwater discharges.
- Develop a spill prevention and response plan.

Acknowledgement: This Fact Sheet is based directly on EPA guidance provided in *Developing Your Stormwater Pollution Prevent Plan* (EPA 2007).

Photographs GH-1 and GH-2. Proper materials storage and secondary containment for fuel tanks are important good housekeeping practices. Photos courtesy of CDOT and City of Aurora.

Appropriate Uses

Good housekeeping practices are necessary at all construction sites.

Design and Installation

The following principles and actions should be addressed in SWMPs:

- **Provide for Waste Management.** Implement management procedures and practices to prevent or reduce the exposure and transport of pollutants in stormwater from solid, liquid and sanitary wastes that will be generated at the site. Practices such as trash disposal, recycling, proper material handling, and cleanup measures can reduce the potential for stormwater runoff to pick up construction site wastes and discharge them to surface waters. Implement a comprehensive set of waste-management practices for hazardous or toxic materials, such as paints, solvents, petroleum products, pesticides, wood preservatives, acids, roofing tar, and other materials. Practices should include storage, handling, inventory, and cleanup procedures, in case of spills. Specific practices that should be considered include:

  Solid or Construction Waste

  - Designate trash and bulk waste-collection areas on-site.

Good Housekeeping	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

- Recycle materials whenever possible (e.g., paper, wood, concrete, oil).
- Segregate and provide proper disposal options for hazardous material wastes.
- Clean up litter and debris from the construction site daily.
- Locate waste-collection areas away from streets, gutters, watercourses, and storm drains. Waste-collection areas (dumpsters, and such) are often best located near construction site entrances to minimize traffic on disturbed soils. Consider secondary containment around waste collection areas to minimize the likelihood of contaminated discharges.
- Empty waste containers before they are full and overflowing.

Sanitary and Septic Waste

- Provide convenient, well-maintained, and properly located toilet facilities on-site.
- Locate toilet facilities away from storm drain inlets and waterways to prevent accidental spills and contamination of stormwater.
- Maintain clean restroom facilities and empty portable toilets regularly.
- Where possible, provide secondary containment pans under portable toilets.
- Provide tie-downs or stake-downs for portable toilets.
- Educate employees, subcontractors, and suppliers on locations of facilities.
- Treat or dispose of sanitary and septic waste in accordance with state or local regulations. Do not discharge or bury wastewater at the construction site.
- Inspect facilities for leaks. If found, repair or replace immediately.
- Special care is necessary during maintenance (pump out) to ensure that waste and/or biocide are not spilled on the ground.

Hazardous Materials and Wastes

- Develop and implement employee and subcontractor education, as needed, on hazardous and toxic waste handling, storage, disposal, and cleanup.
- Designate hazardous waste-collection areas on-site.
- Place all hazardous and toxic material wastes in secondary containment.

Photograph GH-3. Locate portable toilet facilities on level surfaces away from waterways and storm drains. Photo courtesy of WWE.

- Hazardous waste containers should be inspected to ensure that all containers are labeled properly and that no leaks are present.

- **Establish Proper Building Material Handling and Staging Areas**. The SWMP should include comprehensive handling and management procedures for building materials, especially those that are hazardous or toxic. Paints, solvents, pesticides, fuels and oils, other hazardous materials or building materials that have the potential to contaminate stormwater should be stored indoors or under cover whenever possible or in areas with secondary containment. Secondary containment measures prevent a spill from spreading across the site and may include dikes, berms, curbing, or other containment methods. Secondary containment techniques should also ensure the protection of groundwater. Designate staging areas for activities such as fueling vehicles, mixing paints, plaster, mortar, and other potential pollutants. Designated staging areas enable easier monitoring of the use of materials and clean up of spills. Training employees and subcontractors is essential to the success of this pollution prevention principle. Consider the following specific materials handling and staging practices:

  - Train employees and subcontractors in proper handling and storage practices.

  - Clearly designate site areas for staging and storage with signs and on construction drawings. Staging areas should be located in areas central to the construction site. Segment the staging area into sub-areas designated for vehicles, equipment, or stockpiles. Construction entrances and exits should be clearly marked so that delivery vehicles enter/exit through stabilized areas with vehicle tracking controls (See Vehicle Tracking Control Fact Sheet).

  - Provide storage in accordance with Spill Protection, Control and Countermeasures (SPCC) requirements and plans and provide cover and impermeable perimeter control, as necessary, for hazardous materials and contaminated soils that must be stored on site.

  - Ensure that storage containers are regularly inspected for leaks, corrosion, support or foundation failure, or other signs of deterioration and tested for soundness.

  - Reuse and recycle construction materials when possible.

- **Designate Concrete Washout Areas**. Concrete contractors should be encouraged to use the washout facilities at their own plants or dispatch facilities when feasible; however, concrete washout commonly occurs on construction sites. If it is necessary to provide for concrete washout areas on-site, designate specific washout areas and design facilities to handle anticipated washout water. Washout areas should also be provided for paint and stucco operations. Because washout areas can be a source of pollutants from leaks or spills, care must be taken with regard to their placement and proper use. See the Concrete Washout Area Fact Sheet for detailed guidance.

  Both self-constructed and prefabricated washout containers can fill up quickly when concrete, paint, and stucco work are occurring on large portions of the site. Be sure to check for evidence that contractors are using the washout areas and not dumping materials onto the ground or into drainage facilities. If the washout areas are not being used regularly, consider posting additional signage, relocating the facilities to more convenient locations, or providing training to workers and contractors.

  When concrete, paint, or stucco is part of the construction process, consider these practices which will help prevent contamination of stormwater. Include the locations of these areas and the maintenance and inspection procedures in the SWMP.

- Do not washout concrete trucks or equipment into storm drains, streets, gutters, uncontained areas, or streams. Only use designated washout areas.

- Establish washout areas and advertise their locations with signs. Ensure that signage remains in good repair.

- Provide adequate containment for the amount of wash water that will be used.

- Inspect washout structures daily to detect leaks or tears and to identify when materials need to be removed.

- Dispose of materials properly. The preferred method is to allow the water to evaporate and to recycle the hardened concrete. Full service companies may provide dewatering services and should dispose of wastewater properly. Concrete wash water can be highly polluted. It should not be discharged to any surface water, storm sewer system, or allowed to infiltrate into the ground in the vicinity of waterbodies. Washwater should not be discharged to a sanitary sewer system without first receiving written permission from the system operator.

- **Establish Proper Equipment/Vehicle Fueling and Maintenance Practices**. Create a clearly designated on-site fueling and maintenance area that is clean and dry. The on-site fueling area should have a spill kit, and staff should know how to use it. If possible, conduct vehicle fueling and maintenance activities in a covered area. Consider the following practices to help prevent the discharge of pollutants to stormwater from equipment/vehicle fueling and maintenance. Include the locations of designated fueling and maintenance areas and inspection and maintenance procedures in the SWMP.

  - Train employees and subcontractors in proper fueling procedures (stay with vehicles during fueling, proper use of pumps, emergency shutoff valves, etc.).

  - Inspect on-site vehicles and equipment regularly for leaks, equipment damage, and other service problems.

  - Clearly designate vehicle/equipment service areas away from drainage facilities and watercourses to prevent stormwater run-on and runoff.

  - Use drip pans, drip cloths, or absorbent pads when replacing spent fluids.

  - Collect all spent fluids, store in appropriate labeled containers in the proper storage areas, and recycle fluids whenever possible.

- **Control Equipment/Vehicle Washing and Allowable Non-Stormwater Discharges.** Implement practices to prevent contamination of surface and groundwater from equipment and vehicle wash water. Representative practices include:

  - Educate employees and subcontractors on proper washing procedures.

  - Use off-site washing facilities, when available.

  - Clearly mark the washing areas and inform workers that all washing must occur in this area.

  - Contain wash water and treat it using BMPs. Infiltrate washwater when possible, but maintain separation from drainage paths and waterbodies.

- Use high-pressure water spray at vehicle washing facilities without detergents. Water alone can remove most dirt adequately.

- Do not conduct other activities, such as vehicle repairs, in the wash area.

- Include the location of the washing facilities and the inspection and maintenance procedures in the SWMP.

- **Develop a Spill Prevention and Response Plan.** Spill prevention and response procedures must be identified in the SWMP. Representative procedures include identifying ways to reduce the chance of spills, stop the source of spills, contain and clean up spills, dispose of materials contaminated by spills, and train personnel responsible for spill prevention and response. The plan should also specify material handling procedures and storage requirements and ensure that clear and concise spill cleanup procedures are provided and posted for areas in which spills may potentially occur. When developing a spill prevention plan, include the following:

  - Note the locations of chemical storage areas, storm drains, tributary drainage areas, surface waterbodies on or near the site, and measures to stop spills from leaving the site.

  - Provide proper handling and safety procedures for each type of waste. Keep Material Safety Data Sheets (MSDSs) for chemical used on site with the SWMP.

  - Establish an education program for employees and subcontractors on the potential hazards to humans and the environment from spills and leaks.

  - Specify how to notify appropriate authorities, such as police and fire departments, hospitals, or municipal sewage treatment facilities to request assistance. Emergency procedures and contact numbers should be provided in the SWMP and posted at storage locations.

  - Describe the procedures, equipment and materials for immediate cleanup of spills and proper disposal.

  - Identify personnel responsible for implementing the plan in the event of a spill. Update the spill prevention plan and clean up materials as changes occur to the types of chemicals stored and used at the facility.

Spill Prevention, Control, and Countermeasure (SPCC) Plan

Construction sites may be subject to 40 CFR Part 112 regulations that require the preparation and implementation of a SPCC Plan to prevent oil spills from aboveground and underground storage tanks. The facility is subject to this rule if it is a non-transportation-related facility that:

- Has a total storage capacity greater than 1,320 gallons or a completely buried storage capacity greater than 42,000 gallons.
- Could reasonably be expected to discharge oil in quantities that may be harmful to navigable waters of the United States and adjoining shorelines.

Furthermore, if the facility is subject to 40 CFR Part 112, the SWMP should reference the SPCC Plan. To find out more about SPCC Plans, see EPA's website on SPPC at www.epa.gov/oilspill/spcc.htm.

Reporting Oil Spills

In the event of an oil spill, contact the National Response Center toll free at 1-800-424- 8802 for assistance, or for more details, visit their website: www.nrc.uscg.mil.

Maintenance and Removal

Effective implementation of good housekeeping practices is dependent on clear designation of personnel responsible for supervising and implementing good housekeeping programs, such as site cleanup and disposal of trash and debris, hazardous material management and disposal, vehicle and equipment maintenance, and other practices. Emergency response "drills" may aid in emergency preparedness.

Checklists may be helpful in good housekeeping efforts.

Staging and storage areas require permanent stabilization when the areas are no longer being used for construction-related activities.

Construction-related materials, debris and waste must be removed from the construction site once construction is complete.

Design Details

See the following Fact Sheets for related Design Details:

MM-1 Concrete Washout Area

MM-2 Stockpile Management

SM-4 Vehicle Tracking Control

Design details are not necessary for other good housekeeping practices; however, be sure to designate where specific practices will occur on the appropriate construction drawings.

Silt Fence (SF) SC-1

Description

A silt fence is a woven geotextile fabric attached to wooden posts and trenched into the ground. It is designed as a sediment barrier to intercept sheet flow runoff from disturbed areas.

Photograph SF-1. Silt fence creates a sediment barrier, forcing sheet flow runoff to evaporate or infiltrate.

Appropriate Uses

A silt fence can be used where runoff is conveyed from a disturbed area as sheet flow. Silt fence is not designed to receive concentrated flow or to be used as a filter fabric. Typical uses include:

- Down slope of a disturbed area to accept sheet flow.
- Along the perimeter of a receiving water such as a stream, pond or wetland.
- At the perimeter of a construction site.

Design and Installation

Silt fence should be installed along the contour of slopes so that it intercepts sheet flow. The maximum recommended tributary drainage area per 100 lineal feet of silt fence, installed along the contour, is approximately 0.25 acres with a disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1. Longer and steeper slopes require additional measures. This recommendation only applies to silt fence installed along the contour. Silt fence installed for other uses, such as perimeter control, should be installed in a way that will not produce concentrated flows. For example, a "J-hook" installation may be appropriate to force runoff to pond and evaporate or infiltrate in multiple areas rather than concentrate and cause erosive conditions parallel to the silt fence.

See Detail SF-1 for proper silt fence installation, which involves proper trenching, staking, securing the fabric to the stakes, and backfilling the silt fence. Properly installed silt fence should not be easily pulled out by hand and there should be no gaps between the ground and the fabric.

Silt fence must meet the minimum allowable strength requirements, depth of installation requirement, and other specifications in the design details. Improper installation of silt fence is a common reason for silt fence failure; however, when properly installed and used for the appropriate purposes, it can be highly effective.

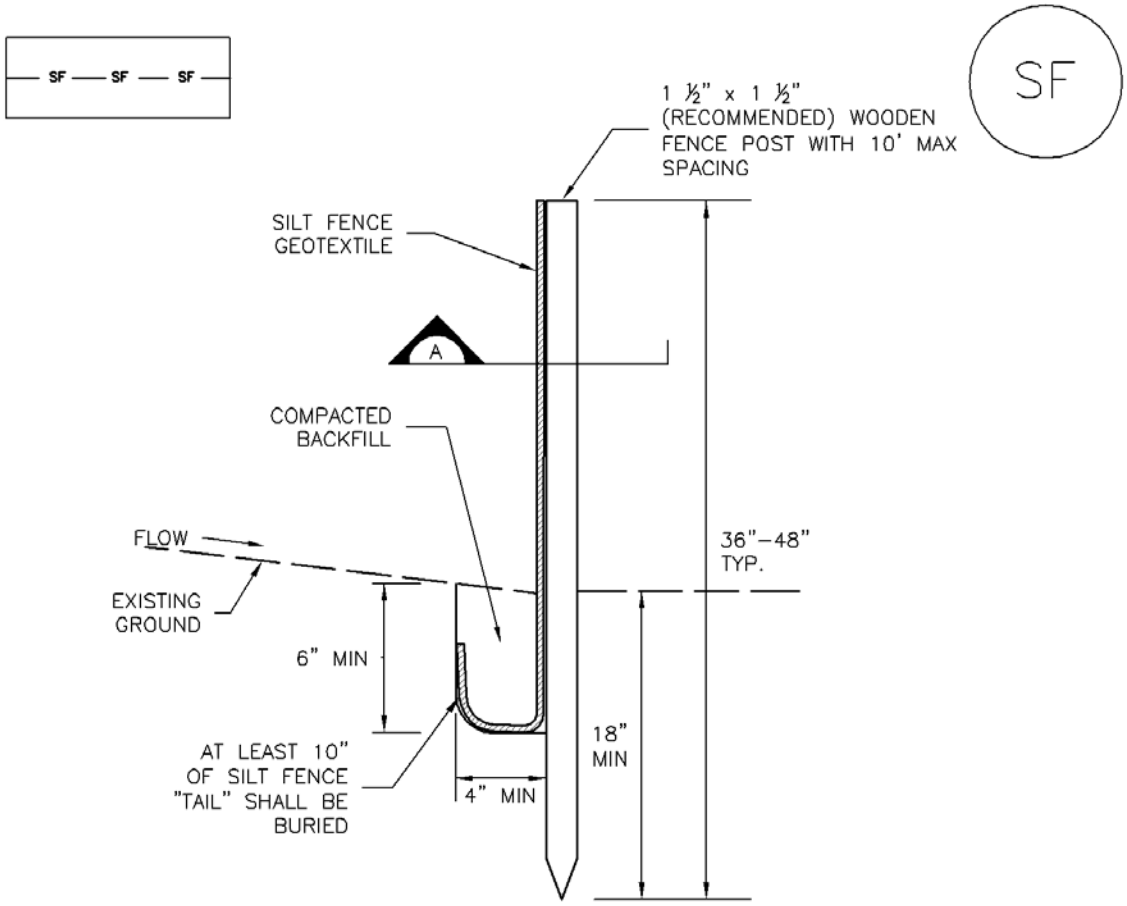
Silt Fence	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No

Maintenance and Removal

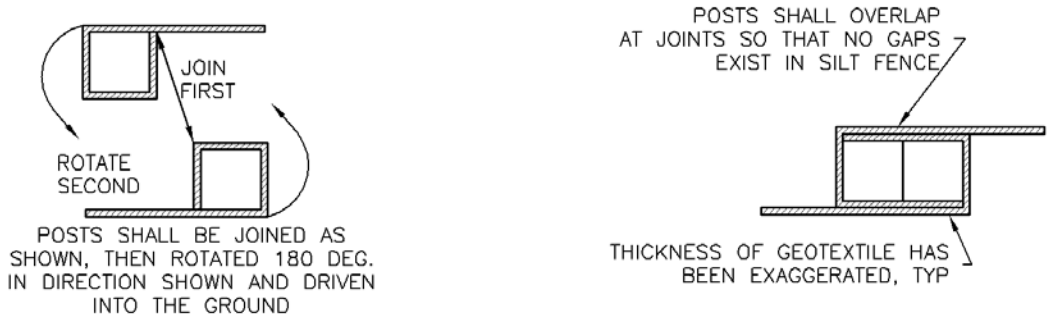
Inspection of silt fence includes observing the material for tears or holes and checking for slumping fence and undercut areas bypassing flows. Repair of silt fence typically involves replacing the damaged section with a new section. Sediment accumulated behind silt fence should be removed, as needed to maintain BMP effectiveness, typically before it reaches a depth of 6 inches.

Silt fence may be removed when the upstream area has reached final stabilization.

Photograph SF-2. When silt fence is not installed along the contour, a "J-hook" installation may be appropriate to ensure that the BMP does not create concentrated flow parallel to the silt fence. Photo courtesy of Tom Gore.



SILT FENCE



SECTION A

SF–1. SILT FENCE

SILT FENCE INSTALLATION NOTES

1. SILT FENCE MUST BE PLACED AWAY FROM THE TOE OF THE SLOPE TO ALLOW FOR WATER PONDING. SILT FENCE AT THE TOE OF A SLOPE SHOULD BE INSTALLED IN A FLAT LOCATION AT LEAST SEVERAL FEET (2–5 FT) FROM THE TOE OF THE SLOPE TO ALLOW ROOM FOR PONDING AND DEPOSITION.

2. A UNIFORM 6" X 4" ANCHOR TRENCH SHALL BE EXCAVATED USING TRENCHER OR SILT FENCE INSTALLATION DEVICE. NO ROAD GRADERS, BACKHOES, OR SIMILAR EQUIPMENT SHALL BE USED.

3. COMPACT ANCHOR TRENCH BY HAND WITH A "JUMPING JACK" OR BY WHEEL ROLLING. COMPACTION SHALL BE SUCH THAT SILT FENCE RESISTS BEING PULLED OUT OF ANCHOR TRENCH BY HAND.

4. SILT FENCE SHALL BE PULLED TIGHT AS IT IS ANCHORED TO THE STAKES. THERE SHOULD BE NO NOTICEABLE SAG BETWEEN STAKES AFTER IT HAS BEEN ANCHORED TO THE STAKES.

5. SILT FENCE FABRIC SHALL BE ANCHORED TO THE STAKES USING 1" HEAVY DUTY STAPLES OR NAILS WITH 1" HEADS. STAPLES AND NAILS SHOULD BE PLACED 3" ALONG THE FABRIC DOWN THE STAKE.

6. AT THE END OF A RUN OF SILT FENCE ALONG A CONTOUR, THE SILT FENCE SHOULD BE TURNED PERPENDICULAR TO THE CONTOUR TO CREATE A "J–HOOK." THE "J–HOOK" EXTENDING PERPENDICULAR TO THE CONTOUR SHOULD BE OF SUFFICIENT LENGTH TO KEEP RUNOFF FROM FLOWING AROUND THE END OF THE SILT FENCE (TYPICALLY 10' – 20').

7. SILT FENCE SHALL BE INSTALLED PRIOR TO ANY LAND DISTURBING ACTIVITIES.

SILT FENCE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF THE SILT FENCE SHALL BE REMOVED AS NEEDED TO MAINTAIN THE FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY 6".

5. REPAIR OR REPLACE SILT FENCE WHEN THERE ARE SIGNS OF WEAR, SUCH AS SAGGING, TEARING, OR COLLAPSE.

6. SILT FENCE IS TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION, OR IS REPLACED BY AN EQUIVALENT PERIMETER SEDIMENT CONTROL BMP.

7. WHEN SILT FENCE IS REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO AND CITY OF AURORA, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

A sediment control log is a linear roll made of natural materials such as straw, coconut fiber, or compost. The most common type of sediment control log has straw filling and is often referred to as a "straw wattle." All sediment control logs are used as a sediment barrier to intercept sheet flow runoff from disturbed areas.

Photographs SCL-1 and SCL-2. Sediment control logs used as 1) a perimeter control around a soil stockpile; and, 2) as a "J-hook" perimeter control at the corner of a construction site.

Appropriate Uses

Sediment control logs can be used in the following applications to trap sediment:

- As perimeter control for stockpiles and the site.
- As part of inlet protection designs.
- As check dams in small drainage ditches. (Sediment control logs are not intended for use in channels with high flow velocities.)
- On disturbed slopes to shorten flow lengths (as an erosion control).
- As part of multi-layered perimeter control along a receiving water such as a stream, pond or wetland.

Sediment control logs work well in combination with other layers of erosion and sediment controls.

Design and Installation

Sediment control logs should be installed along the contour to avoid concentrating flows. The maximum allowable tributary drainage area per 100 lineal feet of sediment control log, installed along the contour, is approximately 0.25 acres with a disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1. Longer and steeper slopes require additional measures. This recommendation only applies to sediment control logs installed along the contour. When installed for other uses, such as perimeter control, it should be installed in a way that will not produce concentrated flows. For example, a "J-hook" installation may be appropriate to force runoff to pond and evaporate or infiltrate in multiple areas rather than concentrate and cause erosive conditions parallel to the BMP.

Sediment Control Log	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	No

Although sediment control logs initially allow runoff to flow through the BMP, they can quickly become a barrier and should be installed as if they are impermeable.

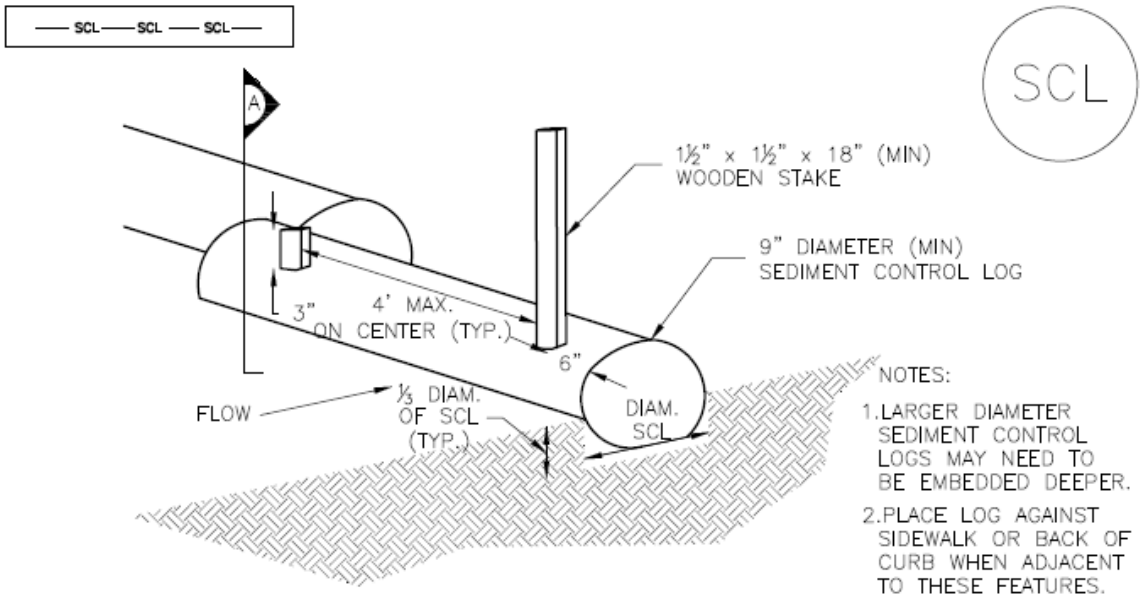
Design details and notes for sediment control logs are provided in the following details. Sediment logs must be properly installed per the detail to prevent undercutting, bypassing and displacement. When installed on slopes, sediment control logs should be installed along the contours (i.e., perpendicular to flow).

Improper installation can lead to poor performance. Be sure that sediment control logs are properly trenched (if lighter than 8 lb/foot), anchored and tightly jointed.

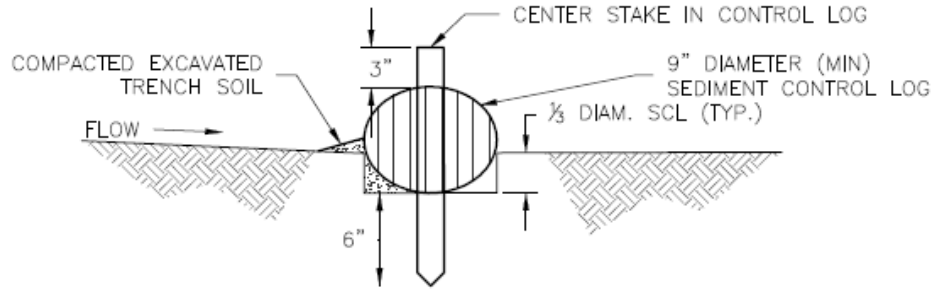
Maintenance and Removal

Be aware that sediment control logs will eventually degrade. Remove accumulated sediment before the depth is one-half the height of the sediment log and repair damage to the sediment log, typically by replacing the damaged section.

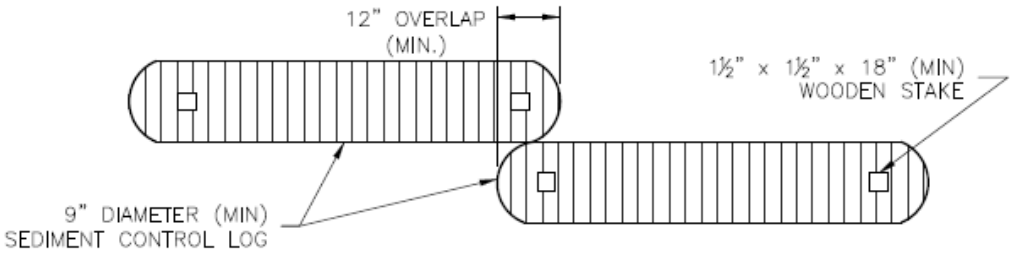
Once the upstream area is stabilized, remove and properly dispose of the logs. Areas disturbed beneath the logs may need to be seeded and mulched. Sediment control logs that are biodegradable may occasionally be left in place (e.g., when logs are used in conjunction with erosion control blankets as permanent slope breaks). However, removal of sediment control logs after final stabilization is typically appropriate when used in perimeter control, inlet protection and check dam applications. Compost from compost sediment control logs may be spread over the area and seeded as long as this does not cover newly established vegetation.



TRENCHED SEDIMENT CONTROL LOG

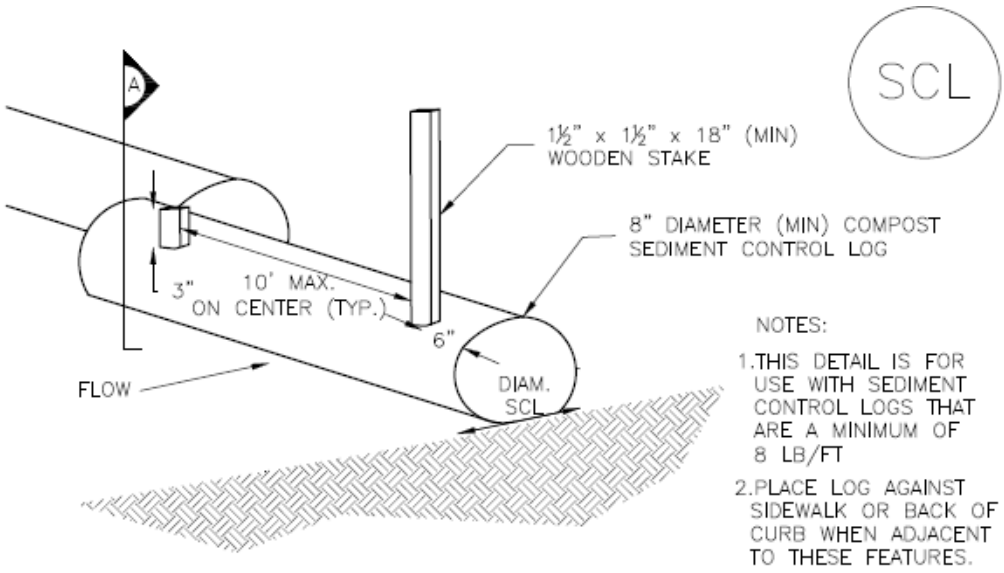


SECTION Ⓐ
TRENCHED SEDIMENT CONTROL LOG

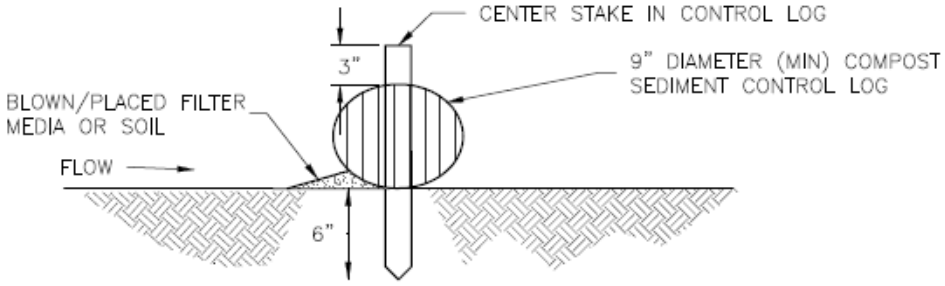


LOG JOINTS

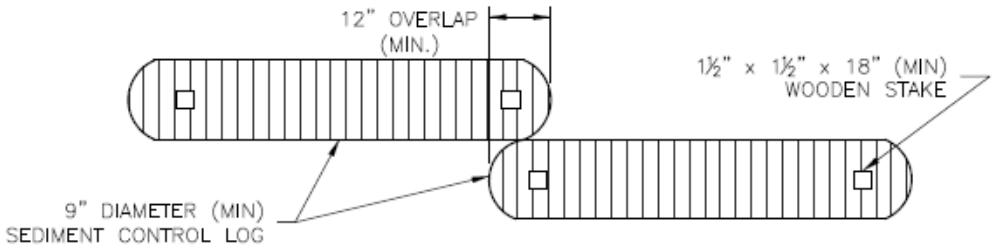
SCL–1. TRENCHED SEDIMENT CONTROL LOG



COMPOST SEDIMENT CONTROL LOG (WEIGHTED)

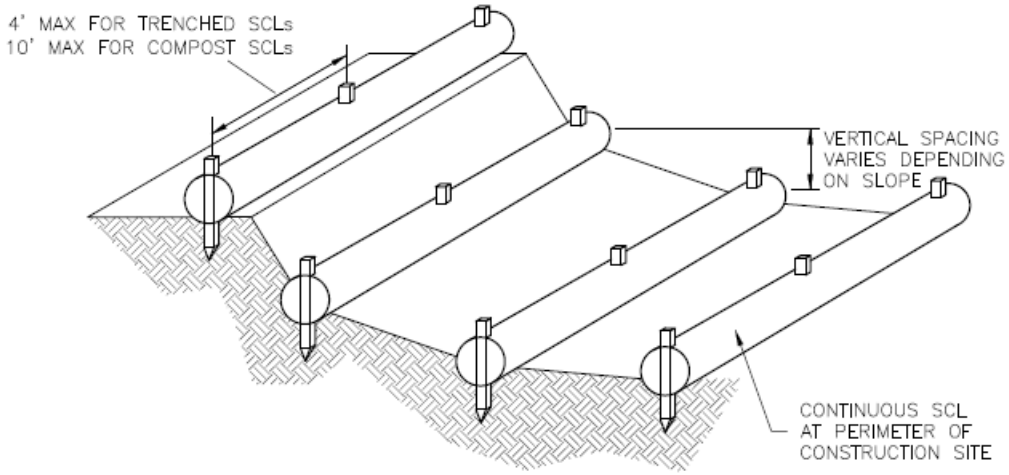


SECTION (A)
COMPOST SEDIMENT CONTROL LOG



LOG JOINTS

SCL–2. COMPOST SEDIMENT CONTROL LOG (WEIGHTED)



SCL–3. SEDIMENT CONTROL LOGS TO CONTROL SLOPE LENGTH

SEDIMENT CONTROL LOG INSTALLATION NOTES

1. SEE PLAN VIEW FOR LOCATION AND LENGTH OF SEDIMENT CONTROL LOGS.

2. SEDIMENT CONTROL LOGS THAT ACT AS A PERIMETER CONTROL SHALL BE INSTALLED PRIOR TO ANY UPGRADIENT LAND–DISTURBING ACTIVITIES.

3. SEDIMENT CONTROL LOGS SHALL CONSIST OF STRAW, COMPOST, EXCELSIOR OR COCONUT FIBER, AND SHALL BE FREE OF ANY NOXIOUS WEED SEEDS OR DEFECTS INCLUDING RIPS, HOLES AND OBVIOUS WEAR.

4. SEDIMENT CONTROL LOGS MAY BE USED AS SMALL CHECK DAMS IN DITCHES AND SWALES. HOWEVER, THEY SHOULD NOT BE USED IN PERENNIAL STREAMS.

5. IT IS RECOMMENDED THAT SEDIMENT CONTROL LOGS BE TRENCHED INTO THE GROUND TO A DEPTH OF APPROXIMATELY ⅓ OF THE DIAMETER OF THE LOG. IF TRENCHING TO THIS DEPTH IS NOT FEASIBLE AND/OR DESIRABLE (SHORT TERM INSTALLATION WITH DESIRE NOT TO DAMAGE LANDSCAPE) A LESSER TRENCHING DEPTH MAY BE ACCEPTABLE WITH MORE ROBUST STAKING. COMPOST LOGS THAT ARE 8 LB/FT DO NOT NEED TO BE TRENCHED.

6. THE UPHILL SIDE OF THE SEDIMENT CONTROL LOG SHALL BE BACKFILLED WITH SOIL OR FILTER MATERIAL THAT IS FREE OF ROCKS AND DEBRIS. THE SOIL SHALL BE TIGHTLY COMPACTED INTO THE SHAPE OF A RIGHT TRIANGLE USING A SHOVEL OR WEIGHTED LAWN ROLLER OR BLOWN IN PLACE.

7. FOLLOW MANUFACTURERS' GUIDANCE FOR STAKING. IF MANUFACTURERS' INSTRUCTIONS DO NOT SPECIFY SPACING, STAKES SHALL BE PLACED ON 4' CENTERS AND EMBEDDED A MINIMUM OF 6" INTO THE GROUND. 3" OF THE STAKE SHALL PROTRUDE FROM THE TOP OF THE LOG. STAKES THAT ARE BROKEN PRIOR TO INSTALLATION SHALL BE REPLACED. COMPOST LOGS SHOULD BE STAKED 10' ON CENTER.

SEDIMENT CONTROL LOG MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF SEDIMENT CONTROL LOG SHALL BE REMOVED AS NEEDED TO MAINTAIN FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY ½ OF THE HEIGHT OF THE SEDIMENT CONTROL LOG.

5. SEDIMENT CONTROL LOG SHALL BE REMOVED AT THE END OF CONSTRUCTION.COMPOST FROM COMPOST LOGS MAY BE LEFT IN PLACE AS LONG AS BAGS ARE REMOVED AND THE AREA SEEDED. IF DISTURBED AREAS EXIST AFTER REMOVAL, THEY SHALL BE COVERED WITH TOP SOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM TOWN OF PARKER, COLORADO, JEFFERSON COUNTY, COLORADO, DOUGLAS COUNTY, COLORADO, AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Straw Bale Barrier (SBB) SC-3

Description

A straw bale barrier is a linear wall of straw bales designed to intercept sheet flow and trap sediment before runoff exits a disturbed area.

Photograph SBB-1. Straw bale barrier used for perimeter control. Photo courtesy of Tom Gore.

Appropriate Uses

Appropriate uses of properly installed straw bale barriers may include:

- As a perimeter control for a site or soil stockpile.
- As a sediment control at the toe of an erodible slope.
- Along the edge of a stream or drainage pathway to reduce sediment laden runoff from entering the waterway.
- As part of an inlet protection design in sump conditions (See Inlet Protection BMP).

Do not use straw bale barriers in areas of concentrated flow or in areas where ponding is not desirable. Straw bales tend to degrade quickly, so they should generally not be used in areas where longer term disturbance is expected.

Due to a history of inappropriate placement, poor installation, and short effective lifespan, the use of straw bales is discouraged or prohibited by some communities.

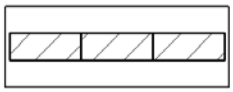
Design and Installation

The maximum recommended tributary drainage area per 100 lineal feet of straw bale barrier is 0.25 acres with a disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1; longer and steeper slopes require additional measures. Design details with notes are provided in Detail SBB-1. To be effective, bales must be installed in accordance with the design details with proper trenching, staking, and binding. Jute and cotton string must not be used to bind the straw bale. The bales should be certified weed-free prior to use.

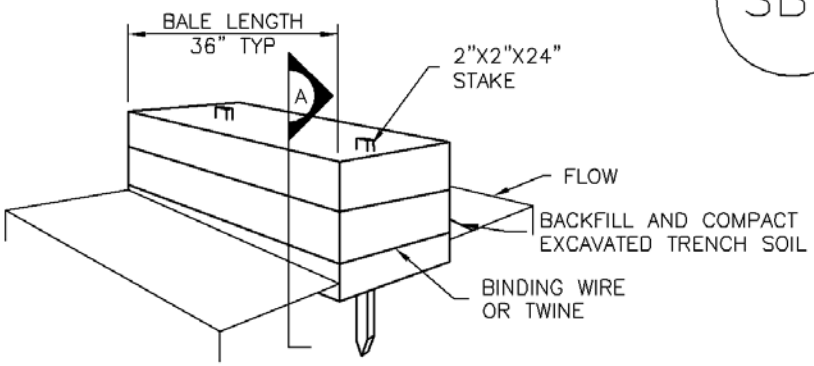
Maintenance and Removal

Check bales for rotting and replace as necessary. Straw bales degrade, and rotting bales require replacement on a regular basis (as often as every three months) depending on environmental conditions. Check for undercutting, bypassed flows, and displacement. Repair by properly re-installing the straw bale barrier and repairing washouts around the bales. Remove sediment accumulated behind the bale when it reaches one-quarter of the bale height. Remove and properly dispose of the straw bale once the upstream area has been stabilized. Areas of disturbance beneath the bale should be seeded and mulched when the bale is removed.

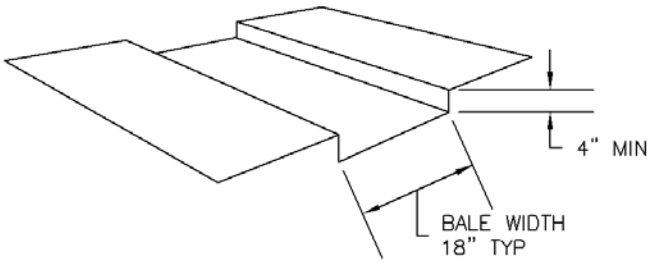
Straw Bale Barrier	
Functions	
Erosion Control	No
Sediment Control	Moderate
Site/Material Management	No



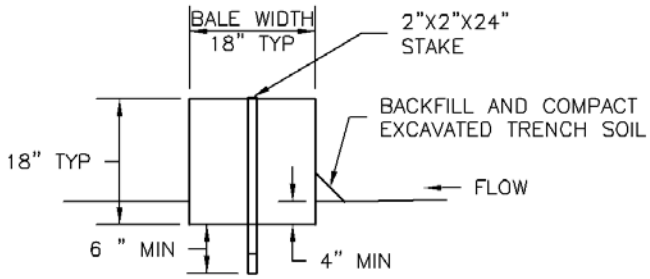
SBB



STRAW BALE



TRENCH FOR STRAW BALE



SECTION A

SBB–1. STRAW BALE

STRAW BALE INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION(S) OF STRAW BALES.

2. STRAW BALES SHALL CONSIST OF CERTIFIED WEED FREE STRAW OR HAY. LOCAL JURISDICTIONS MAY REQUIRE PROOF THAT BALES ARE WEED FREE.

3. STRAW BALES SHALL CONSIST OF APPROXIMATELY 5 CUBIC FEET OF STRAW OR HAY AND WEIGH NOT LESS THAN 35 POUNDS.

4. WHEN STRAW BALES ARE USED IN SERIES AS A BARRIER, THE END OF EACH BALE SHALL BE TIGHTLY ABUTTING ONE ANOTHER.

5. STRAW BALE DIMENSIONS SHALL BE APPROXIMATELY 36"X18"X18".

6. A UNIFORM ANCHOR TRENCH SHALL BE EXCAVATED TO A DEPTH OF 4". STRAW BALES SHALL BE PLACED SO THAT BINDING TWINE IS ENCOMPASSING THE VERTICAL SIDES OF THE BALE(S). ALL EXCAVATED SOIL SHALL BE PLACED ON THE UPHILL SIDE OF THE STRAW BALE(S) AND COMPACTED.

7. TWO (2) WOODEN STAKES SHALL BE USED TO HOLD EACH BALE IN PLACE. WOODEN STAKES SHALL BE 2"X2"X24". WOODEN STAKES SHALL BE DRIVEN 6" INTO THE GROUND.

STRAW BALE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. STRAW BALES SHALL BE REPLACED IF THEY BECOME HEAVILY SOILED, ROTTEN, OR DAMAGED BEYOND REPAIR.

5. SEDIMENT ACCUMULATED UPSTREAM OF STRAW BALE BARRIER SHALL BE REMOVED AS NEEDED TO MAINTAIN FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY ¼ OF THE HEIGHT OF THE STRAW BALE BARRIER.

6. STRAW BALES ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

7. WHEN STRAW BALES ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAILS ADAPTED FROM TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Brush Barrier (BB) SC-4

Description

A brush barrier is a perimeter sediment control constructed with stacked shrubs, tree limbs, and bushy vegetation that has been cleared from a construction area. Brush barriers reduce sediment loads by intercepting and slowing sheet flow from disturbed areas.

Photograph BB-1. Brush barrier constructed with chipped wood. Photo courtesy of EPA.

Appropriate Uses

A brush barrier is an appropriate BMP at sites where there is adequate brush from the clearing and grubbing of the construction site to construct an effective brush barrier. Brush barriers are typically used at the toe of slopes and should be implemented in combination with other BMPs such as surface roughening and reseeding. Brush barriers should be considered short-term, supplemental BMPs because they are constructed of materials that naturally decompose. Brush barriers are not acceptable as a sole means of perimeter control, but they may be used internally within a site to reduce slope length or at the site perimeter in combination with other perimeter control BMPs for multi-layered protection.

Brush barriers are not appropriate for high-velocity flow areas. A large amount of material is needed to construct a useful brush barrier; therefore, alternative perimeter controls such as a fabric silt fence may be more appropriate for sites with little material from clearing.

Design and Installation

The drainage area for brush barriers should be no greater than 0.25 acre per 100 feet of barrier length. Additionally, the drainage slope leading down to a brush barrier must be no greater than 3:1 and no longer than 150 feet.

To construct an effective brush barrier, use only small shrubs and limbs with diameters of 6 inches or less. Larger materials (such as a tree stump) can create void spaces in the barrier, making it ineffective. The brush barrier mound should be at least 3 feet high and 5 feet wide at its base.

In order to avoid significant movement of the brush and improve effectiveness, a filter fabric can be placed over the top of the brush pile, keyed in on the upstream side, and anchored on the downstream side. On the upgradient side, the filter fabric cover should be buried in a trench 4 inches deep and 6 inches wide.

Brush Barrier	
Functions	
Erosion Control	Moderate
Sediment Control	Moderate
Site/Material	No

Maintenance and Removal

Inspect the brush barrier for voids where concentrated flow or erosion is occurring. Voids in the brush barrier should be filled with additional brush. Accumulated sediment should be removed from the uphill side of the barrier when sediment height reaches one-third of the height of the barrier.

If filter fabric is used, inspect the filter fabric for damage; replace and properly secure it, as needed.

Once the upstream area has been vegetated or stabilized, the brush barrier should be removed and the underlying area revegetated.

Rock Sock (RS) SC-5

Description

A rock sock is constructed of gravel that has been wrapped by wire mesh or a geotextile to form an elongated cylindrical filter. Rock socks are typically used either as a perimeter control or as part of inlet protection. When placed at angles in the curb line, rock socks are typically referred to as curb socks. Rock socks are intended to trap sediment from stormwater runoff that flows onto roadways as a result of construction activities.

Photograph RS-1. Rock socks placed at regular intervals in a curb line can help reduce sediment loading to storm sewer inlets. Rock socks can also be used as perimeter controls.

Appropriate Uses

Rock socks can be used at the perimeter of a disturbed area to control localized sediment loading. A benefit of rock socks as opposed to other perimeter controls is that they do not have to be trenched or staked into the ground; therefore, they are often used on roadway construction projects where paved surfaces are present.

Use rock socks in inlet protection applications when the construction of a roadway is substantially complete and the roadway has been directly connected to a receiving storm system.

Design and Installation

When rock socks are used as perimeter controls, the maximum recommended tributary drainage area per 100 lineal feet of rock socks is approximately 0.25 acres with disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1. A rock sock design detail and notes are provided in Detail RS-1. Also see the Inlet Protection Fact Sheet for design and installation guidance when rock socks are used for inlet protection and in the curb line.

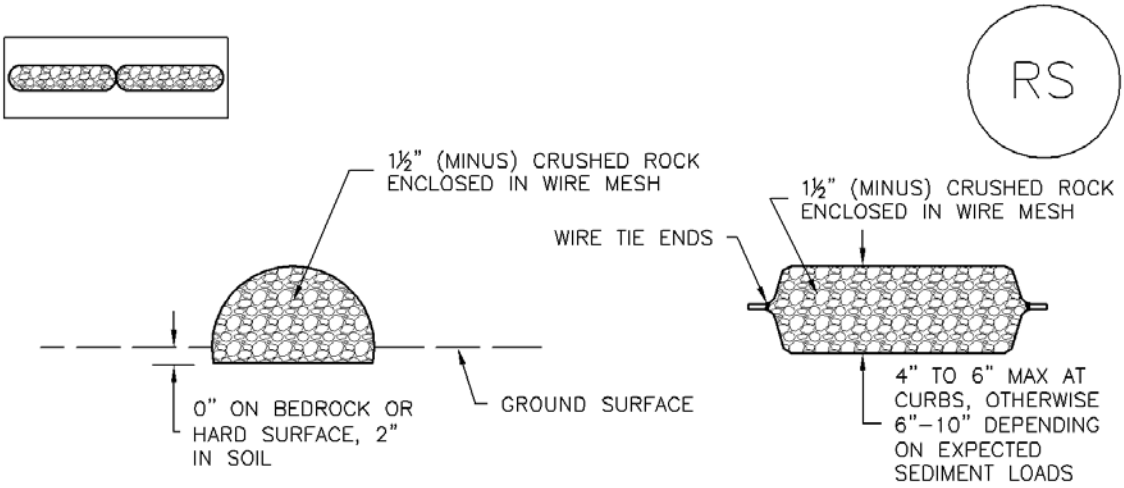
When placed in the gutter adjacent to a curb, rock socks should protrude no more than two feet from the curb in order for traffic to pass safely. If located in a high traffic area, place construction markers to alert drivers and street maintenance workers of their presence.

Maintenance and Removal

Rock socks are susceptible to displacement and breaking due to vehicle traffic. Inspect rock socks for damage and repair or replace as necessary. Remove sediment by sweeping or vacuuming as needed to maintain the functionality of the BMP, typically when sediment has accumulated behind the rock sock to one-half of the sock's height.

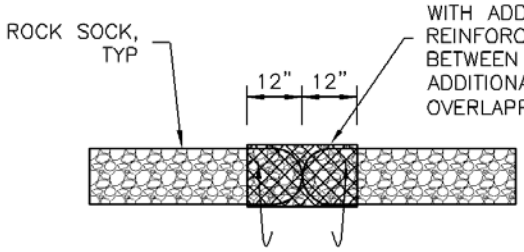
Once upstream stabilization is complete, rock socks and accumulated sediment should be removed and properly disposed.

Rock Sock	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No



ROCK SOCK SECTION

ROCK SOCK PLAN



ANY GAP AT JOINT SHALL BE FILLED WITH AN ADEQUATE AMOUNT OF 1½" (MINUS) CRUSHED ROCK AND WRAPPED WITH ADDITIONAL WIRE MESH SECURED TO ENDS OF ROCK REINFORCED SOCK. AS AN ALTERNATIVE TO FILLING JOINTS BETWEEN ADJOINING ROCK SOCKS WITH CRUSHED ROCK AND ADDITIONAL WIRE WRAPPING, ROCK SOCKS CAN BE OVERLAPPED (TYPICALLY 12–INCH OVERLAP) TO AVOID GAPS.

ROCK SOCK JOINTING

GRADATION TABLE	
SIEVE SIZE	MASS PERCENT PASSING SQUARE MESH SIEVES
	NO. 4
2"	100
1½"	90 – 100
1"	20 – 55
¾"	0 – 15
⅜"	0 – 5
MATCHES SPECIFICATIONS FOR NO. 4 COARSE AGGREGATE FOR CONCRETE PER AASHTO M43. ALL ROCK SHALL BE FRACTURED FACE, ALL SIDES.	

ROCK SOCK INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION(S) OF ROCK SOCKS.

2. CRUSHED ROCK SHALL BE 1½" (MINUS) IN SIZE WITH A FRACTURED FACE (ALL SIDES) AND SHALL COMPLY WITH GRADATION SHOWN ON THIS SHEET (1½" MINUS).

3. WIRE MESH SHALL BE FABRICATED OF 10 GAGE POULTRY MESH, OR EQUIVALENT, WITH A MAXIMUM OPENING OF ½", RECOMMENDED MINIMUM ROLL WIDTH OF 48"

4. WIRE MESH SHALL BE SECURED USING "HOG RINGS" OR WIRE TIES AT 6" CENTERS ALONG ALL JOINTS AND AT 2" CENTERS ON ENDS OF SOCKS.

5. SOME MUNICIPALITIES MAY ALLOW THE USE OF FILTER FABRIC AS AN ALTERNATIVE TO WIRE MESH FOR THE ROCK ENCLOSURE.

RS–1. ROCK SOCK PERIMETER CONTROL

ROCK SOCK MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ROCK SOCKS SHALL BE REPLACED IF THEY BECOME HEAVILY SOILED, OR DAMAGED BEYOND REPAIR.

5. SEDIMENT ACCUMULATED UPSTREAM OF ROCK SOCKS SHALL BE REMOVED AS NEEDED TO MAINTAIN FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY ½ OF THE HEIGHT OF THE ROCK SOCK.

6. ROCK SOCKS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

7. WHEN ROCK SOCKS ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

NOTE: THE DETAILS INCLUDED WITH THIS FACT SHEET SHOW COMMONLY USED, CONVENTIONAL METHODS OF ROCK SOCK INSTALLATION IN THE DENVER METROPOLITAN AREA. THERE ARE MANY OTHER SIMILAR PROPRIETARY PRODUCTS ON THE MARKET. UDFCD NEITHER NDORSES NOR DISCOURAGES USE OF PROPRIETARY PROTECTION PRODUCTS; HOWEVER, IN THE EVENT PROPRIETARY METHODS ARE USED, THE APPROPRIATE DETAIL FROM THE MANUFACTURER MUST BE INCLUDED IN THE SWMP AND THE BMP MUST BE INSTALLED AND MAINTAINED AS SHOWN IN THE MANUFACTURER'S DETAILS.

Description

Inlet protection consists of permeable barriers installed around an inlet to filter runoff and remove sediment prior to entering a storm drain inlet. Inlet protection can be constructed from rock socks, sediment control logs, silt fence, block and rock socks, or other materials approved by the local jurisdiction. Area inlets can also be protected by over-excavating around the inlet to form a sediment trap.

Photograph IP-1. Inlet protection for a curb opening inlet.

Appropriate Uses

Install protection at storm sewer inlets that are operable during construction. Consider the potential for tracked-out sediment or temporary stockpile areas to contribute sediment to inlets when determining which inlets must be protected. This may include inlets in the general proximity of the construction area, not limited to downgradient inlets. Inlet protection is not a stand-alone BMP and should be used in conjunction with other upgradient BMPs.

Design and Installation

To function effectively, inlet protection measures must be installed to ensure that flows do not bypass the inlet protection and enter the storm drain without treatment. However, designs must also enable the inlet to function without completely blocking flows into the inlet in a manner that causes localized flooding. When selecting the type of inlet protection, consider factors such as type of inlet (e.g., curb or area, sump or on-grade conditions), traffic, anticipated flows, ability to secure the BMP properly, safety and other site-specific conditions. For example, block and rock socks will be better suited to a curb and gutter along a roadway, as opposed to silt fence or sediment control logs, which cannot be properly secured in a curb and gutter setting, but are effective area inlet protection measures.

Several inlet protection designs are provided in the Design Details. Additionally, a variety of proprietary products are available for inlet protection that may be approved for use by local governments. If proprietary products are used, design details and installation procedures from the manufacturer must be followed. Regardless of the type of inlet protection selected, inlet protection is most effective when combined with other BMPs such as curb socks and check dams. Inlet protection is often the last barrier before runoff enters the storm sewer or receiving water.

Design details with notes are provided for these forms of inlet protection:

IP-1. Block and Rock Sock Inlet Protection for Sump or On-grade Inlets

IP-2. Curb (Rock) Socks Upstream of Inlet Protection, On-grade Inlets

Inlet Protection (various forms)	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No

IP-3. Rock Sock Inlet Protection for Sump/Area Inlet

IP-4. Silt Fence Inlet Protection for Sump/Area Inlet

IP-5. Over-excavation Inlet Protection

IP-6. Straw Bale Inlet Protection for Sump/Area Inlet

CIP-1. Culvert Inlet Protection

Propriety inlet protection devices should be installed in accordance with manufacturer specifications.

More information is provided below on selecting inlet protection for sump and on-grade locations.

Inlets Located in a Sump

When applying inlet protection in sump conditions, it is important that the inlet continue to function during larger runoff events. For curb inlets, the maximum height of the protective barrier should be lower than the top of the curb opening to allow overflow into the inlet during larger storms without excessive localized flooding. If the inlet protection height is greater than the curb elevation, particularly if the filter becomes clogged with sediment, runoff will not enter the inlet and may bypass it, possibly causing localized flooding, public safety issues, and downstream erosion and damage from bypassed flows.

Area inlets located in a sump setting can be protected through the use of silt fence, concrete block and rock socks (on paved surfaces), sediment control logs/straw wattles embedded in the adjacent soil and stacked around the area inlet (on pervious surfaces), over-excavation around the inlet, and proprietary products providing equivalent functions.

Inlets Located on a Slope

For curb and gutter inlets on paved sloping streets, block and rock sock inlet protection is recommended in conjunction with curb socks in the gutter leading to the inlet. For inlets located along unpaved roads, also see the Check Dam Fact Sheet.

Maintenance and Removal

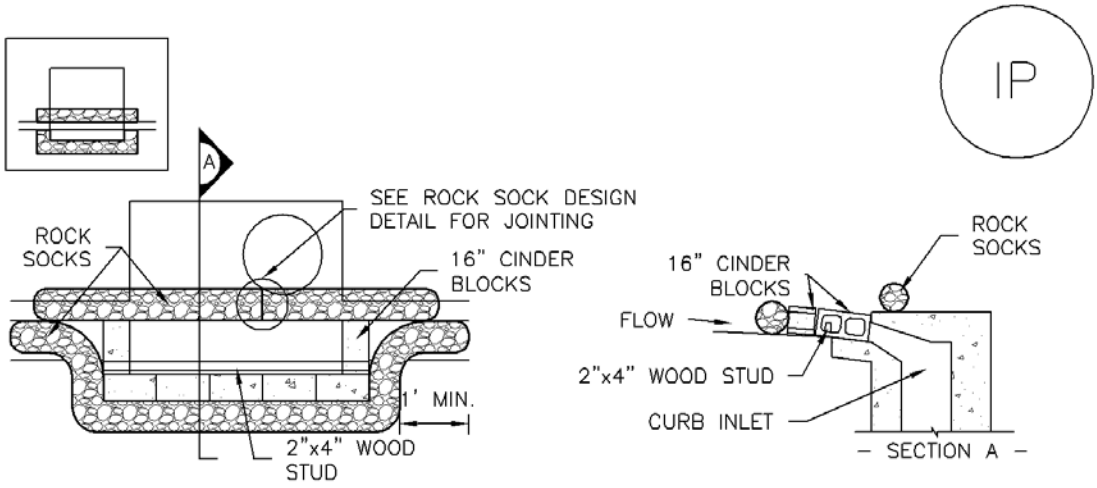
Inspect inlet protection frequently. Inspection and maintenance guidance includes:

- Inspect for tears that can result in sediment directly entering the inlet, as well as result in the contents of the BMP (e.g., gravel) washing into the inlet.
- Check for improper installation resulting in untreated flows bypassing the BMP and directly entering the inlet or bypassing to an unprotected downstream inlet. For example, silt fence that has not been properly trenched around the inlet can result in flows under the silt fence and directly into the inlet.
- Look for displaced BMPs that are no longer protecting the inlet. Displacement may occur following larger storm events that wash away or reposition the inlet protection. Traffic or equipment may also crush or displace the BMP.
- Monitor sediment accumulation upgradient of the inlet protection.

- Remove sediment accumulation from the area upstream of the inlet protection, as needed to maintain BMP effectiveness, typically when it reaches no more than half the storage capacity of the inlet protection. For silt fence, remove sediment when it accumulates to a depth of no more than 6 inches. Remove sediment accumulation from the area upstream of the inlet protection as needed to maintain the functionality of the BMP.

- Propriety inlet protection devices should be inspected and maintained in accordance with manufacturer specifications. If proprietary inlet insert devices are used, sediment should be removed in a timely manner to prevent devices from breaking and spilling sediment into the storm drain.

Inlet protection must be removed and properly disposed of when the drainage area for the inlet has reached final stabilization.



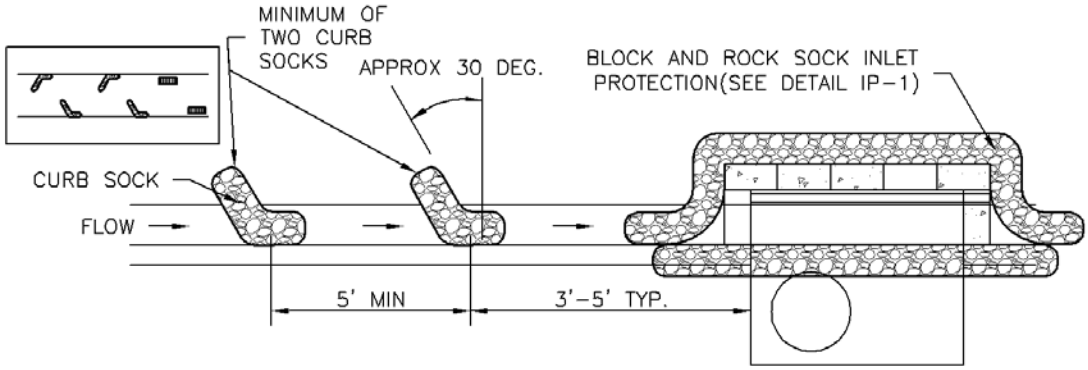
IP–1. BLOCK AND ROCK SOCK SUMP OR ON GRADE INLET PROTECTION

BLOCK AND CURB SOCK INLET PROTECTION INSTALLATION NOTES

1. SEE ROCK SOCK DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. CONCRETE "CINDER" BLOCKS SHALL BE LAID ON THEIR SIDES AROUND THE INLET IN A SINGLE ROW, ABUTTING ONE ANOTHER WITH THE OPEN END FACING AWAY FROM THE CURB.

3. GRAVEL BAGS SHALL BE PLACED AROUND CONCRETE BLOCKS, CLOSELY ABUTTING ONE ANOTHER AND JOINTED TOGETHER IN ACCORDANCE WITH ROCK SOCK DESIGN DETAIL.



IP–2. CURB ROCK SOCKS UPSTREAM OF INLET PROTECTION

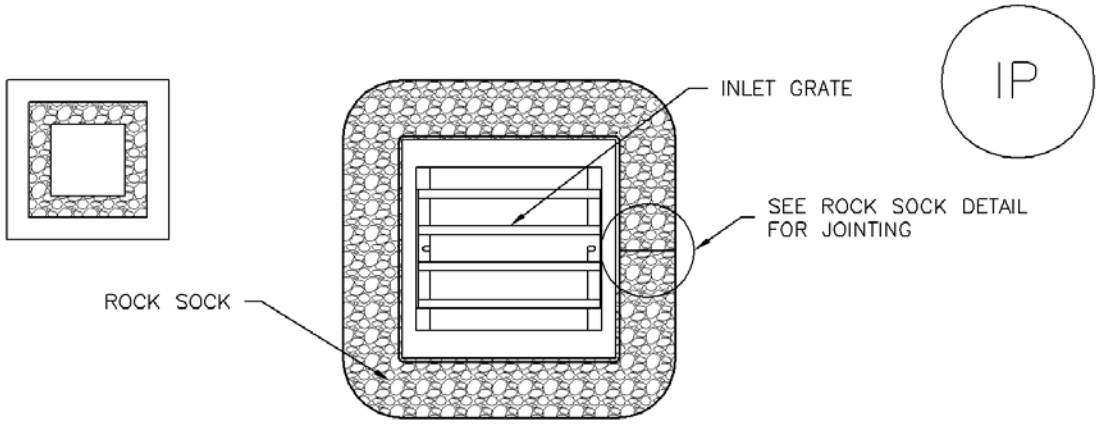
CURB ROCK SOCK INLET PROTECTION INSTALLATION NOTES

1. SEE ROCK SOCK DESIGN DETAIL INSTALLATION REQUIREMENTS.

2. PLACEMENT OF THE SOCK SHALL BE APPROXIMATELY 30 DEGREES FROM PERPENDICULAR IN THE OPPOSITE DIRECTION OF FLOW.

3. SOCKS ARE TO BE FLUSH WITH THE CURB AND SPACED A MINIMUM OF 5 FEET APART.

4. AT LEAST TWO CURB SOCKS IN SERIES ARE REQUIRED UPSTREAM OF ON–GRADE INLETS.

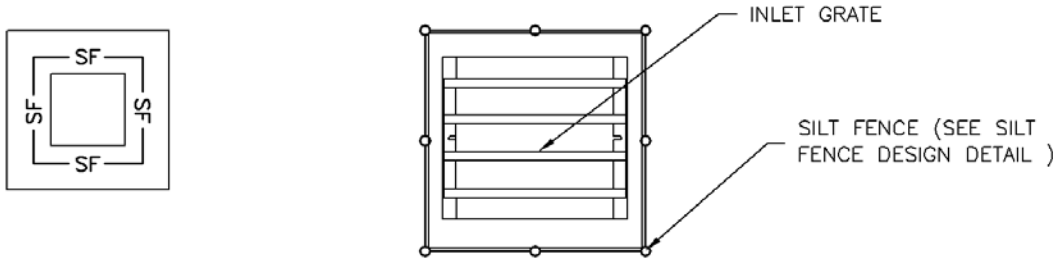


IP–3. ROCK SOCK SUMP/AREA INLET PROTECTION

ROCK SOCK SUMP/AREA INLET PROTECTION INSTALLATION NOTES

1. SEE ROCK SOCK DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. STRAW WATTLES/SEDIMENT CONTROL LOGS MAY BE USED IN PLACE OF ROCK SOCKS FOR INLETS IN PERVIOUS AREAS. INSTALL PER SEDIMENT CONTROL LOG DETAIL.



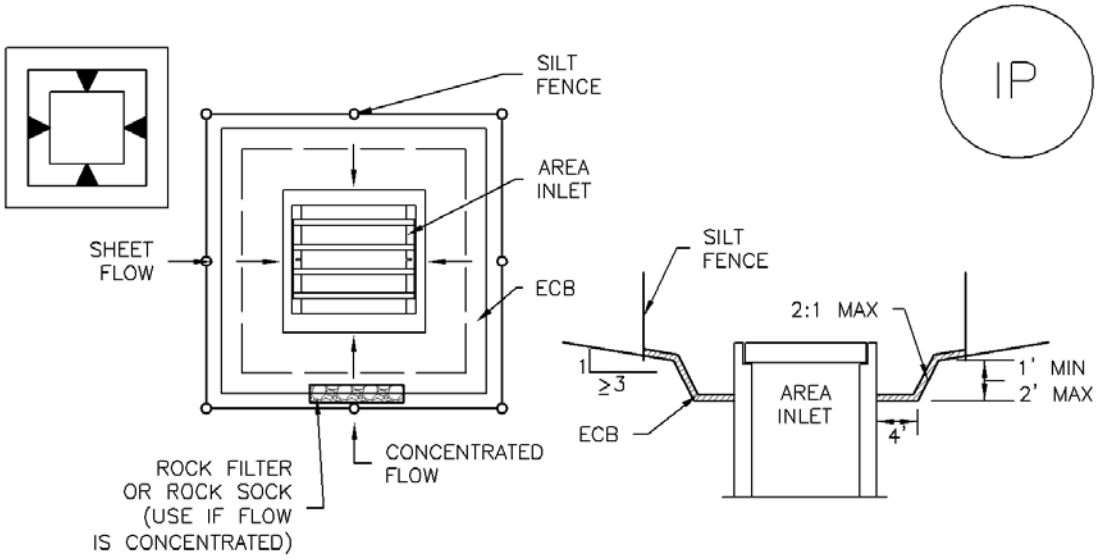
IP–4. SILT FENCE FOR SUMP INLET PROTECTION

SILT FENCE INLET PROTECTION INSTALLATION NOTES

1. SEE SILT FENCE DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. POSTS SHALL BE PLACED AT EACH CORNER OF THE INLET AND AROUND THE EDGES AT A MAXIMUM SPACING OF 3 FEET.

3. STRAW WATTLES/SEDIMENT CONTROL LOGS MAY BE USED IN PLACE OF SILT FENCE FOR INLETS IN PERVIOUS AREAS. INSTALL PER SEDIMENT CONTROL LOG DETAIL.



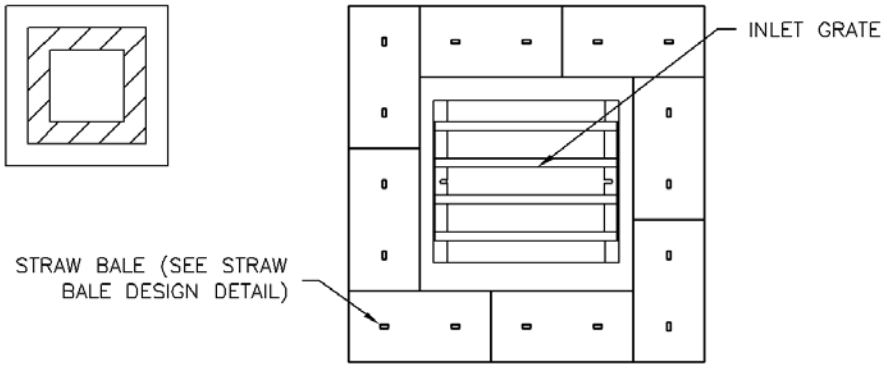
IP–5. OVEREXCAVATION INLET PROTECTION

OVEREXCAVATION INLET PROTECTION INSTALLATION NOTES

1. THIS FORM OF INLET PROTECTION IS PRIMARILY APPLICABLE FOR SITES THAT HAVE NOT YET REACHED FINAL GRADE AND SHOULD BE USED ONLY FOR INLETS WITH A RELATIVELY SMALL CONTRIBUTING DRAINAGE AREA.

2. WHEN USING FOR CONCENTRATED FLOWS, SHAPE BASIN IN 2:1 RATIO WITH LENGTH ORIENTED TOWARDS DIRECTION OF FLOW.

3. SEDIMENT MUST BE PERIODICALLY REMOVED FROM THE OVEREXCAVATED AREA.

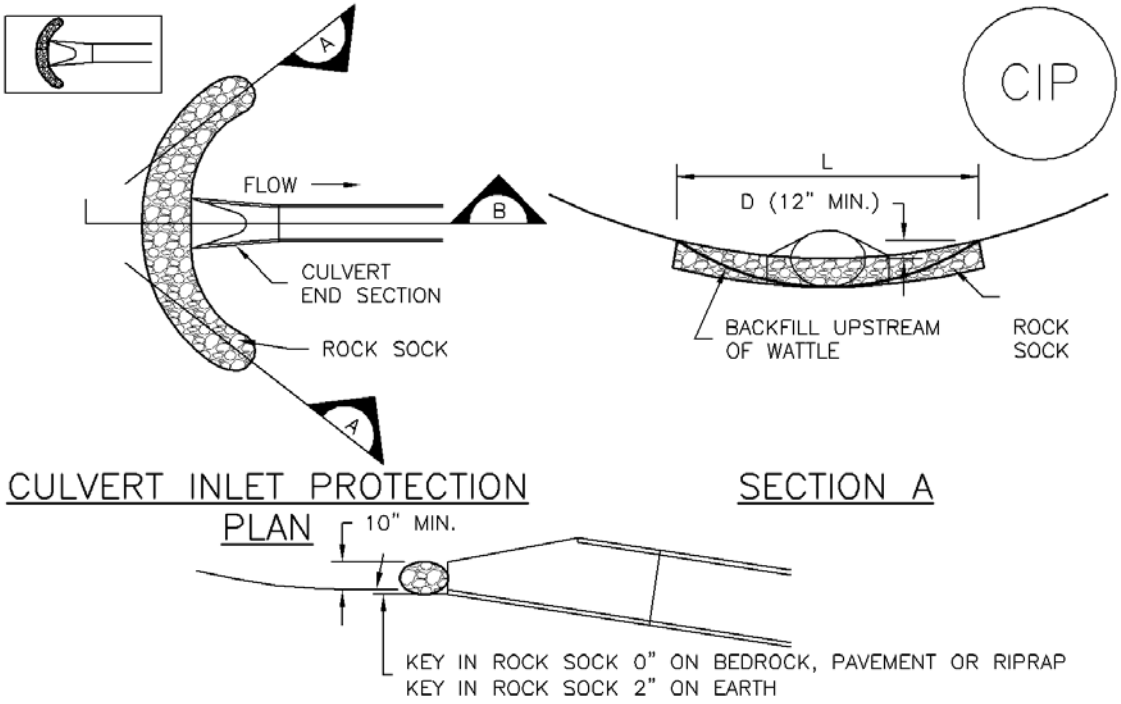


IP–6. STRAW BALE FOR SUMP INLET PROTECTION

STRAW BALE BARRIER INLET PROTECTION INSTALLATION NOTES

1. SEE STRAW BALE DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. BALES SHALL BE PLACED IN A SINGLE ROW AROUND THE INLET WITH ENDS OF BALES TIGHTLY ABUTTING ONE ANOTHER.



CIP–1. CULVERT INLET PROTECTION

CULVERT INLET PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   –LOCATION OF CULVERT INLET PROTECTION.

2. SEE ROCK SOCK DESIGN DETAIL FOR ROCK GRADATION REQUIREMENTS AND JOINTING DETAIL.

CULVERT INLET PROTECTION MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF THE CULVERT SHALL BE REMOVED WHEN THE SEDIMENT DEPTH IS ½ THE HEIGHT OF THE ROCK SOCK.

5. CULVERT INLET PROTECTION SHALL REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS PERMANENTLY STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

GENERAL INLET PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF INLET PROTECTION.
   –TYPE OF INLET PROTECTION (IP.1, IP.2, IP.3, IP.4, IP.5, IP.6)

2. INLET PROTECTION SHALL BE INSTALLED PROMPTLY AFTER INLET CONSTRUCTION OR PAVING IS COMPLETE (TYPICALLY WITHIN 48 HOURS). IF A RAINFALL/RUNOFF EVENT IS FORECAST, INSTALL INLET PROTECTION PRIOR TO ONSET OF EVENT.

3. MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

INLET PROTECTION MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF INLET PROTECTION SHALL BE REMOVED AS NECESSARY TO MAINTAIN BMP EFFECTIVENESS, TYPICALLY WHEN STORAGE VOLUME REACHES 50% OF CAPACITY, A DEPTH OF 6" WHEN SILT FENCE IS USED, OR ¼ OF THE HEIGHT FOR STRAW BALES.

5. INLET PROTECTION IS TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS PERMANENTLY STABILIZED, UNLESS THE LOCAL JURISDICTION APPROVES EARLIER REMOVAL OF INLET PROTECTION IN STREETS.

6. WHEN INLET PROTECTION AT AREA INLETS IS REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOP SOIL, SEEDED AND MULCHED, OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

NOTE: THE DETAILS INCLUDED WITH THIS FACT SHEET SHOW COMMONLY USED, CONVENTIONAL METHODS OF INLET PROTECTION IN THE DENVER METROPOLITAN AREA. THERE ARE MANY PROPRIETARY INLET PROTECTION METHODS ON THE MARKET. UDFCD NEITHER ENDORSES NOR DISCOURAGES USE OF PROPRIETARY INLET PROTECTION; HOWEVER, IN THE EVENT PROPRIETARY METHODS ARE USED, THE APPROPRIATE DETAIL FROM THE MANUFACTURER MUST BE INCLUDED IN THE SWMP AND THE BMP MUST BE INSTALLED AND MAINTAINED AS SHOWN IN THE MANUFACTURER'S DETAILS.

NOTE: SOME MUNICIPALITIES DISCOURAGE OR PROHIBIT THE USE OF STRAW BALES FOR INLET PROTECTION. CHECK WITH LOCAL JURISDICTION TO DETERMINE IF STRAW BALE INLET PROTECTION IS ACCEPTABLE.

Sediment Basin (SB) SC-7

Description

A sediment basin is a temporary pond built on a construction site to capture eroded or disturbed soil transported in storm runoff prior to discharge from the site. Sediment basins are designed to capture site runoff and slowly release it to allow time for settling of sediment prior to discharge. Sediment basins are often constructed in locations that will later be modified to serve as post-construction stormwater basins.

Photograph SB-1. Sediment basin at the toe of a slope. Photo courtesy of WWE.

Appropriate Uses

Most large construction sites (typically greater than 2 acres) will require one or more sediment basins for effective management of construction site runoff. On linear construction projects, sediment basins may be impractical; instead, sediment traps or other combinations of BMPs may be more appropriate.

Sediment basins should not be used as stand-alone sediment controls. Erosion and other sediment controls should also be implemented upstream.

When feasible, the sediment basin should be installed in the same location where a permanent post-construction detention pond will be located.

Design and Installation

The design procedure for a sediment basin includes these steps:

- **Basin Storage Volume**: Provide a storage volume of at least 3,600 cubic feet per acre of drainage area. To the extent practical, undisturbed and/or off-site areas should be diverted around sediment basins to prevent "clean" runoff from mixing with runoff from disturbed areas. For undisturbed areas (both on-site and off-site) that cannot be diverted around the sediment basin, provide a minimum of 500 ft^3/acre of storage for undeveloped (but stable) off-site areas in addition to the 3,600 ft^3/acre for disturbed areas. For stable, developed areas that cannot be diverted around the sediment basin, storage volume requirements are summarized in Table SB-1.

- **Basin Geometry:** Design basin with a minimum length-to-width ratio of 2:1 (L:W). If this cannot be achieved because of site space constraints, baffling may be required to extend the effective distance between the inflow point(s) and the outlet to minimize short-circuiting.

- **Dam Embankment**: It is recommended that embankment slopes be 4:1 (H:V) or flatter and no steeper than 3:1 (H:V) in any location.

Sediment Basins	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No

- **Inflow Structure**: For concentrated flow entering the basin, provide energy dissipation at the point of inflow.

Table SB-1. Additional Volume Requirements for Undisturbed and Developed Tributary Areas Draining through Sediment Basins

Imperviousness (%)	Additional Storage Volume (ft^3) Per Acre of Tributary Area
Undeveloped	500
10	800
20	1230
30	1600
40	2030
50	2470
60	2980
70	3560
80	4360
90	5300
100	6460

- **Outlet Works**: The outlet pipe shall extend through the embankment at a minimum slope of 0.5 percent. Outlet works can be designed using one of the following approaches:

  - **Riser Pipe (Simplified Detail):** Detail SB-1 provides a simplified design for basins treating no more than 15 acres.

  - **Orifice Plate or Riser Pipe**: Follow the design criteria for Full Spectrum Detention outlets in the EDB Fact Sheet provided in Chapter 4 of this manual for sizing of outlet perforations with an emptying time of approximately 72 hours. In lieu of the trash rack, pack uniformly sized 1½ - to 2-inch gravel in front of the plate or surrounding the riser pipe. This gravel will need to be cleaned out frequently during the construction period as sediment accumulates within it. The gravel pack will need to be removed and disposed of following construction to reclaim the basin for use as a permanent detention facility. If the basin will be used as a permanent extended detention basin for the site, a trash rack will need to be installed once contributing drainage areas have been stabilized and the gravel pack and accumulated sediment have been removed.

  - **Floating Skimmer**: If a floating skimmer is used, install it using manufacturer's recommendations. Illustration SB-1 provides an illustration of a Faircloth Skimmer Floating Outlet™, one of the more commonly used floating skimmer outlets. A skimmer should be designed to release the design volume in no less than 48 hours. The use of a floating skimmer outlet can increase the sediment capture efficiency of a basin significantly. A floating outlet continually decants cleanest water off the surface of the pond and releases cleaner water than would discharge from a perforated riser pipe or plate.

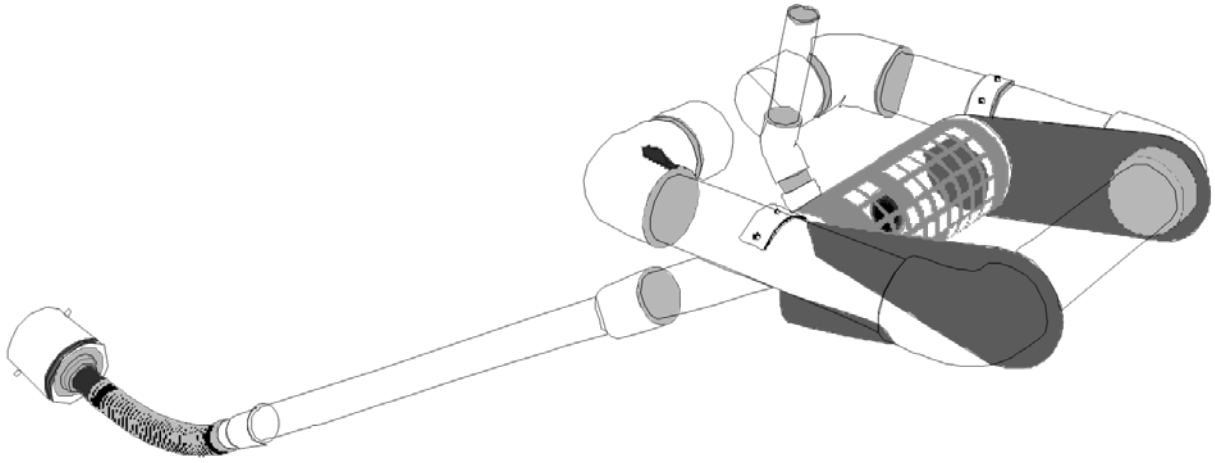


Illustration SB-1. Outlet structure for a temporary sediment basin - Faircloth Skimmer Floating Outlet. Illustration courtesy of J. W. Faircloth & Sons, Inc., FairclothSkimmer.com.

- **Outlet Protection and Spillway:** Consider all flow paths for runoff leaving the basin, including protection at the typical point of discharge as well as overtopping.
  - **Outlet Protection:** Outlet protection should be provided where the velocity of flow will exceed the maximum permissible velocity of the material of the waterway into which discharge occurs. This may require the use of a riprap apron at the outlet location and/or other measures to keep the waterway from eroding.
  - **Emergency Spillway:** Provide a stabilized emergency overflow spillway for rainstorms that exceed the capacity of the sediment basin volume and its outlet. Protect basin embankments from erosion and overtopping. If the sediment basin will be converted to a permanent detention basin, design and construct the emergency spillway(s) as required for the permanent facility. If the sediment basin will not become a permanent detention basin, it may be possible to substitute a heavy polyvinyl membrane or properly bedded rock cover to line the spillway and downstream embankment, depending on the height, slope, and width of the embankments.

Maintenance and Removal

Maintenance activities include the following:

- Dredge sediment from the basin, as needed to maintain BMP effectiveness, typically when the design storage volume is no more than one-third filled with sediment.
- Inspect the sediment basin embankments for stability and seepage.
- Inspect the inlet and outlet of the basin, repair damage, and remove debris. Remove, clean and replace the gravel around the outlet on a regular basis to remove the accumulated sediment within it and keep the outlet functioning.
- Be aware that removal of a sediment basin may require dewatering and associated permit requirements.
- Do not remove a sediment basin until the upstream area has been stabilized with vegetation.

Final disposition of the sediment basin depends on whether the basin will be converted to a permanent post-construction stormwater basin or whether the basin area will be returned to grade. For basins being converted to permanent detention basins, remove accumulated sediment and reconfigure the basin and outlet to meet the requirements of the final design for the detention facility. If the sediment basin is not to be used as a permanent detention facility, fill the excavated area with soil and stabilize with vegetation.

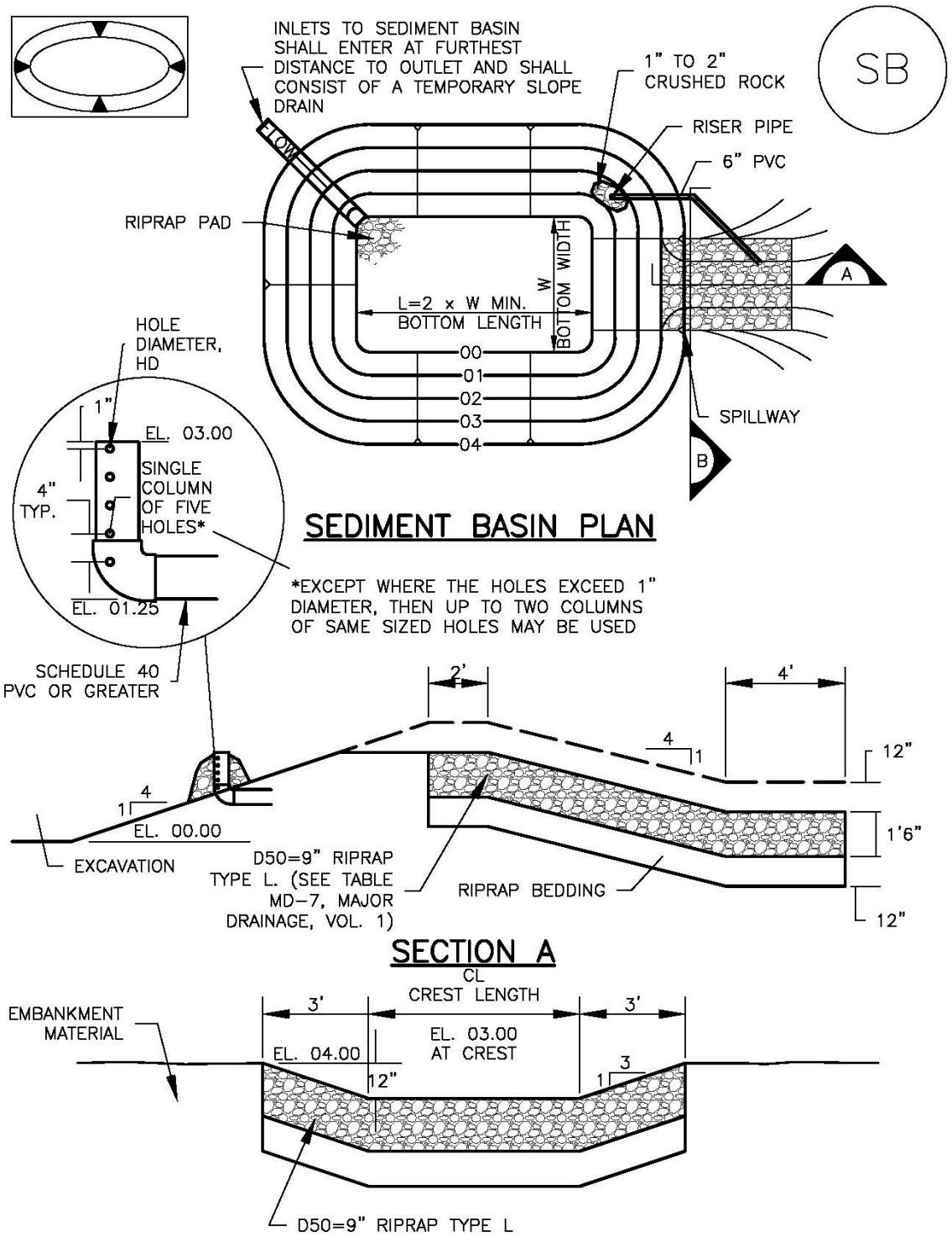

SB
INLETS TO SEDIMENT BASIN SHALL ENTER AT FURTHEST DISTANCE TO OUTLET AND SHALL CONSIST OF A TEMPORARY SLOPE DRAIN
FLOW
1" TO 2" CRUSHED ROCK
RISER PIPE
6" PVC
RIPRAP PAD
W BOTTOM WIDTH
L=2 x W MIN. BOTTOM LENGTH
00
01
02
03
04
A
B
SPILLWAY
HOLE DIAMETER, HD
1"
EL. 03.00
4" TYP.
SINGLE COLUMN OF FIVE HOLES*
EL. 01.25
SCHEDULE 40 PVC OR GREATER
SEDIMENT BASIN PLAN
*EXCEPT WHERE THE HOLES EXCEED 1" DIAMETER, THEN UP TO TWO COLUMNS OF SAME SIZED HOLES MAY BE USED
2'
4'
4
1
12"
4
1
EL. 00.00
1'6"
EXCAVATION
D50=9" RIPRAP TYPE L. (SEE TABLE MD-7, MAJOR DRAINAGE, VOL. 1)
RIPRAP BEDDING
12"
SECTION A
CL
CREST LENGTH
3'
3'
EMBANKMENT MATERIAL
EL. 04.00
EL. 03.00 AT CREST
12"
3
1
D50=9" RIPRAP TYPE L

TABLE SB–1. SIZING INFORMATION FOR STANDARD SEDIMENT BASIN			
Upstream Drainage Area (rounded to nearest acre), (ac)	Basin Bottom Width (W), (ft)	Spillway Crest Length (CL), (ft)	Hole Diameter (HD), (in)
1	12 ½	2	9/32
2	21	3	13/16
3	28	5	½
4	33 ½	6	9/16
5	38 ½	8	21/32
6	43	9	21/32
7	47 ¼	11	25/32
8	51	12	27/32
9	55	13	7/8
10	58 ¼	15	15/16
11	61	16	31/32
12	64	18	1
13	67 ½	19	1 1/16
14	70 ½	21	1 1/8
15	73 ¼	22	1 3/16

SEDIMENT BASIN INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATION OF SEDIMENT BASIN.
   - –TYPE OF BASIN (STANDARD BASIN OR NONSTANDARD BASIN).
   - –FOR STANDARD BASIN, BOTTOM WIDTH W, CREST LENGTH CL, AND HOLE DIAMETER, HD.
   - –FOR NONSTANDARD BASIN, SEE CONSTRUCTION DRAWINGS FOR DESIGN OF BASIN INCLUDING RISER HEIGHT H, NUMBER OF COLUMNS N, HOLE DIAMETER HD AND PIPE DIAMETER D.

2. FOR STANDARD BASIN, BOTTOM DIMENSION MAY BE MODIFIED AS LONG AS BOTTOM AREA IS NOT REDUCED.

3. SEDIMENT BASINS SHALL BE INSTALLED PRIOR TO ANY OTHER LAND–DISTURBING ACTIVITY THAT RELIES ON ON BASINS AS AS A STORMWATER CONTROL.

4. EMBANKMENT MATERIAL SHALL CONSIST OF SOIL FREE OF DEBRIS, ORGANIC MATERIAL, AND ROCKS OR CONCRETE GREATER THAN 3 INCHES AND SHALL HAVE A MINIMUM OF 15 PERCENT BY WEIGHT PASSING THE NO. 200 SIEVE.

5. EMBANKMENT MATERIAL SHALL BE COMPACTED TO AT LEAST 95 PERCENT OF MAXIMUM DENSITY IN ACCORDANCE WITH ASTM D698.

6. PIPE SCH 40 OR GREATER SHALL BE USED.

7. THE DETAILS SHOWN ON THESE SHEETS PERTAIN TO STANDARD SEDIMENT BASIN(S) FOR DRAINAGE AREAS LESS THAN 15 ACRES. SEE CONSTRUCTION DRAWINGS FOR EMBANKMENT, STORAGE VOLUME, SPILLWAY, OUTLET, AND OUTLET PROTECTION DETAILS FOR ANY SEDIMENT BASIN(S) THAT HAVE BEEN INDIVIDUALLY DESIGNED FOR DRAINAGE AREAS LARGER THAN 15 ACRES.

SEDIMENT BASIN MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED IN BASIN SHALL BE REMOVED AS NEEDED TO MAINTAIN BMP EFFECTIVENESS, TYPICALLY WHEN SEDIMENT DEPTH REACHES ONE FOOT (I.E., TWO FEET BELOW THE SPILLWAY CREST).

5. SEDIMENT BASINS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND GRASS COVER IS ACCEPTED BY THE LOCAL JURISDICTION.

6. WHEN SEDIMENT BASINS ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Sediment Trap (ST) SC-8

Description

Sediment traps are formed by excavating an area or by placing an earthen embankment across a low area or drainage swale. Sediment traps are designed to capture drainage from disturbed areas less than one acre and allow settling of sediment.

Photograph ST-1. Sediment traps are used to collect sediment-laden runoff from disturbed area. Photo courtesy of EPA Menu of BMPs.

Appropriate Uses

Sediment traps can be used in combination with other layers of erosion and sediment controls to trap sediment from small drainage areas (less than one acre) or areas with localized high sediment loading. For example, sediment traps are often provided in conjunction with vehicle tracking controls and wheel wash facilities.

Design and Installation

A sediment trap consists of a small excavated basin with an earthen berm and a riprap outlet. The berm of the sediment trap may be constructed from the excavated material and must be compacted to 95 percent of the maximum density in accordance with ASTM D698. An overflow outlet must be provided at an elevation at least 6 inches below the top of the berm. See Detail ST-1 for additional design and installation information.

Maintenance and Removal

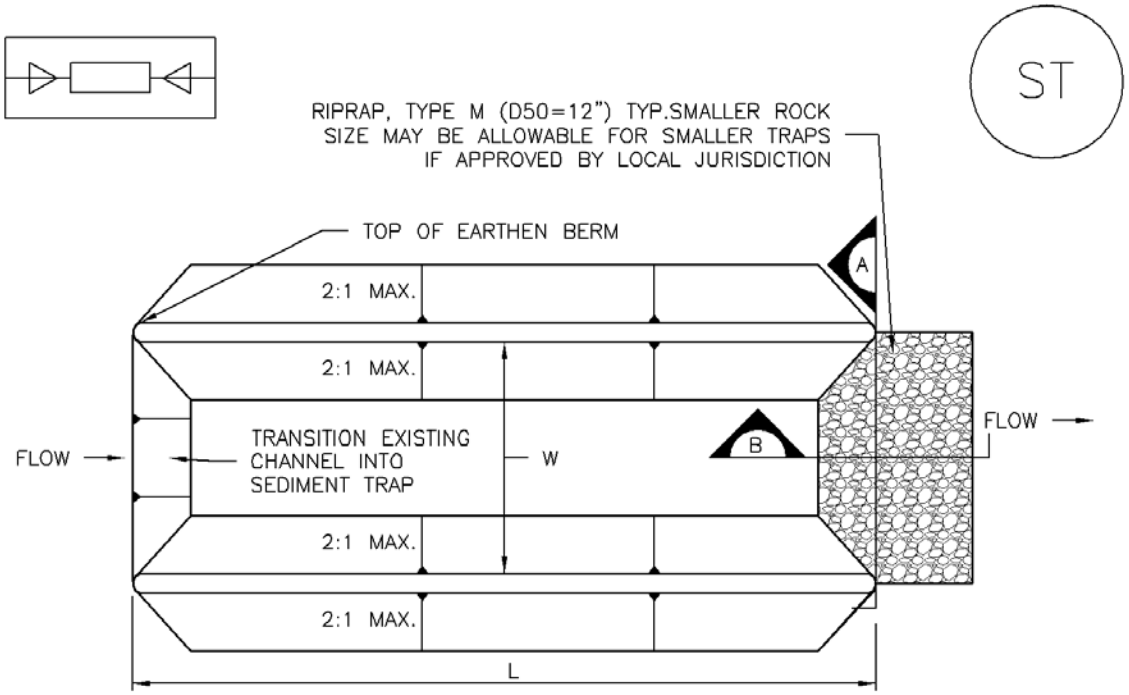
Inspect the sediment trap embankments for stability and seepage.

Remove accumulated sediment as needed to maintain the effectiveness of the sediment trap, typically when the sediment depth is approximately one-half the height of the outflow embankment.

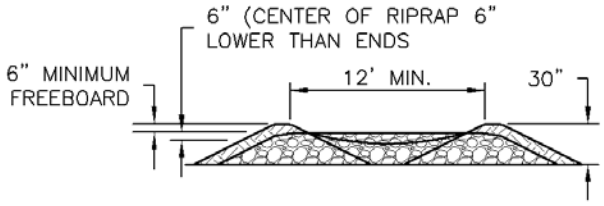
Inspect the outlet for debris and damage. Repair damage to the outlet, and remove all obstructions.

A sediment trap should not be removed until the upstream area is sufficiently stabilized. Upon removal of the trap, the disturbed area should be covered with topsoil and stabilized.

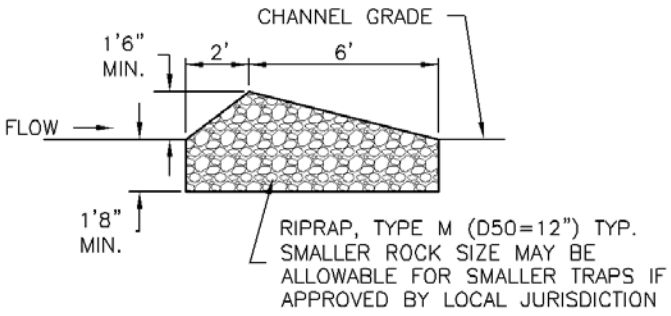
Sediment Trap	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No



SEDIMENT TRAP PLAN



SECTION A



SECTION B

ST–1. SEDIMENT TRAP

SEDIMENT TRAP INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION, LENGTH AND WIDTH OF SEDIMENT TRAP.

2. ONLY USE FOR DRAINAGE AREAS LESS THAN 1 ACRE.

3. SEDIMENT TRAPS SHALL BE INSTALLED PRIOR TO ANY UPGRADIENT LAND–DISTURBING ACTIVITIES.

4. SEDIMENT TRAP BERM SHALL BE CONSTRUCTED FROM MATERIAL FROM EXCAVATION. THE BERM SHALL BE COMPACTED TO 95% OF THE MAXIMUM DENSITY IN ACCORDANCE WITH ASTM D698.

5. SEDIMENT TRAP OUTLET TO BE CONSTRUCTED OF RIPRAP, TYPE M (D50=12") TYP.SMALLER ROCK SIZE MAY BE ALLOWABLE FOR SMALLER TRAPS IF APPROVED BY LOCAL JURISDICTION.

6. THE TOP OF THE EARTHEN BERM SHALL BE A MINIMUM OF 6" HIGHER THAN THE TOP OF THE RIPRAP OUTLET STRUCTURE.

7. THE ENDS OF THE RIPRAP OUTLET STRUCTURE SHALL BE A MINIMUM OF 6" HIGHER THAN THE CENTER OF THE OUTLET STRUCTURE.

SEDIMENT TRAP MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. REMOVE SEDIMENT ACCUMULATED IN TRAP AS NEEDED TO MAINTAIN THE FUNCTIONALITY OF THE BMP, TYPICALLY WHEN THE SEDIMENT DEPTH REACHES ½ THE HEIGHT OF THE RIPRAP OUTLET.

5. SEDIMENT TRAPS SHALL REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

6. WHEN SEDIMENT TRAPS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Buffer strips of preserved natural vegetation or grass help protect waterways and wetlands from land disturbing activities. Vegetated buffers improve stormwater runoff quality by straining sediment, promoting infiltration, and slowing runoff velocities.

Photograph VB-1. A vegetated buffer is maintained between the area of active construction and the drainage swale. Photo courtesy of WWE.

Appropriate Uses

Vegetated buffers can be used to separate land disturbing activities and natural surface waters or conveyances. In many jurisdictions, local governments require some type of setback from natural waterways. Concentrated flow should not be directed through a buffer; instead, runoff should be in the form of sheet flow. Vegetated buffers are typically used in combination with other perimeter control BMPs such as sediment control logs or silt fence for multi-layered protection.

Design and Installation

Minimum buffer widths may vary based on local regulations. Clearly delineate the boundary of the natural buffer area using construction fencing, silt fence, or a comparable technique. In areas that have been cleared and graded, vegetated buffers such as sod can also be installed to create or restore a vegetated buffer around the perimeter of the site.

Maintenance and Removal

Inspect buffer areas for signs of erosion such as gullies or rills. Stabilize eroding areas, as needed. If erosion is due to concentrated flow conditions, it may be necessary to install a level spreader or other technique to restore sheet flow conditions. Inspect perimeter controls delineating the vegetative buffer and repair or replace as needed.

Vegetated Buffers	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	Yes

Chemical Treatment (CT) SC-10

Description

Chemical treatment for erosion and sediment control can take several forms:

1. Applying chemicals to disturbed surfaces to reduce erosion (these uses are discussed in the Soil Binders Fact Sheet).

2. Adding flocculants to sedimentation ponds or tanks to enhance sediment removal prior.

3. Using proprietary barriers or flow-through devices containing flocculants (e.g., "floc logs").

Photograph CT-1. Proprietary chemical treatment system being used on a construction site with sensitive receiving waters. Photo courtesy of WWE.

The use of flocculants as described in No. 2 and No. 3 above will likely require special permitting. Check with the state permitting agency. See the Soil Binder BMP Fact Sheet for information on surface application of chemical treatments, as described in No. 1.

Appropriate Uses

At sites with fine-grained materials such as clays, chemical addition to sedimentation ponds or tanks can enhance settling of suspended materials through flocculation.

Prior to selecting and using chemical treatments, it is important to check state and local permit requirements related to their use.

Design and Installation

Due to variations among proprietary chemical treatment methods, design details are not provided for this BMP. Chemical feed systems for sedimentation ponds, settling tanks and dewatering bags should be installed and operated in accordance with manufacturer's recommendations and applicable regulations. Alum and chitosan are two common chemicals used as flocculants. Because the potential long-term impact of these chemicals to natural drainageways is not yet fully understood, the state does not currently allow chemical addition under the CDPS General Stormwater Construction Discharge Permit. Additional permitting may be necessary, which may include sampling requirements and numeric discharge limits.

Any devices or barriers containing chemicals should be installed following manufacturer's guidelines. Check for state and local jurisdiction usage restrictions and requirements before including these practices in the SWMP and implementing them onsite.

Chemical Treatment	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	No

Maintenance and Removal

Chemical feed systems for sedimentation ponds or tanks should be maintained in accordance with manufacturer's recommendations and removed when the systems are no longer being used. Accumulated sediment should be dried and disposed of either at a landfill or in accordance with applicable regulations.

Barriers and devices containing chemicals should be removed and replaced when tears or other damage to the devices are observed. These barriers should be removed and properly disposed of when the site has been stabilized.

Construction Phasing/Sequencing (CP) SM-1

Description

Photograph CP-1. Construction phasing to avoid disturbing the entire area at one time. Photo courtesy of WWE.

Effective construction site management to minimize erosion and sediment transport includes attention to construction phasing, scheduling, and sequencing of land disturbing activities. On most construction projects, erosion and sediment controls will need to be adjusted as the project progresses and should be documented in the SWMP.

Construction phasing refers to disturbing only part of a site at a time to limit the potential for erosion from dormant parts of a site. Grading activities and construction are completed and soils are effectively stabilized on one part of a site before grading and construction begins on another portion of the site.

Construction sequencing or scheduling refers to a specified work schedule that coordinates the timing of land disturbing activities and the installation of erosion and sediment control practices.

Appropriate Uses

All construction projects can benefit from upfront planning to phase and sequence construction activities to minimize the extent and duration of disturbance. Larger projects and linear construction projects may benefit most from construction sequencing or phasing, but even small projects can benefit from construction sequencing that minimizes the duration of disturbance.

Typically, erosion and sediment controls needed at a site will change as a site progresses through the major phases of construction. Erosion and sediment control practices corresponding to each phase of construction must be documented in the SWMP.

Design and Installation

BMPs appropriate to the major phases of development should be identified on construction drawings. In some cases, it will be necessary to provide several drawings showing construction-phase BMPs placed according to stages of development (e.g., clearing and grading, utility installation, active construction, final stabilization). Some municipalities in the Denver area set maximum sizes for disturbed area associated with phases of a construction project. Additionally, requirements for phased construction drawings vary among local governments within the UDFCD boundary. Some local governments require separate erosion and sediment control drawings for initial BMPs, interim conditions (in active construction), and final stabilization.

Construction Scheduling	
Functions	
Erosion Control	Moderate
Sediment Control	Moderate
Site/Material Management	Yes

Typical construction phasing BMPs include:

- Limit the amount of disturbed area at any given time on a site to the extent practical. For example, a 100-acre subdivision might be constructed in five phases of 20 acres each.

- If there is carryover of stockpiled material from one phase to the next, position carryover material in a location easily accessible for the pending phase that will not require disturbance of stabilized areas to access the stockpile. Particularly with regard to efforts to balance cut and fill at a site, careful planning for location of stockpiles is important.

Typical construction sequencing BMPs include:

- Sequence construction activities to minimize duration of soil disturbance and exposure. For example, when multiple utilities will occupy the same trench, schedule installation so that the trench does not have to be closed and opened multiple times.

- Schedule site stabilization activities (e.g., landscaping, seeding and mulching, installation of erosion control blankets) as soon as feasible following grading.

- Install initial erosion and sediment control practices before construction begins. Promptly install additional BMPs for inlet protection, stabilization, etc., as construction activities are completed.

Table CP-1 provides typical sequencing of construction activities and associated BMPs.

Maintenance and Removal

When the construction schedule is altered, erosion and sediment control measures in the SWMP and construction drawings should be appropriately adjusted to reflect actual "on the ground" conditions at the construction site. Be aware that changes in construction schedules can have significant implications for site stabilization, particularly with regard to establishment of vegetative cover.

Table CP-1. Typical Phased BMP Installation for Construction Projects

Project Phase	BMPs
Pre-disturbance, Site Access	▪ Install sediment controls downgradient of access point (on paved streets this may consist of inlet protection). ▪ Establish vehicle tracking control at entrances to paved streets. Fence as needed. ▪ Use construction fencing to define the boundaries of the project and limit access to areas of the site that are not to be disturbed. **Note: it may be necessary to protect inlets in the general vicinity of the site, even if not downgradient, if there is a possibility that sediment tracked from the site could contribute to the inlets.**
Site Clearing and Grubbing	▪ Install perimeter controls as needed on downgradient perimeter of site (silt fence, wattles, etc). ▪ Limit disturbance to those areas planned for disturbance and protect undisturbed areas within the site (construction fence, flagging, etc). ▪ Preserve vegetative buffer at site perimeter. ▪ Create stabilized staging area. ▪ Locate portable toilets on flat surfaces away from drainage paths. Stake in areas susceptible to high winds. ▪ Construct concrete washout area and provide signage. ▪ Establish waste disposal areas. ▪ Install sediment basins. ▪ Create dirt perimeter berms and/or brush barriers during grubbing and clearing. ▪ Separate and stockpile topsoil, leave roughened and/or cover. ▪ Protect stockpiles with perimeter control BMPs. Stockpiles should be located away from drainage paths and should be accessed from the upgradient side so that perimeter controls can remain in place on the downgradient side. Use erosion control blankets, temporary seeding, and/or mulch for stockpiles that will be inactive for an extended period. ▪ Leave disturbed area of site in a roughened condition to limit erosion. Consider temporary revegetation for areas of the site that have been disturbed but that will be inactive for an extended period. ▪ Water to minimize dust but not to the point that watering creates runoff.

Project Phase	BMPs
Utility And Infrastructure Installation	**In Addition to the Above BMPs:** ▪ Close trench as soon as possible (generally at the end of the day). ▪ Use rough-cut street control or apply road base for streets that will not be promptly paved. ▪ Provide inlet protection as streets are paved and inlets are constructed. ▪ Protect and repair BMPs, as necessary. ▪ Perform street sweeping as needed.
Building Construction	**In Addition to the Above BMPs:** ▪ Implement materials management and good housekeeping practices for home building activities. ▪ Use perimeter controls for temporary stockpiles from foundation excavations. ▪ For lots adjacent to streets, lot-line perimeter controls may be necessary at the back of curb.
Final Grading	**In Addition to the Above BMPs:** ▪ Remove excess or waste materials. ▪ Remove stored materials.
Final Stabilization	**In Addition to the Above BMPs:** ▪ Seed and mulch/tackify. ▪ Seed and install blankets on steep slopes. ▪ Remove all temporary BMPs when site has reached final stabilization.

Protection of Existing Vegetation (PV) SM-2

Description

Protection of existing vegetation on a construction site can be accomplished through installation of a construction fence around the area requiring protection. In cases where upgradient areas are disturbed, it may also be necessary to install perimeter controls to minimize sediment loading to sensitive areas such as wetlands. Existing vegetation may be designated for protection to maintain a stable surface cover as part of construction phasing, or vegetation may be protected in areas designated to remain in natural condition under post-development conditions (e.g., wetlands, mature trees, riparian areas, open space).

Photograph PV-1. Protection of existing vegetation and a sensitive area. Photo courtesy of CDOT.

Appropriate Uses

Existing vegetation should be preserved for the maximum practical duration on a construction site through the use of effective construction phasing. Preserving vegetation helps to minimize erosion and can reduce revegetation costs following construction.

Protection of wetland areas is required under the Clean Water Act, unless a permit has been obtained from the U.S. Army Corps of Engineers (USACE) allowing impacts in limited areas.

If trees are to be protected as part of post-development landscaping, care must be taken to avoid several types of damage, some of which may not be apparent at the time of injury. Potential sources of injury include soil compaction during grading or due to construction traffic, direct equipment-related injury such as bark removal, branch breakage, surface grading and trenching, and soil cut and fill. In order to minimize injuries that may lead to immediate or later death of the tree, tree protection zones should be developed during site design, implemented at the beginning of a construction project, as well as continued during active construction.

Design and Installation

General

Once an area has been designated as a preservation area, there should be no construction activity allowed within a set distance of the area. Clearly mark the area with construction fencing. Do not allow stockpiles, equipment, trailers or parking within the protected area. Guidelines to protect various types of existing vegetation follow.

Protection of Existing Vegetation	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	Yes

Surface Cover During Phased Construction

Install construction fencing or other perimeter controls around areas to be protected from clearing and grading as part of construction phasing.

Maintaining surface cover on steep slopes for the maximum practical duration during construction is recommended.

Open Space Preservation

Where natural open space areas will be preserved as part of a development, it is important to install construction fencing around these areas to protect them from compaction. This is particularly important when areas with soils with high infiltration rates are preserved as part of LID designs. Preserved open space areas should not be used for staging and equipment storage.

Wetlands and Riparian Areas

Install a construction fence around the perimeter of the wetland or riparian (streamside vegetation) area to prevent access by equipment. In areas downgradient of disturbed areas, install a perimeter control such as silt fence, sediment control logs, or similar measure to minimize sediment loading to the wetland.

Tree Protection[1]

- Before beginning construction operations, establish a tree protection zone around trees to be preserved by installing construction fences. Allow enough space from the trunk to protect the root zone from soil compaction and mechanical damage, and the branches from mechanical damage (see Table PV-1). If low branches will be kept, place the fence outside of the drip line. Where this is not possible, place fencing as far away from the trunk as possible. In order to maintain a healthy tree, be aware that about 60 percent of the tree's root zone extends beyond the drip line.

Table PV-1
Guidelines for Determining the Tree Protection Zone
(Source: Matheny and Clark, 1998; as cited in GreenCO and WWE 2008)

	Distance from Trunk (ft) per inch of DBH		
Species Tolerance to Damage	*Young*	*Mature*	*Over mature*
Good	0.5'	0.75'	1.0'
Moderate	0.75'	1.0'	1.25'
Poor	1.0'	1.25'	1.5'
Notes: DBH = diameter at breast height (4.5 ft above grade); Young = <20% of life expectancy; Mature = 20%-80% of life expectancy; Over mature =>80% of life expectancy			

- Most tree roots grow within the top 12 to 18 inches of soil. Grade changes within the tree protection zone should be avoided where possible because seemingly minor grade changes can either smother

[1] Tree Protection guidelines adapted from GreenCO and WWE (2008). *Green Industry Best Management Practices (BMPs) for the Conservation and Protection of Water Resources in Colorado: Moving Toward Sustainability, Third Release.* See www.greenco.org for more detailed guidance on tree preservation.

roots (in fill situations) or damage roots (in cut situations). Consider small walls where needed to avoid grade changes in the tree protection zone.

- Place and maintain a layer of mulch 4 to 6-inch thick from the tree trunk to the fencing, keeping a 6-inch space between the mulch and the trunk. Mulch helps to preserve moisture and decrease soil compaction if construction traffic is unavoidable. When planting operations are completed, the mulch may be reused throughout planting areas.

- Limit access, if needed at all, and appoint one route as the main entrance and exit to the tree protection zone. Within the tree protection zone, do not allow any equipment to be stored, chemicals to be dumped, or construction activities to take place except fine grading, irrigation system installation, and planting operations. These activities should be conducted in consultation with a landscaping professional, following Green Industry BMPs.

- Be aware that soil compaction can cause extreme damage to tree health that may appear gradually over a period of years. Soil compaction is easier to prevent than repair.

Maintenance and Removal

Repair or replace damaged or displaced fencing or other protective barriers around the vegetated area.

If damage occurs to a tree, consult an arborist for guidance on how to care for the tree. If a tree in a designated preservation area is damaged beyond repair, remove and replace with a 2-inch diameter tree of the same or similar species.

Construction equipment must not enter a wetland area, except as permitted by the U.S. Army Corps of Engineers (USACE). Inadvertent placement of fill in a wetland is a 404 permit violation and will require notification of the USACE.

If damage to vegetation occurs in a protected area, reseed the area with the same or similar species, following the recommendations in the USDCM *Revegetation* chapter.

Construction Fence (CF) SM-3

Description

A construction fence restricts site access to designated entrances and exits, delineates construction site boundaries, and keeps construction out of sensitive areas such as natural areas to be preserved as open space, wetlands and riparian areas.

Photograph CF-1. A construction fence helps delineate areas where existing vegetation is being protected. Photo courtesy of Douglas County.

Appropriate Uses

A construction fence can be used to delineate the site perimeter and locations within the site where access is restricted to protect natural resources such as wetlands, waterbodies, trees, and other natural areas of the site that should not be disturbed.

If natural resource protection is an objective, then the construction fencing should be used in combination with other perimeter control BMPs such as silt fence, sediment control logs or similar measures.

Design and Installation

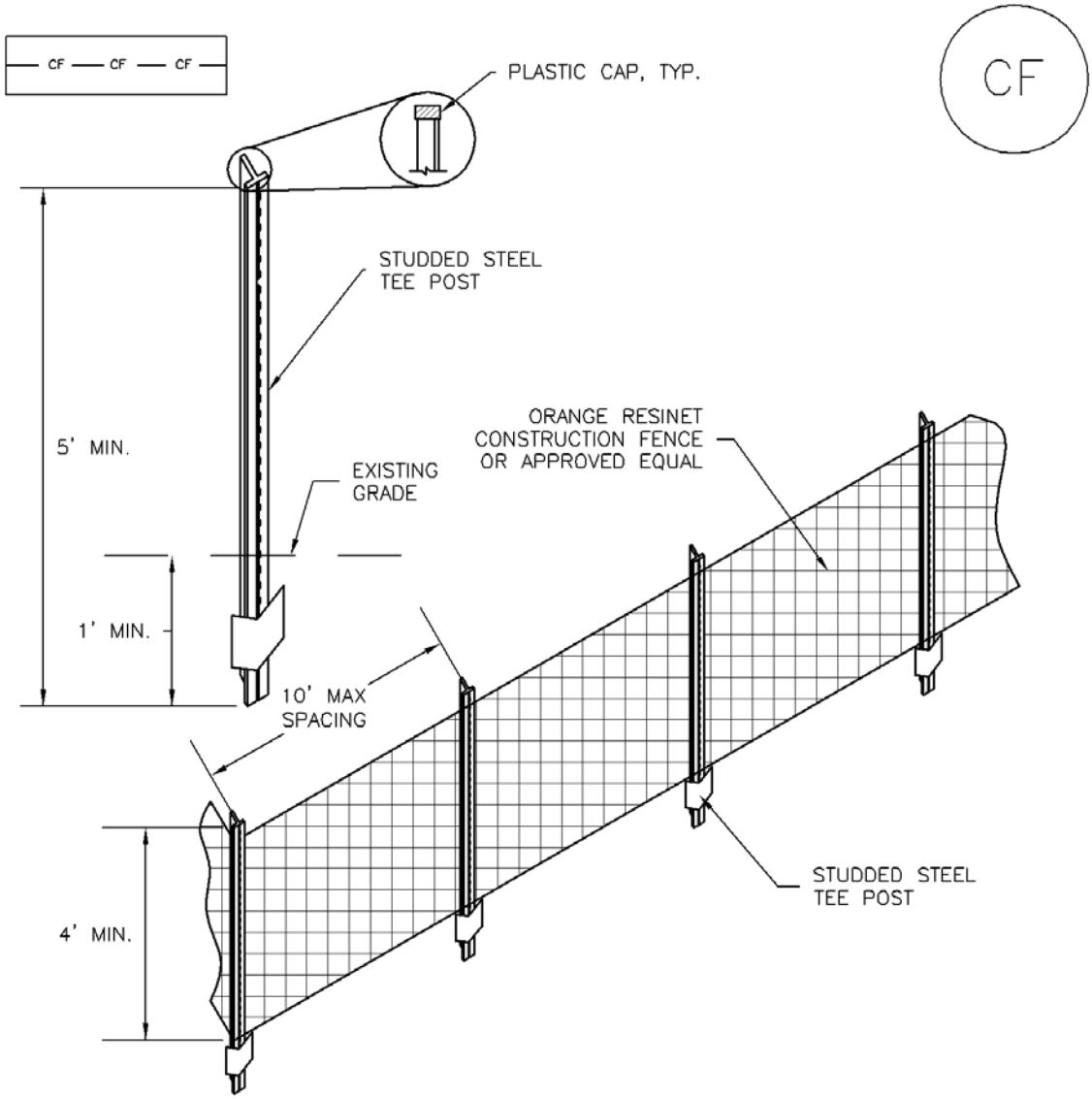
Construction fencing may be chain link or plastic mesh and should be installed following manufacturer's recommendations. See Detail CF-1 for typical installations.

Do not place construction fencing in areas within work limits of machinery.

Maintenance and Removal

- Inspect fences for damage; repair or replace as necessary.
- Fencing should be tight and any areas with slumping or fallen posts should be reinstalled.
- Fencing should be removed once construction is complete.

Construction Fence	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes



CF–1. PLASTIC MESH CONSTRUCTION FENCE

CONSTRUCTION FENCE INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF CONSTRUCTION FENCE.

2. CONSTRUCTION FENCE SHOWN SHALL BE INSTALLED PRIOR TO ANY LAND DISTURBING ACTIVITIES.

3. CONSTRUCTION FENCE SHALL BE COMPOSED OF ORANGE, CONTRACTOR–GRADE MATERIAL THAT IS AT LEAST 4' HIGH. METAL POSTS SHOULD HAVE A PLASTIC CAP FOR SAFETY.

4. STUDDED STEEL TEE POSTS SHALL BE UTILIZED TO SUPPORT THE CONSTRUCTION FENCE. MAXIMUM SPACING FOR STEEL TEE POSTS SHALL BE 10'.

5. CONSTRUCTION FENCE SHALL BE SECURELY FASTENED TO THE TOP, MIDDLE, AND BOTTOM OF EACH POST.

CONSTRUCTION FENCE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. CONSTRUCTION FENCE SHALL BE REPAIRED OR REPLACED WHEN THERE ARE SIGNS OF DAMAGE SUCH AS RIPS OR SAGS. CONSTRUCTION FENCE IS TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

5. WHEN CONSTRUCTION FENCES ARE REMOVED, ALL DISTURBED AREAS ASSOCIATED WITH THE INSTALLATION, MAINTENANCE, AND/OR REMOVAL OF THE FENCE SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED, OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

Vehicle Tracking Control (VTC) SM-4

Description

Vehicle tracking controls provide stabilized construction site access where vehicles exit the site onto paved public roads. An effective vehicle tracking control helps remove sediment (mud or dirt) from vehicles, reducing tracking onto the paved surface.

Photograph VTC-1. A vehicle tracking control pad constructed with properly sized rock reduces off-site sediment tracking.

Appropriate Uses

Implement a stabilized construction entrance or vehicle tracking control where frequent heavy vehicle traffic exits the construction site onto a paved roadway. An effective vehicle tracking control is particularly important during the following conditions:

- Wet weather periods when mud is easily tracked off site.
- During dry weather periods where dust is a concern.
- When poorly drained, clayey soils are present on site.

Although wheel washes are not required in designs of vehicle tracking controls, they may be needed at particularly muddy sites.

Design and Installation

Construct the vehicle tracking control on a level surface. Where feasible, grade the tracking control towards the construction site to reduce off-site runoff. Place signage, as needed, to direct construction vehicles to the designated exit through the vehicle tracking control. There are several different types of stabilized construction entrances including:

VTC-1. Aggregate Vehicle Tracking Control. This is a coarse-aggregate surfaced pad underlain by a geotextile. This is the most common vehicle tracking control, and when properly maintained can be effective at removing sediment from vehicle tires.

VTC-2. Vehicle Tracking Control with Construction Mat or Turf Reinforcement Mat. This type of control may be appropriate for site access at very small construction sites with low traffic volume over vegetated areas. Although this application does not typically remove sediment from vehicles, it helps protect existing vegetation and provides a stabilized entrance.

Vehicle Tracking Control	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	Yes

VTC-3. Stabilized Construction Entrance/Exit with Wheel Wash. This is an aggregate pad, similar to VTC-1, but includes equipment for tire washing. The wheel wash equipment may be as simple as hand-held power washing equipment to more advance proprietary systems. When a wheel wash is provided, it is important to direct wash water to a sediment trap prior to discharge from the site.

Vehicle tracking controls are sometimes installed in combination with a sediment trap to treat runoff.

Maintenance and Removal

Inspect the area for degradation and replace aggregate or material used for a stabilized entrance/exit as needed. If the area becomes clogged and ponds water, remove and dispose of excess sediment or replace material with a fresh layer of aggregate as necessary.

With aggregate vehicle tracking controls, ensure rock and debris from this area do not enter the public right-of-way.

Remove sediment that is tracked onto the public right of way daily or more frequently as needed. Excess sediment in the roadway indicates that the stabilized construction entrance needs maintenance.

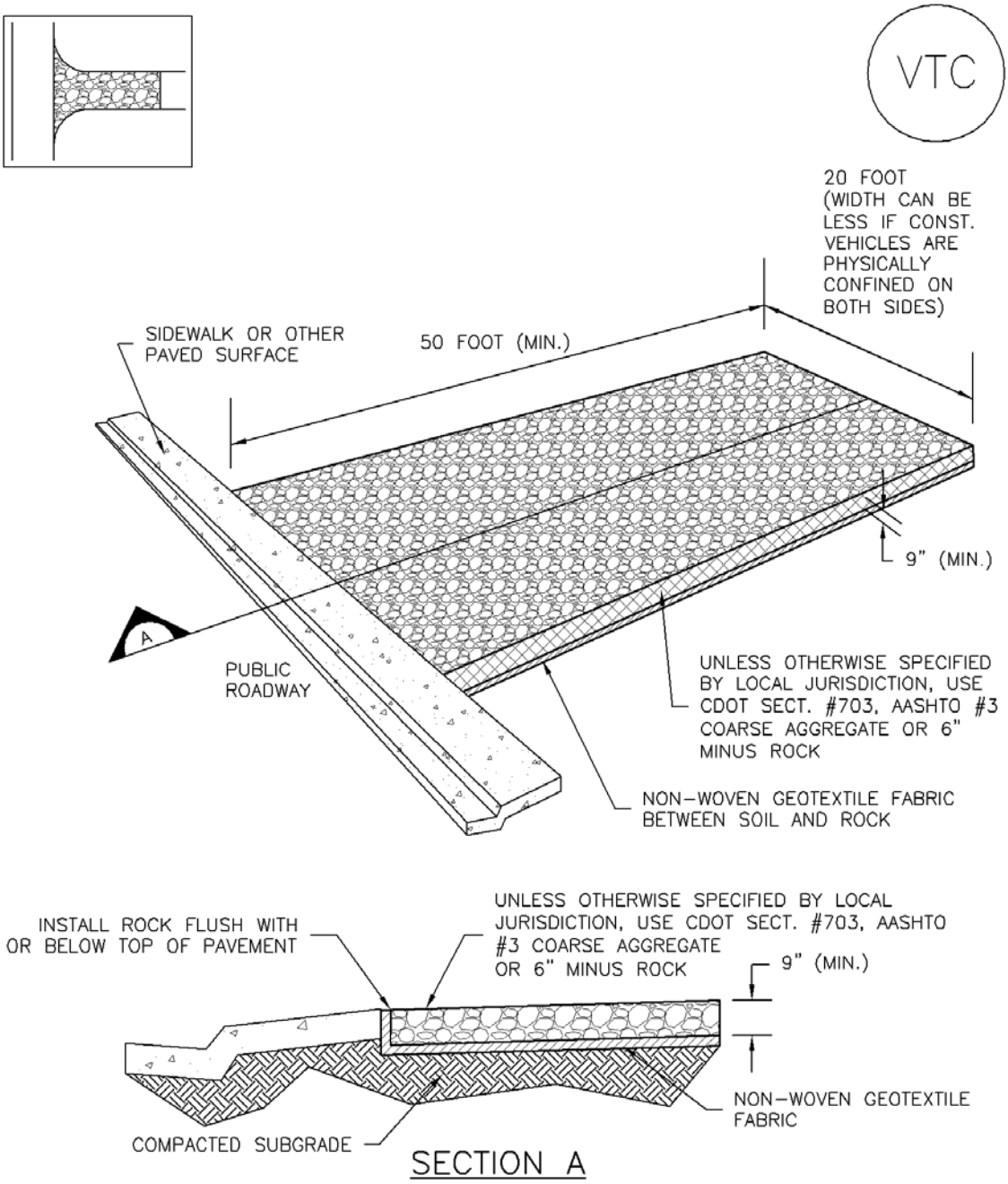
Ensure that drainage ditches at the entrance/exit area remain clear.

Photograph VTC-2. A vehicle tracking control pad with wheel wash facility. Photo courtesy of Tom Gore.

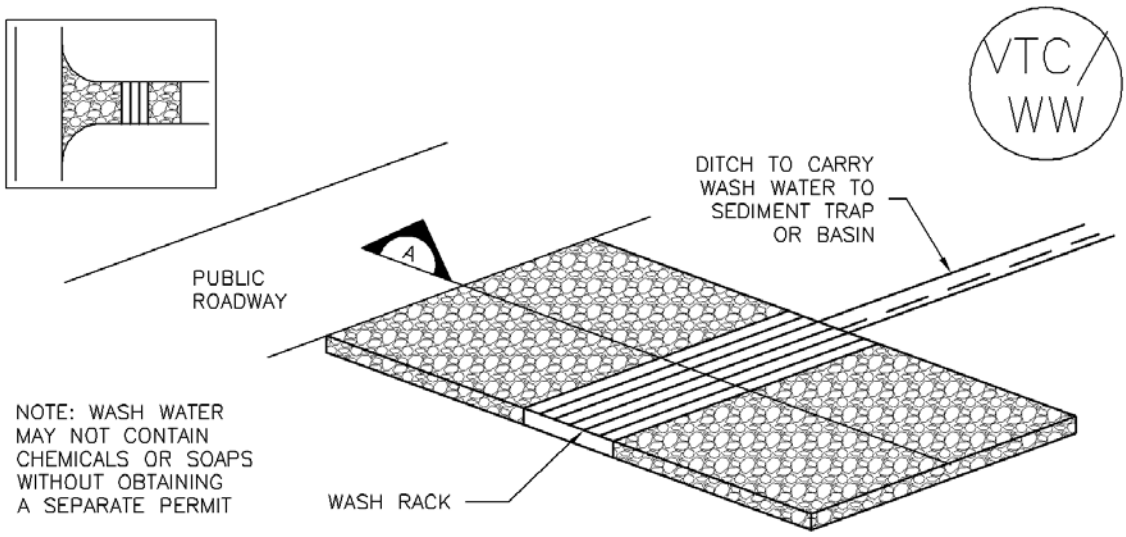
A stabilized entrance should be removed only when there is no longer the potential for vehicle tracking to occur. This is typically after the site has been stabilized.

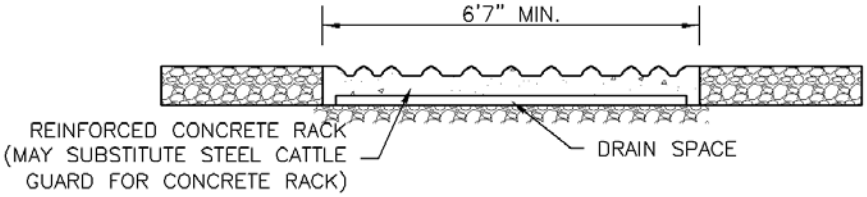
When wheel wash equipment is used, be sure that the wash water is discharged to a sediment trap prior to discharge. Also inspect channels conveying the water from the wash area to the sediment trap and stabilize areas that may be eroding.

When a construction entrance/exit is removed, excess sediment from the aggregate should be removed and disposed of appropriately. The entrance should be promptly stabilized with a permanent surface following removal, typically by paving.



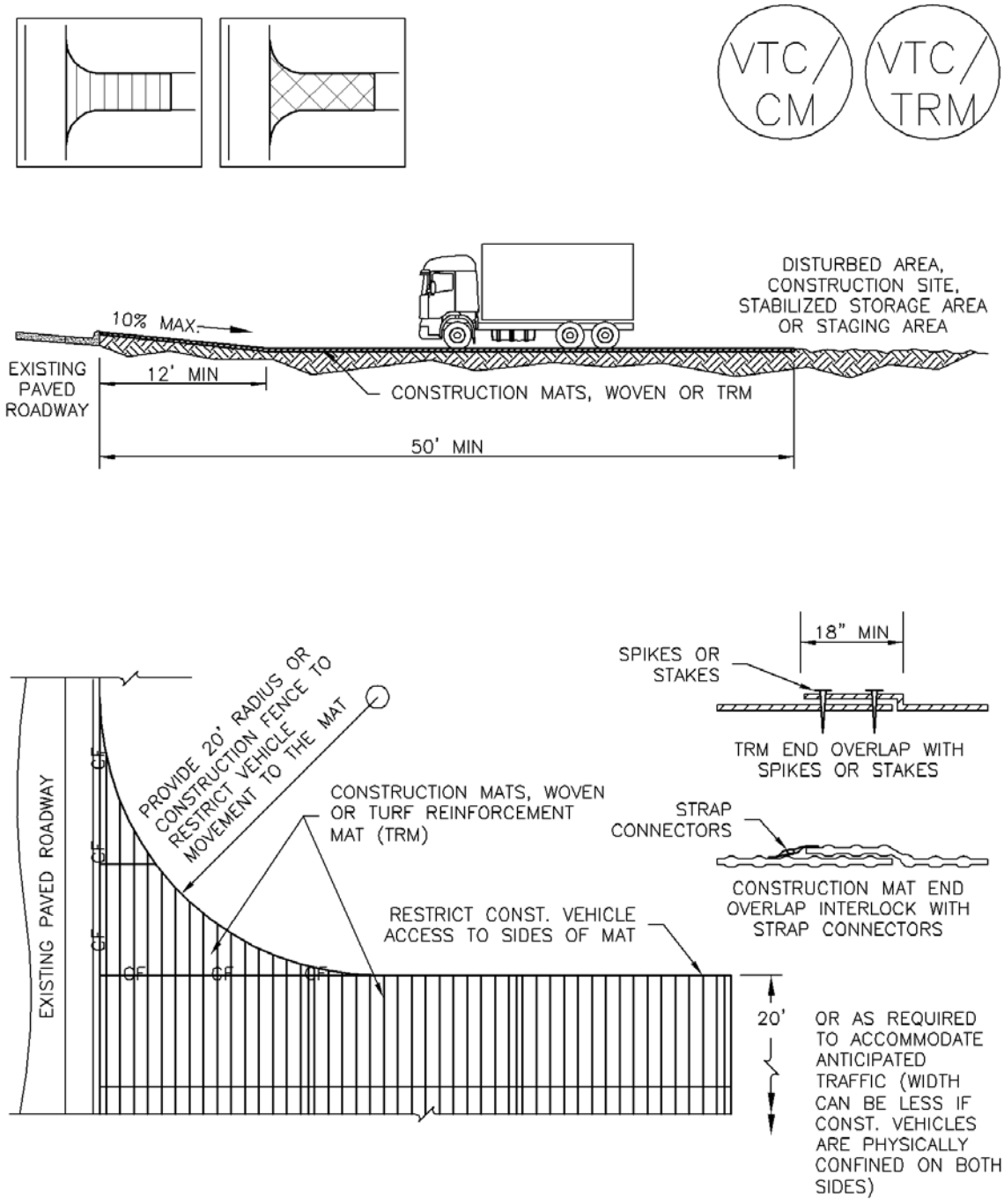
VTC-1. AGGREGATE VEHICLE TRACKING CONTROL





SECTION A

VTC–2. AGGREGATE VEHICLE TRACKING CONTROL WITH WASH RACK



VTC–3. VEHICLE TRACKING CONTROL W/ CONSTRUCTION MAT OR TURF REINFORCEMENT MAT (TRM)

STABILIZED CONSTRUCTION ENTRANCE/EXIT INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   -LOCATION OF CONSTRUCTION ENTRANCE(S)/EXIT(S).
   -TYPE OF CONSTRUCTION ENTRANCE(S)/EXITS(S) (WITH/WITHOUT WHEEL WASH, CONSTRUCTION MAT OR TRM).

2. CONSTRUCTION MAT OR TRM STABILIZED CONSTRUCTION ENTRANCES ARE ONLY TO BE USED ON SHORT DURATION PROJECTS (TYPICALLY RANGING FROM A WEEK TO A MONTH) WHERE THERE WILL BE LIMITED VEHICULAR ACCESS.

3. A STABILIZED CONSTRUCTION ENTRANCE/EXIT SHALL BE LOCATED AT ALL ACCESS POINTS WHERE VEHICLES ACCESS THE CONSTRUCTION SITE FROM PAVED RIGHT-OF-WAYS.

4. STABILIZED CONSTRUCTION ENTRANCE/EXIT SHALL BE INSTALLED PRIOR TO ANY LAND DISTURBING ACTIVITIES.

5. A NON-WOVEN GEOTEXTILE FABRIC SHALL BE PLACED UNDER THE STABILIZED CONSTRUCTION ENTRANCE/EXIT PRIOR TO THE PLACEMENT OF ROCK.

6. UNLESS OTHERWISE SPECIFIED BY LOCAL JURISDICTION, ROCK SHALL CONSIST OF DOT SECT. #703, AASHTO #3 COARSE AGGREGATE OR 6" (MINUS) ROCK.

STABILIZED CONSTRUCTION ENTRANCE/EXIT MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ROCK SHALL BE REAPPLIED OR REGRADED AS NECESSARY TO THE STABILIZED ENTRANCE/EXIT TO MAINTAIN A CONSISTENT DEPTH.

5. SEDIMENT TRACKED ONTO PAVED ROADS IS TO BE REMOVED THROUGHOUT THE DAY AND AT THE END OF THE DAY BY SHOVELING OR SWEEPING. SEDIMENT MAY NOT BE WASHED DOWN STORM SEWER DRAINS.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM CITY OF BROOMFIELD, COLORADO, NOT AVAILABLE IN AUTOCAD)

Stabilized Construction Roadway (SCR) SM-5

Description

A stabilized construction roadway is a temporary method to control sediment runoff, vehicle tracking, and dust from roads during construction activities.

Photograph SCR-1. Stabilized construction roadway.

Appropriate Uses

Use on high traffic construction roads to minimize dust and erosion.

Stabilized construction roadways are used instead of rough-cut street controls on roadways with frequent construction traffic.

Design and Installation

Stabilized construction roadways typically involve two key components: 1) stabilizing the road surface with an aggregate base course of 3-inch-diameter granular material and 2) stabilizing roadside ditches, if applicable. Early application of road base is generally suitable where a layer of coarse aggregate is specified for final road construction.

Maintenance and Removal

Apply additional gravel as necessary to ensure roadway integrity.

Inspect drainage ditches along the roadway for erosion and stabilize, as needed, through the use of check dams or rolled erosion control products.

Gravel may be removed once the road is ready to be paved. Prior to paving, the road should be inspected for grade changes and damage. Regrade and repair as necessary.

Stabilized Construction Roadway	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	Yes

Stabilized Staging Area (SSA) SM-6

Description

A stabilized staging area is a clearly designated area where construction equipment and vehicles, stockpiles, waste bins, and other construction-related materials are stored. The contractor office trailer may also be located in this area. Depending on the size of the construction site, more than one staging area may be necessary.

Photograph SSA-1. Example of a staging area with a gravel surface to prevent mud tracking and reduce runoff. Photo courtesy of Douglas County.

Appropriate Uses

Most construction sites will require a staging area, which should be clearly designated in SWMP drawings. The layout of the staging area may vary depending on the type of construction activity. Staging areas located in roadways due to space constraints require special measures to avoid materials being washed into storm inlets.

Design and Installation

Stabilized staging areas should be completed prior to other construction activities beginning on the site. Major components of a stabilized staging area include:

- Appropriate space to contain storage and provide for loading/unloading operations, as well as parking if necessary.
- A stabilized surface, either paved or covered, with 3-inch diameter aggregate or larger.
- Perimeter controls such as silt fence, sediment control logs, or other measures.
- Construction fencing to prevent unauthorized access to construction materials.
- Provisions for Good Housekeeping practices related to materials storage and disposal, as described in the Good Housekeeping BMP Fact Sheet.
- A stabilized construction entrance/exit, as described in the Vehicle Tracking Control BMP Fact Sheet, to accommodate traffic associated with material delivery and waste disposal vehicles.

Over-sizing the stabilized staging area may result in disturbance of existing vegetation in excess of that required for the project. This increases costs, as well as requirements for long-term stabilization following the construction period. When designing the stabilized staging area, minimize the area of disturbance to the extent practical.

Stabilized Staging Area	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material	Yes

Minimizing Long-Term Stabilization Requirements

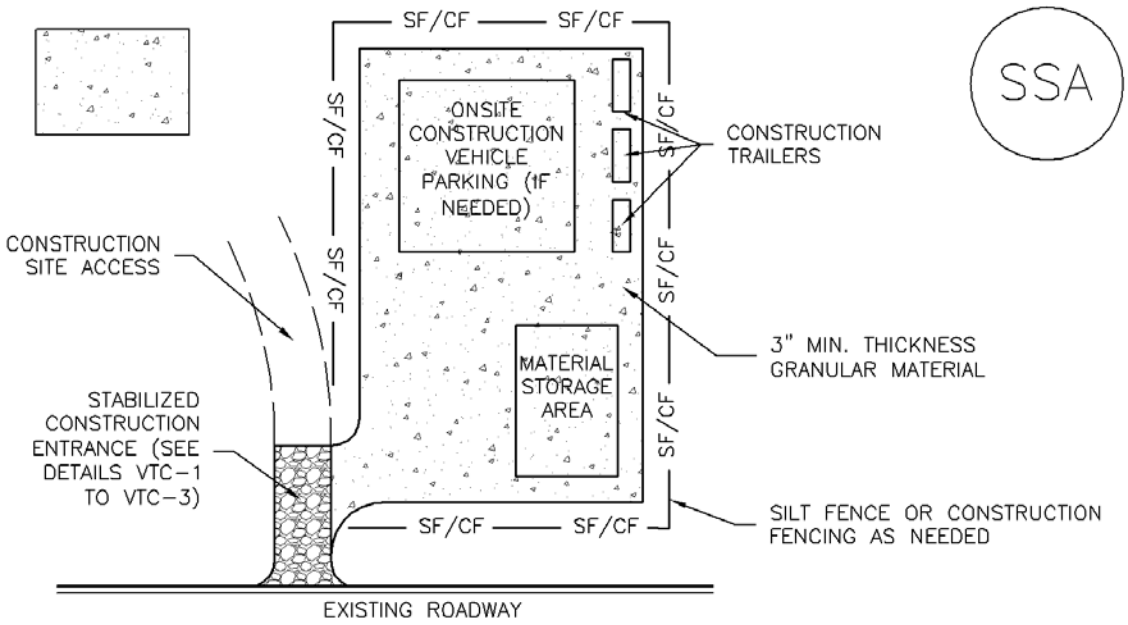
- Utilize off-site parking and restrict vehicle access to the site.
- Use construction mats in lieu of rock when staging is provided in an area that will not be disturbed otherwise.
- Consider use of a bermed contained area for materials and equipment that do not require a stabilized surface.
- Consider phasing of staging areas to avoid disturbance in an area that will not be otherwise disturbed.

See Detail SSA-1 for a typical stabilized staging area and SSA-2 for a stabilized staging area when materials staging in roadways is required.

Maintenance and Removal

Maintenance of stabilized staging areas includes maintaining a stable surface cover of gravel, repairing perimeter controls, and following good housekeeping practices.

When construction is complete, debris, unused stockpiles and materials should be recycled or properly disposed. In some cases, this will require disposal of contaminated soil from equipment leaks in an appropriate landfill. Staging areas should then be permanently stabilized with vegetation or other surface cover planned for the development.



SSA–1. STABILIZED STAGING AREA

STABILIZED STAGING AREA INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   –LOCATION OF STAGING AREA(S).
   –CONTRACTOR MAY ADJUST LOCATION AND SIZE OF STAGING AREA WITH APPROVAL FROM THE LOCAL JURISDICTION.

2. STABILIZED STAGING AREA SHOULD BE APPROPRIATE FOR THE NEEDS OF THE SITE. OVERSIZING RESULTS IN A LARGER AREA TO STABILIZE FOLLOWING CONSTRUCTION.

3. STAGING AREA SHALL BE STABILIZED PRIOR TO OTHER OPERATIONS ON THE SITE.

4. THE STABILIZED STAGING AREA SHALL CONSIST OF A MINIMUM 3" THICK GRANULAR MATERIAL.

5. UNLESS OTHERWISE SPECIFIED BY LOCAL JURISDICTION, ROCK SHALL CONSIST OF DOT SECT. #703, AASHTO #3 COARSE AGGREGATE OR 6" (MINUS) ROCK.

6. ADDITIONAL PERIMETER BMPs MAY BE REQUIRED INCLUDING BUT NOT LIMITED TO SILT FENCE AND CONSTRUCTION FENCING.

STABILIZED STAGING AREA MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ROCK SHALL BE REAPPLIED OR REGRADED AS NECESSARY IF RUTTING OCCURS OR UNDERLYING SUBGRADE BECOMES EXPOSED.

STABILIZED STAGING AREA MAINTENANCE NOTES

5. STABILIZED STAGING AREA SHALL BE ENLARGED IF NECESSARY TO CONTAIN PARKING, STORAGE, AND UNLOADING/LOADING OPERATIONS.

6. THE STABILIZED STAGING AREA SHALL BE REMOVED AT THE END OF CONSTRUCTION. THE GRANULAR MATERIAL SHALL BE REMOVED OR, IF APPROVED BY THE LOCAL JURISDICTION, USED ON SITE, AND THE AREA COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

NOTE: MANY MUNICIPALITIES PROHIBIT THE USE OF RECYCLED CONCRETE AS GRANULAR MATERIAL FOR STABILIZED STAGING AREAS DUE TO DIFFICULTIES WITH RE-ESTABLISHMENT OF VEGETATION IN AREAS WHERE RECYCLED CONCRETE WAS PLACED.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

Street Sweeping and Vacuuming (SS) SM-7

Description

Street sweeping and vacuuming remove sediment that has been tracked onto roadways to reduce sediment transport into storm drain systems or a surface waterway.

Photograph SS-1. A street sweeper removes sediment and potential pollutants along the curb line at a construction site. Photo courtesy of Tom Gore.

Appropriate Uses

Use this practice at construction sites where vehicles may track sediment offsite onto paved roadways.

Design and Installation

Street sweeping or vacuuming should be conducted when there is noticeable sediment accumulation on roadways adjacent to the construction site. Typically, this will be concentrated at the entrance/exit to the construction site. Well-maintained stabilized construction entrances, vehicle tracking controls and tire wash facilities can help reduce the necessary frequency of street sweeping and vacuuming.

On smaller construction sites, street sweeping can be conducted manually using a shovel and broom. Never wash accumulated sediment on roadways into storm drains.

Maintenance and Removal

- Inspect paved roads around the perimeter of the construction site on a daily basis and more frequently, as needed. Remove accumulated sediment, as needed.
- Following street sweeping, check inlet protection that may have been displaced during street sweeping.
- Inspect area to be swept for materials that may be hazardous prior to beginning sweeping operations.

Street Sweeping/ Vacuuming	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	Yes

Temporary Diversion Methods (TDM) SM-8

Description

Temporary diversion methods are used to reroute water from a stream or restrict flows to a designated portion of the stream channel to allow for construction activities to take place in the stream, along the banks or beneath the active channel. Temporary diversion methods are often required during the construction of detention ponds, dams, in-stream grade control structures, utility installation and other activities, including maintenance, that require working in waterways. Temporary diversion methods include temporary diversion channels, pump-arounds, piped diversions, coffer dams and other similar practices. The primary purpose of all temporary diversion methods is to protect water quality by passing upstream flows around the active construction zone.

Photograph TDM-1. This coffer dam, installed to allow grading and stabilization of the stream bank, consists of concrete blocks covered by an impermeable linear held in place by sand bags.

Appropriate Uses

Temporary diversion methods are appropriate in situations when it is necessary to divert the flow around the area where work is being conducted. Temporary diversion methods vary with the size of the waterway that is being diverted.

Temporary Diversion Channel	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

For large streams, a temporary diversion may consist of berms or coffer dams constructed within the stream to confine flow to one side of the stream while work progresses on the "dry" side of the berm. For smaller streams and often for construction of dams and detention basins, a temporary diversion method may divert the entire waterway. For short duration projects (typically less than a month of active construction) with low baseflows, a pump and/or bypass pipe may serve as a temporary diversion. Whenever a temporary diversion is used, construction should be scheduled during drier times of the year (November through March) to the extent feasible, and construction in the waterway should progress as quickly as practical to reduce the risk of exceeding the temporary diversion capacity. Timing and duration of construction are primary considerations for determining the design flow most appropriate for a diversion. A sizing method that does not consider these variables is overly simplistic and can result in inflated project costs and land disturbances that provide little to no water quality benefit. Additionally, disturbing more area than necessary can result in increased erosion.

Temporary diversion method section and approach should occur on a project- and site-specific basis. For short duration projects (typically associated with maintenance of utilities and stream crossings and minor repairs to outfalls and eroded banks) constructed during dry times of the year, diversion construction can create greater disturbance and mobilization of sediment than all of the other earth disturbing activities of the project combined, and the cost of the diversion could be a significant percentage of the overall project cost. If it can be reasonably determined, based on area and duration of disturbance, that channel work will result in less disturbance and movement of sediment than would occur through installation of a temporary diversion, it is reasonable to exempt these activities from the requirement to construct a temporary diversion.

On the other end of the spectrum, a basis of design for a temporary diversion in excess of the methodology presented in this Fact Sheet may be appropriate for longer duration projects and/or projects where the consequences of exceeding diversion capacity are significant in terms of public safety, damage to infrastructure and property, environmental impacts, damage or delay to the project and other factors. In short, engineers should recognize that temporary diversions must be thoughtfully analyzed on a case-by-case basis, considering site-specific circumstances.

Design Considerations

Selection and design of temporary diversion methods should consider many factors, including:

- Will construction of a temporary diversion cause greater environmental impacts than if the project is constructed without a temporary diversion? This frequently applies to short duration, small scale projects associated with maintenance activities such as bank erosion repair, drop structure and pond maintenance, outfall improvements/repair and other limited construction activities.

- Size of stream, tributary watershed area and anticipated flow rates during construction. Special consideration should be given to large streams with large tributary areas with higher flow rates since the sizing methodology presented in this Fact Sheet is based on data from watersheds less than 20 square miles.

- Any special water quality or aquatic life conditions the waterway.

- Nature of surrounding land use, property ownership, and easements in the project area are important considerations in determining feasibility and methods for temporary diversions. For example, in a highly urbanized setting or an area with limited right-of-way, there may not be adequate space to construct a diversion channel.

- Seasonal variations in stream hydrology (baseflow vs. peak flow).
    - Irrigation flows: If an irrigation ditch enters the stream, it is recommended that the ditch company be contacted to confirm when flows from the ditch may be expected.
    - Weather (storm runoff): If diversions are constructed in summer months when thunderstorms and flash flooding can occur, contractors will need to track weather forecasts closely and provide additional protection when higher flows from runoff are anticipated. The UDFCD Alert System can be used for daily forecasts and to provide warnings for severe weather.

- Probability of flood flows exceeding diversion capacity and/or diversion failure. Consider the consequences of exceedance or failure such as:
    - Public safety
    - Environmental
    - Legal
    - Regulatory
    - Economic
    - Project disruption/delay

- Realistic estimation of project duration and time of year during which construction will occur.

- Comparison of the overall project costs to the temporary diversion costs (design and construction) and determining the costs and benefits of different diversion strategies relative to the protection that they provide.

- Permitting requirements for overall project and for diversion methods (United States Army Corps of Engineers, United States Fish and Wildlife Service, Colorado Department of Public Health and Environment, Federal Emergency Management Agency, Division of Water Resources, local governments, and others). Permit requirements and existing vegetative cover may limit the allowable area disturbance.

- Public safety aspects. For example, if a pipeline is being used, consideration should be given to public access and inlet protection.

- Legal considerations, which are a function of many different factors such as property ownership, history of localized flooding, or parties that will have interest in project.

Design and Installation

1. Determine if a diversion is appropriate based on appropriate uses and design considerations stated earlier. As noted, in some cases, constructing a project under wet conditions is preferable to constructing a temporary diversion to create dry conditions, especially if construction of the temporary diversion will require a significant amount of disturbance relative to the overall project.

2. Determine project duration.

    - "Long duration" projects are projects that last longer than three months and in many cases are Capital Improvement Projects or traditional land development projects.

    - "Short duration" projects are projects that are completed within one month or less and generally are associated with maintenance and repair activities.

    - "Interim duration" projects are projects that will last longer than one month but up to three months.

3. Determine the time of year in which construction will occur.

4. Gather necessary temporary diversion sizing parameters that may include tributary area, imperviousness, project duration safety factor, and seasonal sizing coefficient.

5. Apply applicable sizing methodology and perform necessary calculations (provided following this section). Use engineering judgment to determine if the temporary diversion design flow is adequate for the specific project.

6. Determine appropriate method of diversion. Follow the design steps for the selected method discussed below.

    - Channel Diversion – For smaller streams, construction of dams and detention basins, or as the site allows, a channel diversion may divert the entire waterway as illustrated in Figure TDM-1.

- Berm or Coffer Dam – A berm or coffer dam is appropriate for streams of all sizes to confine flow to one side of the stream.
- Piped Diversion – A bypass pipe is generally appropriate for short duration projects with low baseflows.
- Pumped Diversion – A pumped diversion may be appropriate for short duration projects with low baseflows. It may also be the only option where space for the diversion is limited as shown in photograph TDM-2.

Selecting a Diversion Method

Selection of the appropriate diversion type is largely site specific. The best choice represents the most efficient method while keeping disturbance to a minimum.

7. Consider developing an emergency action plan, as a precaution, for rapidly removing equipment and materials with potential to contribute pollutants to runoff from the waterway in advance of imminent runoff with the potential to exceed diversion capacity. The emergency action plan should designate an individual who will be on the site throughout most of the construction project with the authority to order that work be halted and equipment and materials with potential to contribute to stormwater pollution be moved to high ground outside of the active channel. The emergency action plan should identify where equipment and materials removed from the channel will be stored temporarily during a runoff event that is expected to exceed temporary diversion capacity. The UDFCD Alert System and warnings of the potential for severe weather issued by UDFCD should be consulted daily during construction.

Channel Diversion

1. Use sizing methodology to determine temporary diversion design flow rate.

2. Determine channel slope based on existing and proposed site conditions.

   Perform initial channel sizing calculations using Manning's Equation. Determine maximum permissible velocities based on lining material. Pay particular attention to diversion channel entrance, bends, transitions and downstream return to stream where scour forces may require greater protection. Unlined channels should not be used. Table TDM-1 gives Manning's "n" values for the most commonly used lining materials.

   Because temporary diversion channels typically are not in service long enough to establish adequate vegetative lining, they must be designed to be stable for the design flow with the channel shear stress less than the critical tractive shear stress for the channel lining material.

3. Determine the channel geometry and check the capacity using Manning's Equation and the "n" value given in Table TDM-1. The steepest side slope allowable is two horizontal to one vertical (2:1), unless vertical walls are installed using sheet piling, concrete or stacked stone. Consideration for public access and safety should be accounted for when determining channel geometry.

4. Determine depth of flow. A maximum depth of 1-foot is allowed for flows less than 20 cfs and a maximum of 3 feet for flows less than 100 cfs. (Flows in excess of 100 cfs should be designed in accordance with the *Major Drainage* chapter in Volume 1). Provide a minimum of 0.5 feet of freeboard above the design water surface elevation.

Table TDM-1. Manning's n Values for Temporary Diversion Channel Design

Lining Material	Manning's n Depth = 0 to 1.0 ft	Manning's n Depth = 1.0 to 3.0 ft	Manning's n Depth = 3.0 to 5.0 ft
Plastic Membrane	0.011	0.010	0.009
Straw/Curled Wood Mats	0.035	0.025	0.020
Riprap, Type VL	0.070	0.045	0.035
Riprap, Type L	0.100	0.070	0.040
Riprap, Type M	0.125	0.075	0.045

Note: Use manufacturer's Manning's n when available. See the *Major Drainage* chapter of the USDCM for riprap gradation. Erosion protection should extend a minimum of 0.5 feet above the design water depth.

Berm or Coffer Dam

For coffer dams or berms that are intended to isolate a portion of the stream from the work area steps 1-4 should be applied to the "wet" side of the coffer dam or berm.

1. Use sizing methodology to determine temporary diversion design flow rate.

2. Determine channel slope based on existing and proposed site conditions.

3. Perform initial channel sizing calculations using Manning's Equation. Determine maximum permissible velocities based on lining material. Because temporary diversion measures typically are not in service long enough to establish adequate vegetative lining, they must be designed to be stable for the design flow with the channel shear stress less than the critical tractive shear stress for the channel lining material. This stability criterion applies to the stream-side of berms when berms are used to isolate a work area within a stream.

4. Determine the channel geometry and check the capacity using Manning's Equation and the "n" value given in Table TDM-1. The steepest side slope allowable is two horizontal to one vertical (2:1), unless vertical walls are installed using sheet piling, concrete or stacked stone. Provide a minimum of 0.5 feet of freeboard above the design water surface elevation.

Piped Diversion

1. Use sizing methodology to determine temporary diversion design flow rate.

2. Size the pipe to accommodate the design flow using no more than 80 percent of the pipe full flow capacity. Select a Manning's n value based on the type of pipe material that will be used (concrete n = 0.013 [typ.], corrugated metal pipe n = 0.024 [typ.]).

Pumped Diversion

1. Use sizing methodology to determine temporary diversion design flow rate.

2. A backup pump (or pumps) with capacity equal to or greater than the diversion design flow rate should be on site and in good working order at all times.

Photograph TDM-2. Despite a relatively significant baseflow, a pumped diversion was selected for this Lakewood Gulch project due to a lack of space crossing Federal Boulevard. Photo courtesy of City and County of Denver.

Sizing Methodology

The methodology for sizing of temporary diversion methods was developed using baseflow observations and Crest Stage Indicator (CSI) peak flow data collected from 21 watersheds within the UDFCD boundary. These data were collected over extended periods of time (up to 31 years) and, as a result, provide a sound statistical basis for the sizing methodology.

Determine sizing procedure to use based on the project duration.

- "Long duration" projects last longer than three months and in many cases are Capital Improvement Projects or traditional land development projects.

- "Short duration" projects are completed within one month or less and generally are associated with maintenance and repair activities. For these projects, it is recommended that the temporary diversion be sized based on the statistics identified for baseflows (i.e., vs. peak flows) and be of sufficient size to convey a flow that has a less than 50% chance of being exceeded between November – March, including a project duration safety factor.

"Long duration" projects last longer than three months.

"Short duration" projects are completed within one month or less.

"Interim duration" projects last longer than one month and up to three months.

- "Interim duration" projects will last longer than one month but up to three months. In these projects, engineering judgment must be applied, drawing on sizing methods for "short duration" and "long duration" project criteria and the time of year of construction to develop a basis of design for the temporary diversion method that is appropriate for the project.

It is highly recommended that projects involving temporary diversions be constructed between November and March. If a short duration project requiring a temporary diversion must be conducted between April and October, the extended weather forecast should be evaluated to avoid periods of anticipated precipitation and a conservative safety factor should be applied. Additional protection may need to be provided for the site if higher flows from runoff are anticipated.

Sizing Procedure for Long Duration Projects (duration greater than three months)

1. Determine the tributary drainage area, *A*, in square miles.

2. Determine the watershed imperviousness (adjusted as appropriate for disconnected impervious area, see Chapter 3).

3. Determine the design peak flow rate according to Figure TDM-2. Note: For long duration projects, or where the consequences of diversion failure warrant, a larger design flow may be necessary, and/or a more detailed, site-specific hydrologic analysis.

Figure TDM-2 may be used to estimate the design discharge for the sizing of temporary diversion methods for projects exceeding three months in duration. The curves in this figure were originally developed using annual peak flow data collected from 17 watersheds within the UDFCD boundary and then updated in 2012 using annual peak flow data from 21 watersheds with CSI gages. These data were collected over extended periods of time (up to 31 years) and, as a result, provide a sound statistical basis for the figure. The data supporting Figure TDM-2 were taken during the high flood potential period of April through September.

Figure TDM-2 provides estimated 2-year peak flow rates with the upper 5% and lower 95% confidence limits shown and is based on watershed imperviousness for small waterways (25 square miles or less).[1] Because Figure TDM-2 was developed using data from small watersheds, it is not appropriate to extrapolate from this figure for larger, more complex watersheds. For larger waterways (e.g., South Platte River, Sand Creek, Bear Creek, etc.), including ones controlled by flood control reservoirs (e.g., Chatfield Dam, Cherry Creek Dam, etc.), site-specific hydrologic analysis and risk assessment will be necessary to evaluate the appropriate level of protection to be provided by the temporary diversion. For any size watershed, it is important that the designer understand watershed characteristics to determine applicability of the simplified method and how these characteristics influence the choice of diversion method. It is also important to recognize that larger floods can and do occur. It is the responsibility of the designer and the contractor to assess their risk of having the temporary diversion being exceeded and to evaluate the damages such an event may cause to the project, adjacent properties and others.

[1] There are a multitude of factors affecting rainfall-runoff response of a watershed in addition to impervious area. Other factors include soil types, total area, fraction of connected/disconnected impervious area, watershed shape, topography and many other factors). Figure TDM-2 provides a simplified design tool based on watershed imperviousness but should not be blindly relied upon without due consideration of other factors including those listed above and others.

Sizing Procedure for Short Duration Projects (one month or less of active construction)

1. Determine the tributary drainage area, *A*, in square miles.

2. Select a safety factor, *S*, based on project duration from Table TDM-2. Short duration projects have been broken down further into projects less than two weeks and projects from two weeks up to one month.

3. Select the sizing coefficient, *K*, corresponding to the month in which the project will occur (see Table TDM-2). For projects that span two months with different *K* values, use the greater of the two *K* values. For short duration projects that will occur during the traditionally dry period of the year (November through March) a *K* value of 0.2 is recommended. For short duration projects that will occur April through October, and wet weather is not predicted, a *K* value of 0.5 is recommended.

When a diversion is determined to be appropriate, safety factors and *K* values in Table TDM-2 are **minimum** recommended values. Depending on the many factors to consider in selecting and sizing a temporary diversion listed above, higher values for *K* and *S* may be appropriate.

Table TDM-2.Temporary Diversion Sizing Coefficients and Safety Factors for Short Duration Projects

Time of Year	Project Duration	Safety Factor, S	Temporary Diversion Sizing Coefficient, K
November - March	Less than 2 weeks	1.0	0.2
November - March	2 weeks to 1 month	1.5	0.2
April - October	Less than 2 weeks (during dry weather conditions)	1.0	0.5
April - October	2 weeks to 1 month	1.5	0.5

Note: K coefficients were developed from regression analysis of baseflow data from USGS Crest Stage Indicator (CSI) data to approximate flows that have a less than 50% chance of being exceeded between November - March.

4. Calculate the recommended temporary diversion design flow rate using equation TDM-1:

$$Q = S \; K \; A \qquad \text{(Equation TDM-1)}$$

In which,

Q = temporary diversion design flow rate for short-duration projects (cfs).

S = safety factor coefficient from Table TDM-2 based on duration.

K = diversion sizing coefficient from Table TDM-2 based on seasonality.

A = tributary area (square miles).

Of course, if the observed condition at the construction site suggests a higher flow, this should be estimated and used instead.

Example of Short-Duration Temporary Diversion Sizing Methodology

Project Location: Goldsmith Gulch Downstream (north) of E. Cornell Avenue

Planned project will involve approximately 0.12 acres of disturbance for bank stabilization, which will be completed within two weeks during the November to March time period. Using StreamStats, the gross contributing watershed area was determined to be approximately 6.2 mi^2. Based on project duration and seasonal timing, Table TDM-2 yields S = 1.0, K = 0.2. Equation TDM-1 can be used to calculate the recommended diversion flow:

$$Q = S\ K\ A$$

$$Q = 1.0 \bullet 0.2 \bullet 6.2\ mi^2 = 1.2\ cfs$$

Had this been a larger restorative maintenance project that will last 4 weeks, but will be started and completed within the November through March period, application of Equation TDM-1 and the recommended safety factor suggest the following diversion design flow:

$$Q = S\ K\ A$$

$$Q = 1.5 \bullet 0.2 \bullet 6.2\ mi^2 = 1.9\ cfs$$

Sizing Procedure for Interim Duration Projects (longer than one month and up to three months)

When projects last longer than one month but up to three months, a combination of sizing methods should be applied. The recommended temporary diversion flow rate should be evaluated using both the sizing procedure for short duration projects as well as the sizing procedure for long duration projects. These calculated flow rates should be weighed in combination with site-specific factors to determine an appropriate design flow rate. Each site should be evaluated individually to determine factors that may affect the design flow choice. For example, the designer may select to use the more conservative design flow for an interim duration project occurring in July and August where a chance for wet weather is forecast and flooding or damage to the area surrounding the project is unacceptable.

Maintenance and Removal

Because temporary diversions are one of the most critical BMPs for work in waterways, they must be inspected and maintained frequently to remain in effective operating condition. Flow barriers should be inspected at the start and end of each workday and at any time that excess water is noted in dry work areas. For diversion channels, the diversion channel itself should be inspected for signs of erosion, and the lining should be repaired or replaced if there are signs of failure. Check armoring at the diversion return point to the waterway, and add additional armoring if erosion is noted.

Water should not be allowed to flow back through the natural stream until all construction is completed. After redirecting the flow through the natural channel, temporary diversion measures should be removed. For temporary diversion channels, lining materials should be removed, and the diversion channel should then be backfilled and stabilized. Points of tie-in to the natural channel should be protected with riprap sized

in accordance with the *Major Drainage* chapter in Volume 1.

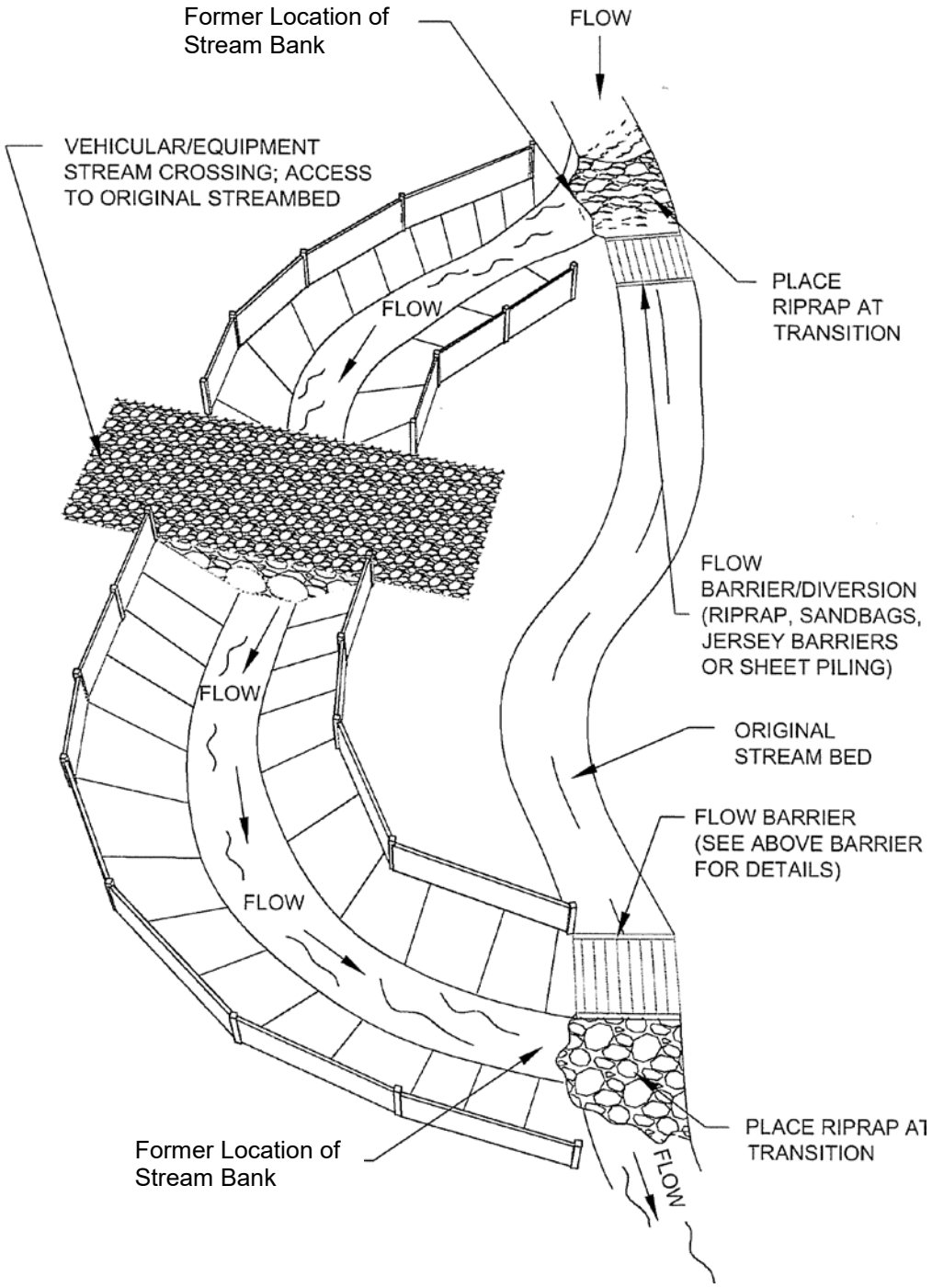


Figure TDM-1. Typical Temporary Diversion Channel

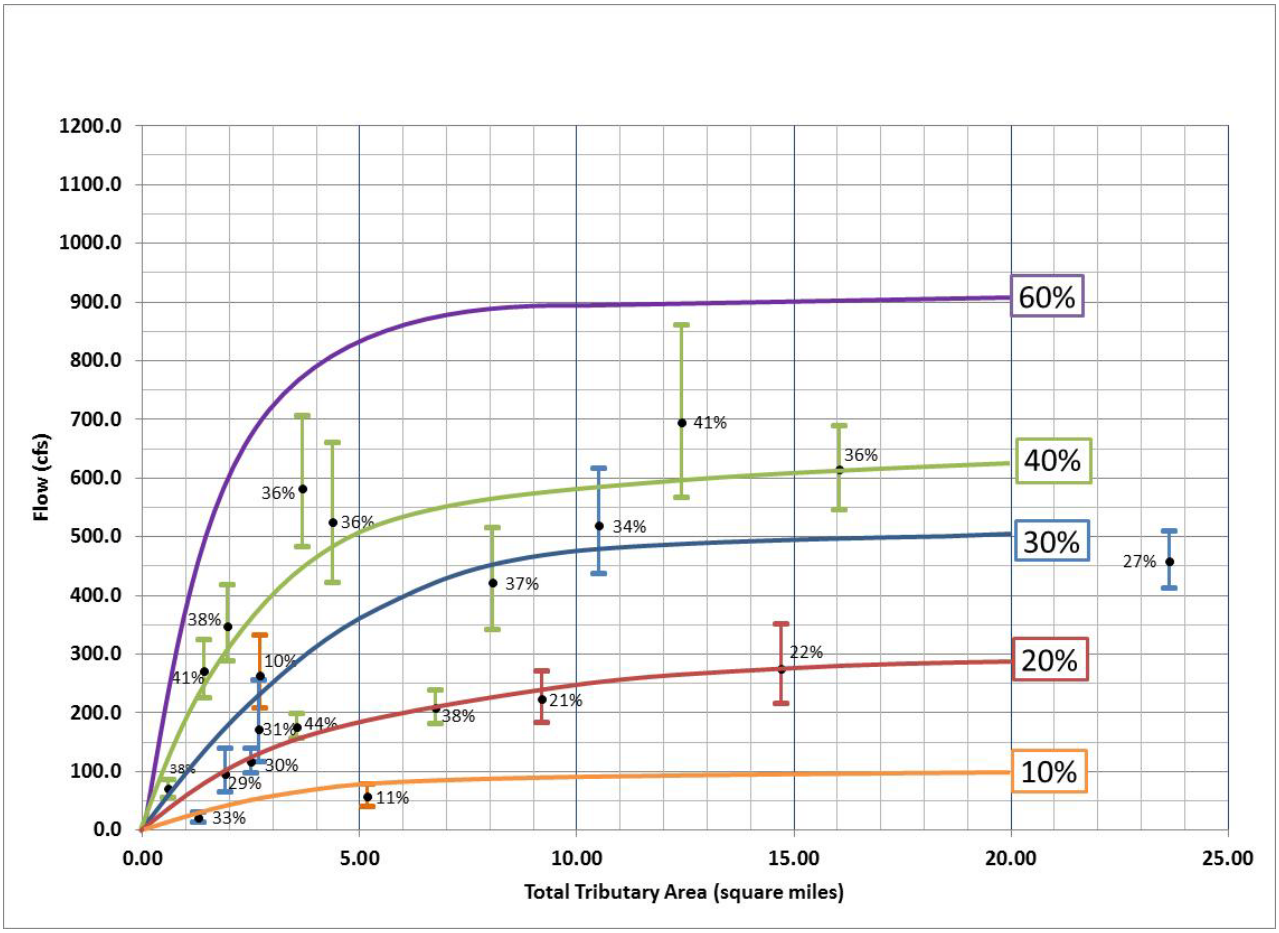
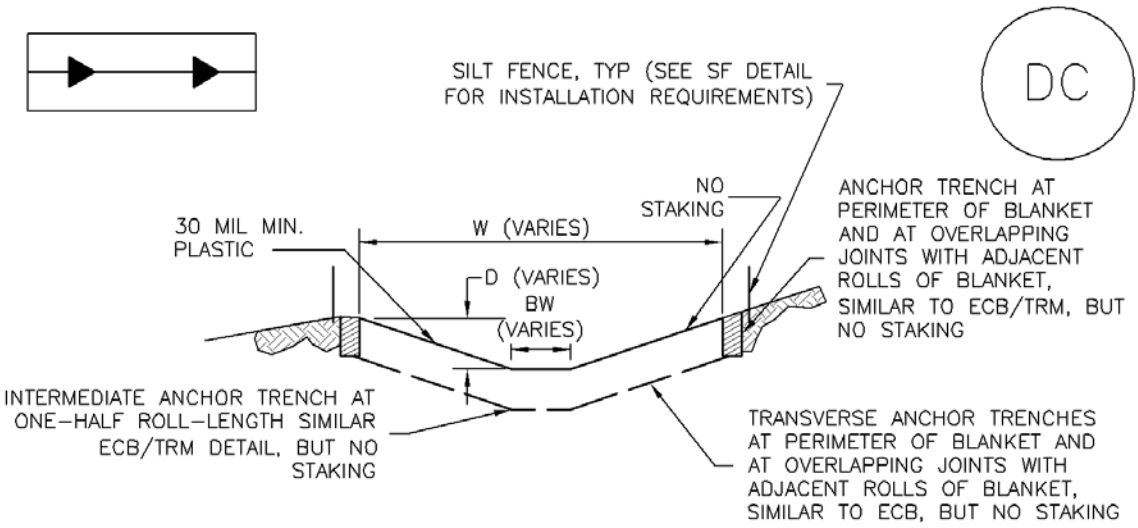
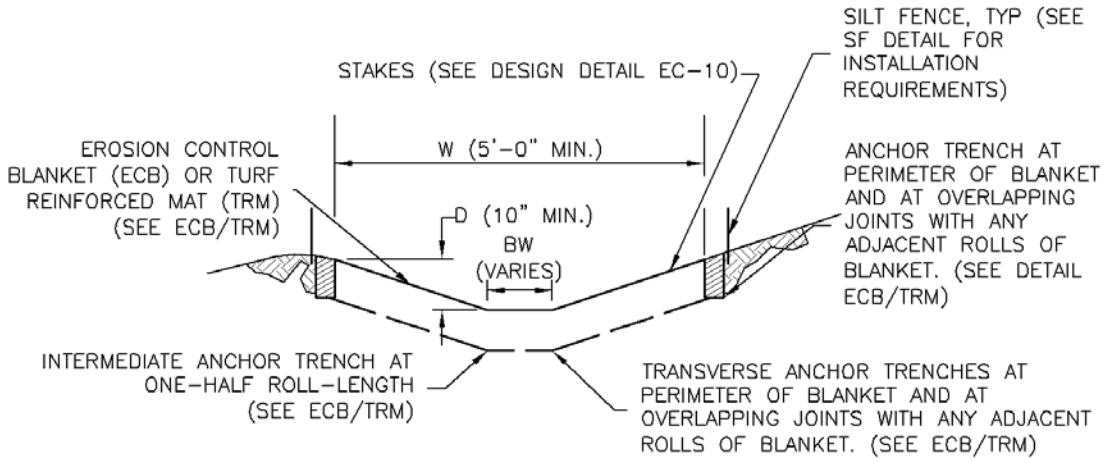


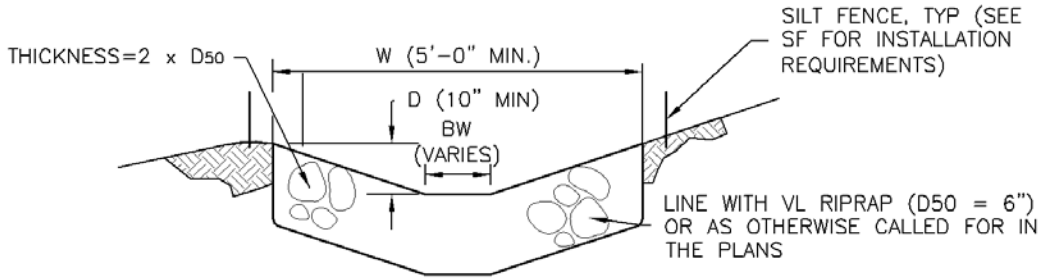
Figure TDM-2. Temporary Diversion Facility Sizing Nomograph for Long Duration Projects (Duration in excess of three months) Based on 2-year Peak Flows - Denver Metropolitan and Adjacent Areas, Updated April 2012



DC-1. PLASTIC LINED DIVERSION CHANNEL



DC-2. GEOTEXTILE OR MAT LINED DIVERSION CHANNEL



DC-3. RIPRAP LINED DIVERSION CHANNEL

CHANNEL DIVERSION INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATION OF DIVERSION CHANNEL
   - –TYPE OF CHANNEL (UNLINED, GEOTEXTILE OR MAT LINED, PLASTIC LINE, OR RIPRAP LINED).
   - –LENGTH OF EACH TYPE OF CHANNEL.
   - –DEPTH, D, WIDTH, W, AND BOTTOM WIDTH, BW.
   - –FOR RIPRAP LINED CHANNEL, SIZE OF RIPRAP, D50, SHALL BE SHOWN ON PLANS.

2. SEE DRAINAGE PLANS FOR DETAILS OF PERMANENT CONVEYANCE FACILITIES.

3. DIVERSION CHANNELS INDICATED ON THE SWMP PLAN SHALL BE INSTALLED PRIOR TO WORK IN DOWNGRADIENT AREAS OR NATURAL CHANNELS.

4. FOR GEOTEXTILE OR MAT LINED CHANNELS, INSTALLATION OF GEOTEXTILE OR MAT SHALL CONFORM TO THE REQUIREMENTS OF DETAIL ECB, FOR PLASTIC LINED CHANNELS, INSTALLATION OF ANCHOR TRENCHES SHALL CONFORM TO THE REQUIREMENTS OF DETAIL ECB.

5. WHERE CONSTRUCTION TRAFFIC MUST CROSS A DIVERSION CHANNEL, THE PERMITTEE SHALL INSTALL A TEMPORARY STREAM CROSSING CONFORMING TO THE REQUIREMENTS OF DETAIL TSC.

DIVERSION CHANNEL MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. DIVERSION CHANNELS ARE TO REMAIN IN PLACE UNTIL WORK IN THE DOWNGRADIENT AREA OR NATURAL CHANNEL IS NO LONGER REQUIRED. IF APPROVED BY LOCAL JURISDICTION DIVERSION CHANNEL MAY BE LEFT IN PLACE.

5. IF DIVERSION CHANNELS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Dewatering Operations (DW) SM-9

Description

The BMPs selected for construction dewatering vary depending on site-specific features such as soils, topography, anticipated discharge quantities, and discharge location. Dewatering typically involves pumping water from an inundated area to a BMP, and then downstream to a receiving waterway, sediment basin, or well-vegetated area. Dewatering typically involves use of several BMPs in sequence.

Photograph DW-1. A relatively small dewatering operation using straw bales and a dewatering bag.

Appropriate Uses

Dewatering operations are used when an area of the construction site needs to be dewatered as the result of a large storm event, groundwater, or existing ponding conditions. This can occur during deep excavation, utility trenching, and wetland or pond excavation.

Photograph DW-2. Dewatering bags used for a relatively large dewatering operation.

Design and Installation

Dewatering techniques will vary depending on site conditions. However, all dewatering discharges must be treated to remove sediment before discharging from the construction site. Discharging water into a sediment trap or basin is an acceptable treatment option. Water may also be treated using a dewatering filter bag, and a series of straw bales or sediment logs. If these previous options are not feasible due to space or the ability to passively treat the discharge to remove sediment, then a settling tank or an active treatment system may need to be utilized. Settling tanks are manufactured tanks with a series of baffles to promote settling. Flocculants can also be added to the tank to induce more rapid settling. This is an approach sometimes used on highly urbanized construction sites. Contact the state agency for special requirements prior to using flocculents and land application techniques.

Some commonly used methods to handle the pumped water without surface discharge include land application to vegetated areas through a perforated discharge hose (i.e., the "sprinkler method") or dispersal from a water truck for dust control.

Dewatering Operations	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	Yes

Dewatering discharges to non-paved areas must minimize the potential for scour at the discharge point either using a velocity dissipation device or dewatering filter bag.

Design Details are provided for these types of dewatering situations:

DW-1. Dewatering for Pond Already Filled with Water

DW-2 Dewatering Sump for Submersed Pump

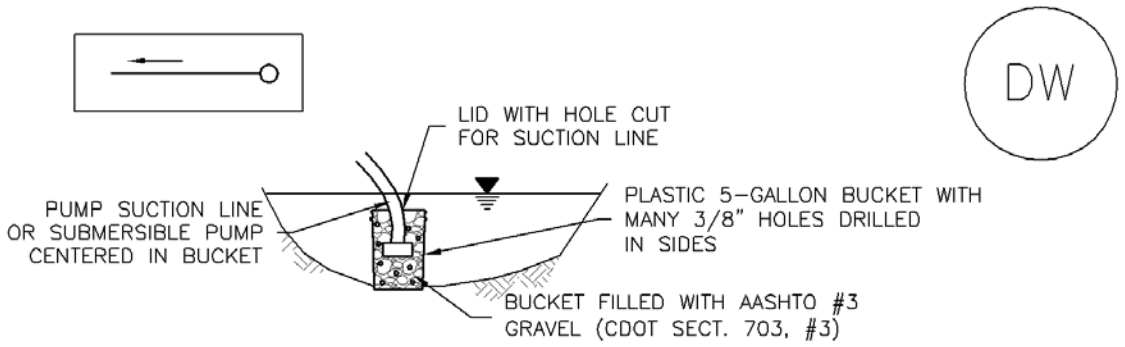
DW-3 Sump Discharge Settling Basin

DW-4 Dewatering Filter Bag

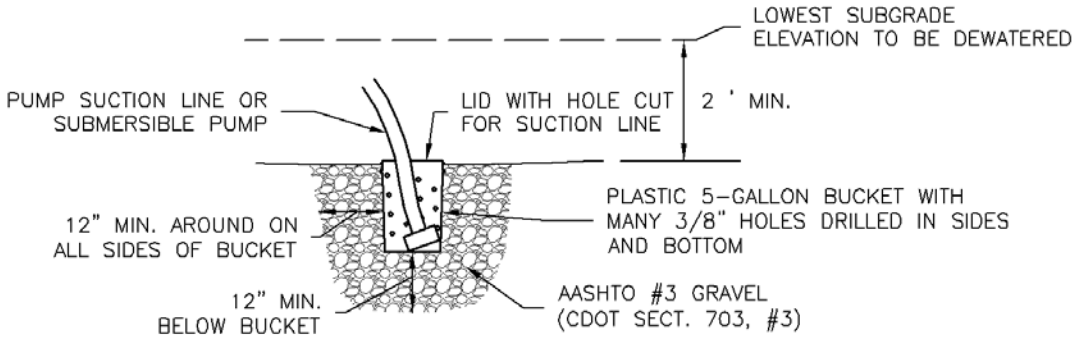
Maintenance and Removal

When a sediment basin or trap is used to enable settling of sediment from construction dewatering discharges, inspect the basin for sediment accumulation. Remove sediment prior to the basin or trap reaching half full. Inspect treatment facilities prior to any dewatering activity. If using a sediment control practice such as a sediment trap or basin, complete all maintenance requirements as described in the fact sheets prior to dewatering.

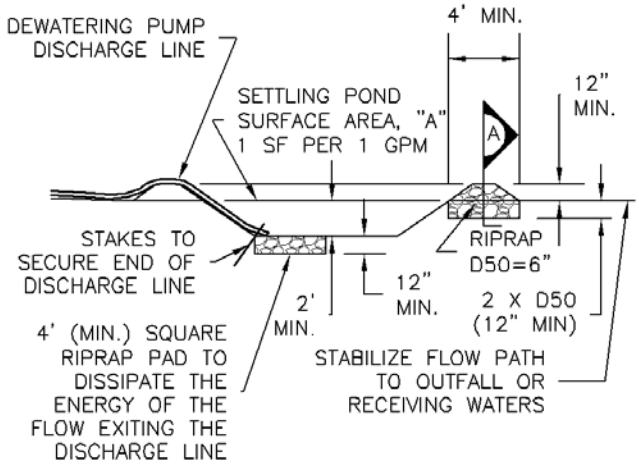
Properly dispose of used dewatering bags, as well as sediment removed from the dewatering BMPs. Depending on the size of the dewatering operation, it may also be necessary to revegetate or otherwise stabilize the area where the dewatering operation was occurring.



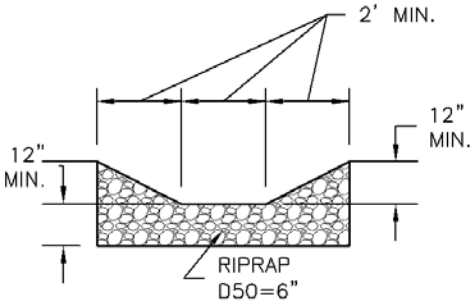
DW-1. DEWATERING POND ALREADY FILLED WITH WATER



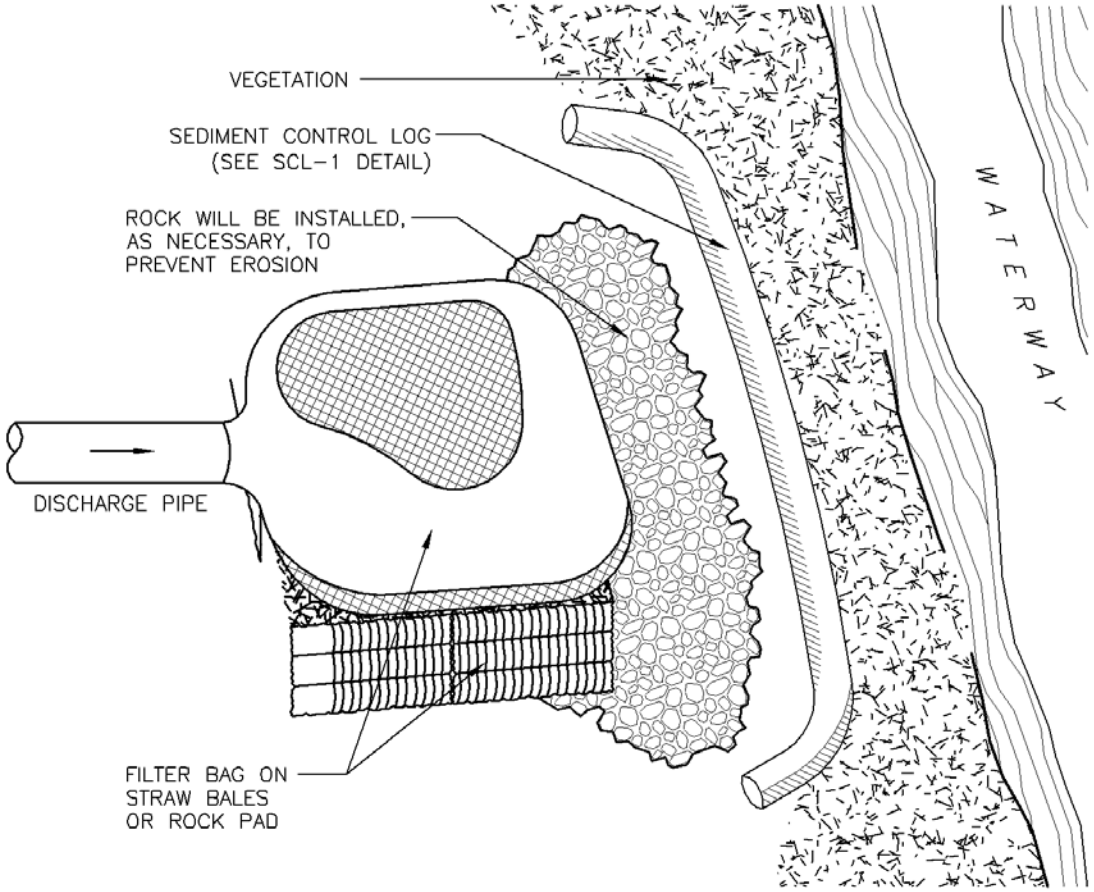
DW-2. DEWATERING SUMP FOR SUBMERSED PUMP



DW-3. SUMP DISCHARGE SETTLING BASIN



SETTLING BASIN SECTION A



DW-4. DEWATERING FILTER BAG

DEWATERING INSTALLATION NOTES

1. SEE PLAN VIEW FOR;
   -LOCATION OF DEWATERING EQUIPMENT.
   -TYPE OF DEWATERING OPERATION (DW-1 TO DW-4).

2. THE OWNER OR CONTRACTOR SHALL OBTAIN A CONSTRUCTION DISCHARGE (DEWATERING) PERMIT FROM THE STATE PRIOR TO ANY DEWATERING OPERATIONS DISCHARGING FROM THE SITE. ALL DEWATERING SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS OF THE PERMIT.

3. THE OWNER OR OPERATOR SHALL PROVIDE, OPERATE, AND MAINTAIN DEWATERING SYSTEMS OF SUFFICIENT SIZE AND CAPACITY TO PERMIT EXCAVATION AND SUBSEQUENT CONSTRUCTION IN DRY CONDITIONS AND TO LOWER AND MAINTAIN THE GROUNDWATER LEVEL A MINIMUM OF 2-FEET BELOW THE LOWEST POINT OF EXCAVATION AND CONTINUOUSLY MAINTAIN EXCAVATIONS FREE OF WATER UNTIL BACK-FILLED TO FINAL GRADE.

DEWATERING INSTALLATION NOTES

4. DEWATERING OPERATIONS SHALL USE ONE OR MORE OF THE DEWATERING SUMPS SHOWN ABOVE, WELL POINTS, OR OTHER MEANS APPROVED BY THE LOCAL JURISDICTION TO REDUCE THE PUMPING OF SEDIMENT, AND SHALL PROVIDE A TEMPORARY SEDIMENT BASIN OR FILTRATION BMP TO REDUCE SEDIMENT TO ALLOWABLE LEVELS PRIOR TO RELEASE OFF SITE OR TO A RECEIVING WATER. A SEDIMENT BASIN MAY BE USED IN LIEU OF SUMP DISCHARGE SETTLING BASIN SHOWN ABOVE IF A 4-FOOT-SQUARE RIPRAP PAD IS PLACED AT THE DISCHARGE POINT AND THE DISCHARGE END OF THE LINE IS STAKED IN PLACE TO PREVENT MOVEMENT OF THE LINE.

DEWATERING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. DEWATERING BMPs ARE REQUIRED IN ADDITION TO ALL OTHER PERMIT REQUIREMENTS.

5. TEMPORARY SETTLING BASINS SHALL BE REMOVED WHEN NO LONGER NEEDED FOR DEWATERING OPERATIONS. ANY DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

Temporary Stream Crossing (TSC) SM-10

Description

Where an actively flowing watercourse must be crossed regularly by construction vehicles, a temporary crossing should be provided. Three primary methods are available:

- Culvert crossing
- Stream ford
- Temporary bridge

Culvert crossings and fords are the most commonly used methods. Due to the expense associated with a temporary bridge, these are used primarily on long-term projects.

Photograph TSC-1. A temporary stream crossing using culverts. Photo courtesy of Tom Gore.

Appropriate Uses

Construction vehicles shall be kept out of waterways to the maximum extent practicable. Use a temporary stream crossing when it is absolutely necessary to cross a stream on a construction site. Construct a temporary crossing even if the stream or drainageway is typically dry. Multiple stream crossings should be avoided to minimize environmental impacts.

A permit is required for placement of fill in a waterway under Section 404 of the Clean Water Act. The local office of the U.S. Army Corps of Engineers (USACE) should be contacted concerning the requirements for obtaining a 404 permit. In addition, a permit from the U.S. Fish and Wildlife Service (USFWS) may be needed if endangered species are of concern in the work area. Typically, the USFWS issues are addressed by a 404 permit, if one is required. The municipality of jurisdiction should also be consulted, and can provide assistance. Other permits to be obtained may include a floodplain development permit from the local jurisdiction.

Design and Installation

Design details are provided for these types of stream crossings:

TSC-1. Culvert Crossing

TSC-2. Ford Crossing

TSC-3. Flume Crossing

Temporary Stream Crossing	
Functions	
Erosion Control	Yes
Sediment Control	Yes
Site/Material Management	No

A culvert crossing should be sized appropriately with consideration for the duration of construction and seasonal variation of flows. The sizing methodology provided in the Temporary Diversion Methods Fact Sheet is also appropriate for determining the design flow for temporary stream crossings. Culvert sizing must account for the headwater and tailwater controls to properly size the culvert. For additional discussion on design of box culverts and pipes, see the *Major Drainage* chapter in Volume 1. The designer also needs to confirm that the riprap selected is appropriate for the conditions in the channel being crossed.

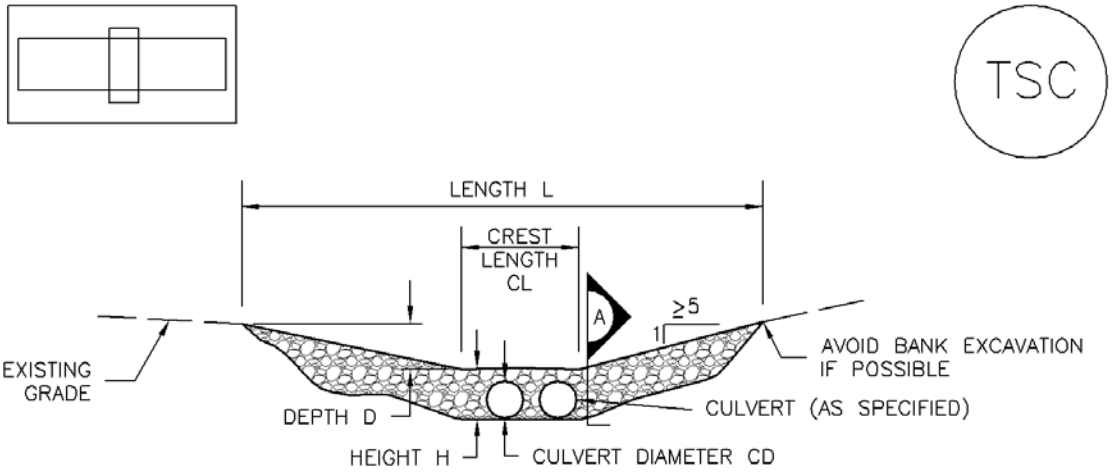
When a ford must be used, namely when a culvert is not practical or the best solution, the ford should be lined with at least a 12-inch thick layer of Type VL (D_{50} = 6 inches) or Type L (D_{50} = 9 inches) riprap with void spaces filed with 1-1/2 inch diameter rock. Ford crossings are recommended primarily for crossings of ephemeral (i.e. intermittently, briefly flowing) streams.

For a temporary bridge crossing, consult with a structural and/or geotechnical engineer for temporary bridge design or consider pre-fabricated alternatives.

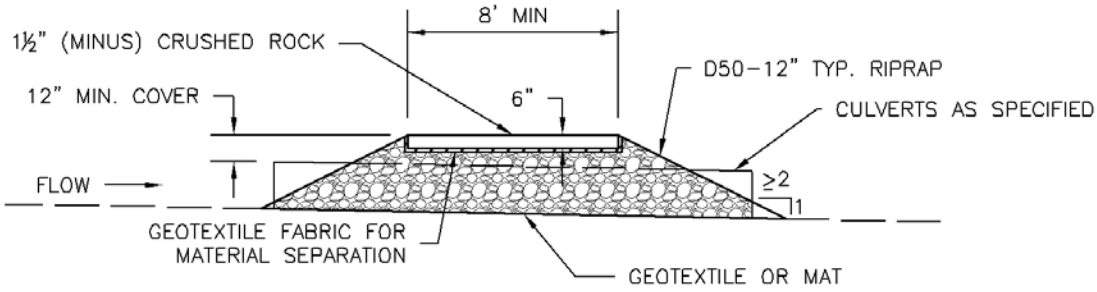
Maintenance and Removal

Inspect stream for bank erosion and in-stream degradation. If bank erosion is occurring, stabilize banks using erosion control practices such as erosion control blankets. If in-stream degradation is occurring, armor the culvert outlet(s) with riprap to dissipate energy. If sediment is accumulating upstream of the crossing, remove excess sediment as needed to maintain the functionality of the crossing.

Remove the temporary crossing when it is no longer needed for construction. Take care to minimize the amount of sediment lost into the stream upon removal. Once the crossing has been removed, stabilize the stream banks with seed and erosion control blankets.

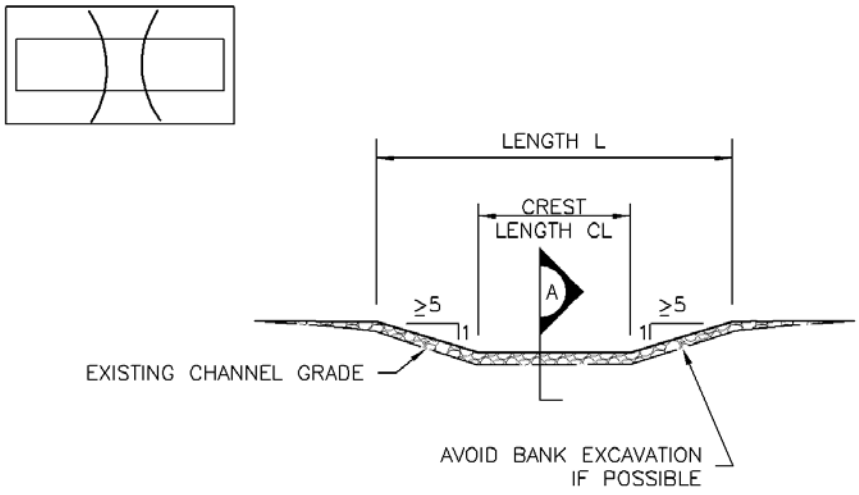


CULVERT CROSSING SECTION

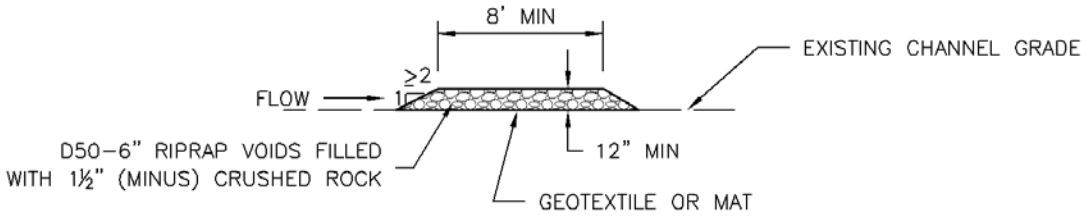


SECTION A

TSC-1. CULVERT CROSSING

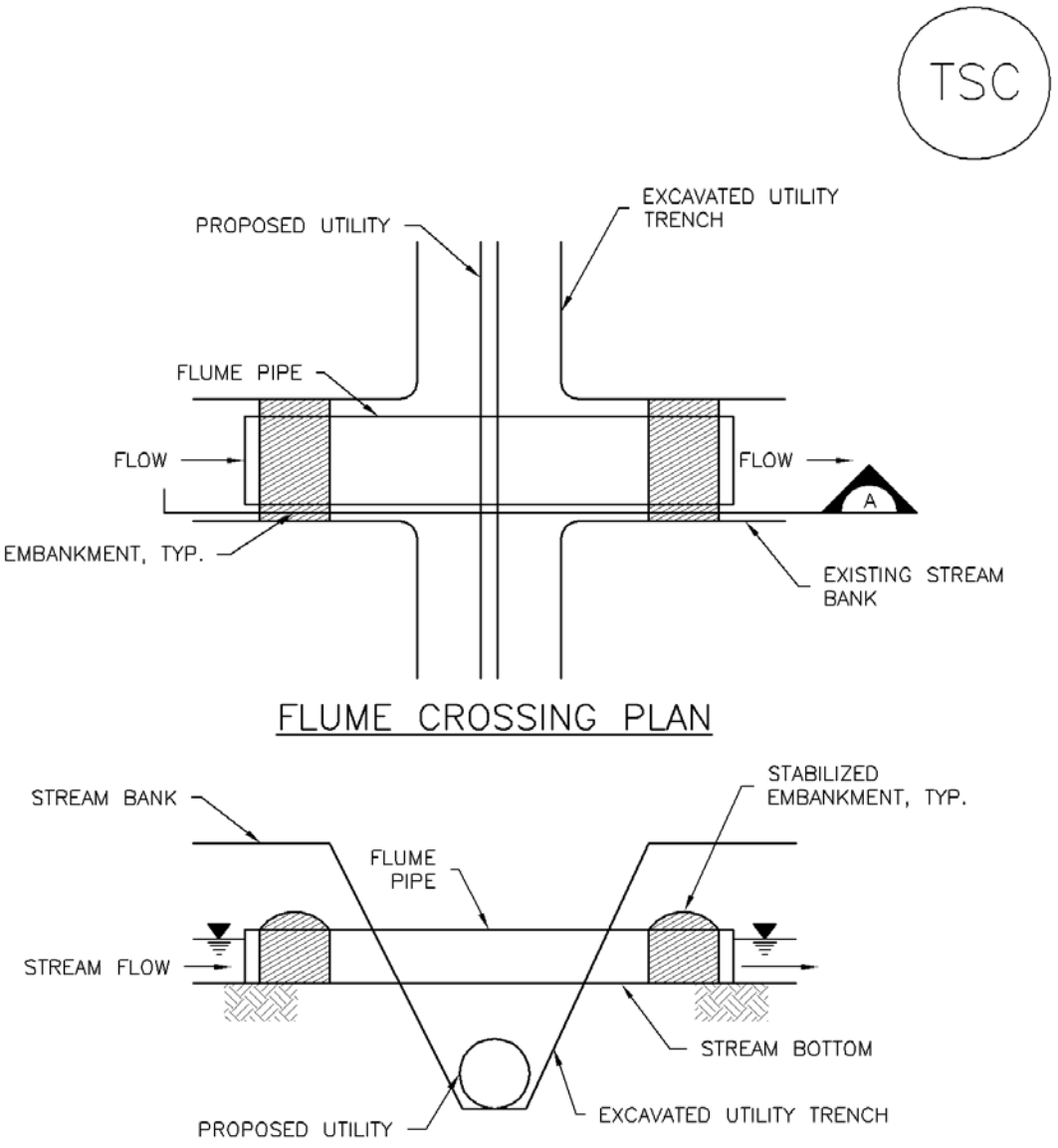


FORD CROSSING SECTION



SECTION A

TSC-2. FORD CROSSING



TSC–3. FLUME CROSSING

TEMPORARY STREAM CROSSING INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATIONS OF TEMPORARY STREAM CROSSINGS.
   - –STREAM CROSSING TYPE (FORD, CULVERT, OR FLUME).
   - –FOR FORD CROSSING: LENGTH (L), CREST LENGTH (CL), AND DEPTH (D).
   - –FOR CULVERT CROSSING: LENGTH (L), CREST LENGTH (CL), CROSSING HEIGHT (H), DEPTH (D), CULVERT DIAMETER (CD), AND NUMBER, TYPE AND CLASS OR GAUGE OF CULVERTS.

2. TEMPORARY STREAM CROSSING DIMENSIONS, D50, AND NUMBER OF CULVERTS INDICATED (FOR CULVERT CROSSING) SHALL BE CONSIDERED MINIMUM DIMENSIONS; ENGINEER MAY ELECT TO INSTALL LARGER FACILITIES. ANY DAMAGE TO STREAM CROSSING OR EXISTING STREAM CHANNEL DURING BASEFLOW OR FLOOD EVENTS SHALL BE PROMPTLY REPAIRED.

3. SEE MAJOR DRAINAGE CHAPTER FOR RIPRAP GRADATIONS.

4. WHERE FAILURE OF A STREAM CROSSING CAN RESULT IN SIGNIFICANT DAMAGE OR HARM IT MUST BE DESIGNED BY A STRUCTURAL ENGINEER.

TEMPORARY STREAM CROSSING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. REMOVE SEDIMENT ACCUMULATED UPSTREAM OF CROSSING AS NEEDED TO MAINTAIN THE FUNCTIONALITY OF THE CROSSING.

5. STREAM CROSSINGS ARE TO REMAIN IN PLACE UNTIL NO LONGER NEEDED AND SHALL BE REMOVED PRIOR TO THE END OF CONSTRUCTION.

6. WHEN STREAM CROSSINGS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED AND COVERED WITH GEOTEXTILE OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND CITY OF AURORA, COLORADO (Va. DSWC), NOT AVAILABLE IN AUTOCAD)

Temporary Batch Plant (TBP) SM-11

Description

Temporary batch plant management includes implementing multiple BMPs such as perimeter controls, concrete washout area, stabilized construction access, good housekeeping, and other practices designed to reduce polluted runoff from the batch plant area.

Photograph TBP-1. Effective stormwater management at temporary batch plants requires implementation of multiple BMPs. Photo courtesy of California Stormwater BMP Handbook.

Appropriate Uses

Implement this BMP at temporary batch plants and identify the location of the batch plant in the SWMP.

Additional permitting may be required for the operation of batch plants depending on their duration and location.

Design and Installation

The following lists temporary management strategies to mitigate runoff from batch plant operations:

- When stockpiling materials, follow the Stockpile Management BMP.
- Locate batch plants away from storm drains and natural surface waters.
- A perimeter control should be installed around the temporary batch plant.
- Install run-on controls where feasible.
- A designated concrete washout should be located within the perimeter of the site following the procedures in the Concrete Washout Area BMP.
- Follow the Good Housekeeping BMP, including proper spill containment measures, materials storage, and waste storage practices.
- A stabilized construction entrance or vehicle tracking control pad should be installed at the plant entrance, in accordance with the Vehicle Tracking Control BMP.

Maintenance and Removal

Inspect the batch plant for proper functioning of the BMPs, with attention to material and waste storage areas, integrity of perimeter BMPs, and an effective stabilized construction entrance.

Temporary Batch Plants	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

After the temporary batch plant is no longer needed, remove stockpiled materials and equipment, regrade the site as needed, and revegetate or otherwise stabilize the area.

Paving and Grinding Operations (PGO) SM-12

Description

Manage runoff from paving and grinding operations to reduce pollutants entering storm drainage systems and natural drainageways.

Appropriate Uses

Use runoff management practices during all paving and grinding operations such as surfacing, resurfacing, and saw cutting.

Photograph PGO-1. Paving operations on a Colorado highway. Photo courtesy of CDOT.

Design and Installation

There are a variety of management strategies that can be used to manage runoff from paving and grinding operations:

- Establish inlet protection for all inlets that could potentially receive runoff.
- Schedule paving operations when dry weather is forecasted.
- Keep spill kits onsite for equipment spills and keep drip pans onsite for stored equipment.
- Install perimeter controls when asphalt material is used on embankments or shoulders near waterways, drainages, or inlets.
- Do not wash any paved surface into receiving storm drain inlets or natural drainageways. Instead, loose material should be swept or vacuumed following paving and grinding operations.
- Store materials away from drainages or waterways.
- Recycle asphalt and pavement material when feasible. Material that cannot be recycled must be disposed of in accordance with applicable regulations.

See BMP Fact Sheets for Inlet Protection, Silt Fence and other perimeter controls selected for use during paving and grinding operations.

Maintenance and Removal

Perform maintenance and removal of inlet protection and perimeter controls in accordance with their respective fact sheets.

Promptly respond to spills in accordance with the spill prevention and control plan.

Paving and Grinding Operations	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

Glossary[1]

Note: This glossary is not intended to provide regulatory or legal definitions of terms. Instead, it is intended to provide users of Volume 3 with a basic understanding of terms used in this manual.

303(d) List: Section 303(d) of federal Clean Water Act requires states to list those waterbodies that are not attaining water quality standards, including designated uses, and identify relative priorities among the impaired waterbodies. Once a stream is listed on the state 303(d) list, a Total Maximum Daily Load (TMDL) is typically required to assign allowable pollutant loads to various sources to enable the waterbody to attain designated uses in the future.

404 Permit: A federal discharge permit authorized under Section 404 of the Clean Water Act, which regulates the discharge of dredged, excavated, or fill material into wetlands, streams, rivers, and other Waters of the U.S. The U.S. Army Corps of Engineers is the federal agency authorized to issue Section 404 Permits for certain activities conducted in wetlands or other U.S. waters. When working in or around waterways or wetlands, 404 Permits are often required.

Best Management Practice (BMP): A technique, process, activity, or structure used to reduce pollutant discharges in stormwater. BMPs include source control practices (non-structural BMPs) and engineered structures designed to treat runoff. BMPs are most effective when used in combination and selected and designed based on site-specific characteristics.

Biofilter: Dense vegetation designed to filter pollutants from stormwater runoff. (Also see definition of Grass Buffer and Grass Swale.)

Bioretention: A method of stormwater quality treatment that relies on soils and vegetation for reduction of the quantity (volume) of stormwater runoff and removal/retention of stormwater pollutants. Bioretention facilities reduce runoff volume discharged downstream by infiltration and evapotranspiration. Bioretention facilities may be designed for infiltration to subsoils or with underdrains, depending on site-specific conditions. Pollutant removal processes include filtration, biological uptake, sorption and sedimentation (in the temporary surface pool during an event). Bioretention facilities are also known as rain gardens and porous landscape detention.

Buffer Zone: A designated transitional area around a stream, lake, or wetland left in a natural, usually vegetated state so as to protect the waterbody from runoff pollution. Development is often restricted or prohibited in a buffer zone.

Catch Basin: A depressed entryway to the storm drain system, usually located at a street corner.

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[1] Definitions in this glossary have been compiled from several key references and websites including: Denver Water Quality Management Plan Glossary, Denver Wastewater Management Division Rules and Regulations http://www.denvergov.org/admin/template3/forms/Sewer%20charges.PDF, CWQCD http://www.cdphe.state.co.us/wq/, Utah APWA http://www.ulct.org/apwa/Glossary.htm, EPA website glossaries http://www.epa.gov/ednnrmrl/main/gloss.htm and http://cfpub.epa.gov/npdes/glossary.cfm?program_id=0, the Low Impact Development website: http://www.lowimpactdevelopment.org/school/glossary.html, the Maryland website http://www.mde.state.md.us/assets/document/sedimentstormwater/Glossary.pdf, and the NRDC website http://www.nrdc.org/water/pollution/storm/gloss.asp.

Clean Water Act: Federal legislation that provides statutory authority for the National Pollutant Discharge Elimination System (NPDES) program and other water quality protection requirements; Public law 92-500; 33 U.S.C. 1251 et seq. Also known as the Federal Water Pollution Control Act. Under the Clean Water Act stormwater requirements, most urban areas must meet requirements of Municipal Separate Storm Sewer System (MS4) permits, and many industries and institutions such as state departments of transportation must also meet NPDES stormwater permit requirements. Operators of regulated MS4s are required to develop a Stormwater Management Plan (SWMP) that includes measurable goals and to implement needed stormwater management controls (BMPs). MS4s are also required to assess controls and the effectiveness of their stormwater programs and reduce the discharge of pollutants to the "maximum extent practicable."

Colorado Discharge Permit System (CDPS): The State of Colorado's system of permitting discharges (e.g., stormwater, wastewater) to Waters of the State that corresponds to the federal NPDES permits under the federal Clean Water Act.

Constructed Wetland Basin: An engineered stormwater BMP designed with a permanent shallow water surface and hydrophytic vegetation such as rushes, willows, cattails, and reeds. Constructed wetland basins included outlet structures to control peak flows and treat the WQCV through settling of pollutants and biological uptake. A perennial supply of water is necessary for constructed wetland basins.

Design Storm: A rainfall event of specific duration, intensity, and return frequency (e.g., the 1-year, 24-hour storm) that is used to calculate runoff volume and peak discharge rate for the purpose of designing stormwater facilities.

Detention: The storage and slow release of stormwater from an excavated pond, enclosed depression, or tank. Detention is used for pollutant removal, stormwater storage, and peak flow reduction. Both wet and dry detention methods can be applied.

Directly Connected Impervious Area (DCIA): The impervious portion of a site that drains directly to the storm sewer system. DCIA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Distributed Controls: Use of multiple BMPs distributed throughout a development site to control and treat stormwater close to it source, as opposed to routing flows to a larger, centralized stormwater facility. Use of distributed stormwater controls is key component of Low Impact Development.

Dry Pond: See definition of Extended Detention Basin (EDB).

Dry Weather Flows: Flows from municipal storm sewer systems that are not due to rain or snow-generated urban runoff.

Effective Imperviousness: Impervious areas that contribute surface runoff to the drainage system. For the purposes of this manual, Effective Imperviousness includes Directly Connected Impervious Area and portions of the Unconnected Impervious Area that also contribute to runoff from a site. For small, frequently occurring events, the Effective Imperviousness may be equivalent to Directly Connected Impervious Area since runoff from Unconnected Impervious Areas may infiltrate into Receiving Pervious Areas; however, for larger events, the Effective Imperviousness is increased to account for runoff from Unconnected Impervious Areas that exceeds the infiltration capacity of the Receiving Pervious Area. *Note: Users should be aware that some national engineering literature defines the Effective Impervious Area more narrowly to include only Directly Connected Impervious Area.*

Effluent Limitation Guidelines (ELGs): EPA-published guidelines in the Federal Register (Volume 74, Number 229, pages 62997-63057) establishing technology-based effluent limitation guidelines and new source performance standards for the construction and development industry. This rule requires construction site owners and operators to implement a range of erosion and sediment control measures and pollution prevention practices to control pollutants in discharges from construction sites. Additionally, the rule will eventually require monitoring and sampling of stormwater discharges and compliance with a numeric standard for turbidity in these discharges for larger construction sites (i.e., 10 acres or more).

Endangered Species Act: The Endangered Species Act of 1973 protects animal and plant species currently in danger of extinction (endangered) and those that may become endangered in the foreseeable future (threatened). It provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through federal action and by encouraging the establishment of state programs.

Erosion Control Measures: Source controls used to limit erosion of soil at construction sites and other erosion-prone areas. Representative measures include surface treatments that stabilize soil that has been exposed due to excavation or grading and flow controls that redirect flows or reduce velocities of concentrated flow.

Erosion: Process by which soil particles are detached and transported by wind, water, and gravity to a downslope or downstream location

Eutrophication: An increase in the concentration of chemical nutrients (e.g., phosphorus, nitrogen) in an ecosystem to an extent that increases the primary productivity (e.g., algal growth) of the ecosystem, resulting in decreased oxygen levels and deteriorated water quality.

Event Mean Concentration (EMC): Pollutant concentration based on a composite of multiple samples (aliquots) collected during the course of a storm. Because EMCs represent conditions at multiple points on a storm hydrograph, they are most representative of average pollutant concentrations over an entire runoff event. EMCs are contrasted with single "grab" samples, which reflect storm conditions at a particular point in time.

Excess Urban Runoff Volume (EURV): The difference between urban and pre-development runoff volumes. The EURV is the basis of design for Full Spectrum Detention facilities.

Extended Detention Basin (EDB): An engineered basin with an outlet structure designed to slowly release urban runoff over an extended time period to provide water quality benefits and control peak flows for frequently occurring storm events. The basins are sometimes called "dry ponds" because they are designed not to have a significant permanent pool of water remaining between storm runoff events. Outlet structures for extended detention basins are sized to control more frequently occurring storm events, whereas flood control detention facilities are designed to control less frequent, larger storm events. Outlet structures can be designed to integrate water quality and flood control into a single detention facility. Also see Full Spectrum Detention.

Extensive Green Roof: A shallow green roof, typically 6 inches or shallower, that is designed to satisfy specific engineering and performance goals such as water quality treatment. An extensive green roof has low lying plants designed to provide maximum groundcover, water retention, erosion resistance, and respirative transpiration of moisture. Extensive green roofs usually use plants with foliage from 2 to 6 inches and provide 2 to 4 inches of soil/growing media.

Forebay: Storage space located near a stormwater BMP inlet designed to trap incoming coarse sediments and other gross solids before they accumulate in the main treatment area of the BMP.

Full Spectrum Detention: A stormwater detention facility design to provide water quality and flood control benefits and reduced impacts on downstream channels by detaining the Excess Urban Runoff Volume (EURV) and releasing it over a 72 hour period. The EURV is approximately

Geographic Information System (GIS): A database of digital information and data on land-use, land cover, ecological characteristics, and other geographic attributes that can be overlaid, statistically analyzed, mathematically manipulated, and graphically displayed using maps, charts, and graphs.

Grass Buffer: Uniformly graded and densely vegetated area, typically turfgrass. This BMP requires sheet flow to promote filtration, infiltration, and settling to reduce runoff pollutants.

Grass Swale: Densely vegetated drainageway with low-pitched side slopes that collects and slowly conveys runoff. The design of the longitudinal slope and cross-section size forces the flow to be slow and shallow, thereby facilitating sedimentation while limiting erosion.

Green Roof: An engineered vegetated roof that can be used to detain and treat precipitation. Green roofs require an engineered structure that can support soils, vegetation and loads associated with rainfall, snow, people and equipment. Key components include a waterproof membrane, root barrier, drainage layer, soil/growing medium, irrigation system and plants.

Hot Spot: Area where land use or activities have the potential to generate highly contaminated runoff with concentrations of pollutants in excess of those typically found in stormwater.

Household Hazardous Waste: Common everyday products such as paint, paint thinner and pesticides that can be hazardous if not properly disposed.

Illicit Connection: A sanitary plumbing fixture connected to a storm sewer, resulting in illicit discharges to the storm sewer system.

Illicit Discharge: A discharge to a municipal separate storm sewer that is not composed entirely of stormwater and is not authorized by an NPDES permit, with some exceptions (e.g., discharges due to fire-fighting activities).

Impervious Area: A hard surface area (e.g., parking lot or rooftop) that prevents or retards the infiltration of water into the soil, thus causing water to run off the surface in greater quantities and at an increased rate of flow relative to pervious areas.

Infiltration: The percolation of water from the land surface into the ground.

Inlet: An entrance into a ditch, storm sewer, or other waterway.

Integrated Pest Management (IPM): The practice of using biological, chemical, cultural, and physical measures to manage pests while minimizing or eliminating the use of chemical pesticides.

Intensive Green Roof: Landscaped roofs with several feet of soil and a variety of plant types, often including trees.

Level Spreader: An engineered structure designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope, thereby preventing/minimizing erosion.

Low Impact Development (LID): LID is an overall land planning and engineering design approach to managing stormwater runoff. LID emphasizes conservation and use of on-site natural features to protect water quality. This approach implements engineered small-scale hydrologic controls to mimic the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. The term Green Infrastructure (GI) may also be used, particularly in areas with combined sewer overflow (CSO) issues.

Low Impact Development Practice: Individual practices used as part of overall LID developments or integrated into traditional developments include practices such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels, permeable pavements and other infiltration-oriented practices.

Materials Management Practices: Source control practices at construction sites intended to limit contact of runoff with pollutants such as construction materials and equipment-related fluids. By intentionally controlling and managing areas where chemicals are handled, the likelihood of these materials being transported to waterways is reduced.

Media Filter: A stormwater BMP designed to filter runoff as it passes through media such as sand, compost, sand-peat, perlite-zeolite, or similar materials. (See Sand Filter Extended Detention Basin.)

Micropool: A smaller permanent pool incorporated into the design of larger stormwater ponds to reduce potential of clogging of the outlet and minimize resuspension of sediment.

Minimizing Directly Connected Impervious Areas (MDCIA): A variety of runoff reduction strategies that route runoff from impervious surfaces over pervious areas to decrease runoff velocities and promote infiltration.

Minimum Measures: Stormwater management activities required under Phase II MS4 permits. The six minimum measures include 1) public education and outreach, 2) public participation/involvement, 3) illicit discharge detection and elimination, 4) construction site stormwater runoff control, 5) post-construction stormwater management, and 6) pollution prevention/good housekeeping for municipal operations.

Municipal Separate Storm Sewer System (MS4): A publicly owned conveyance or system of conveyances that discharges to waters of the U.S. and is designed or used for collecting or conveying stormwater, is not a combined sewer, and is not part of a publicly owned treatment works (POTW).

MS4 Permit: A state or federal stormwater discharge permit to regulate discharges from municipal separate storm sewers (MS4s) for compliance with Clean Water Act regulations.

National Pollutant Discharge Elimination System (NPDES): The national program under Section 402 of the Clean Water Act for regulation of discharges of pollutants from point sources to waters of the U.S.

Non-Point Source (NPS) Pollution: Pollution that occurs when rainwater, snowmelt, or irrigation transports pollutants from diffuse sources across land surfaces into waterbodies. Nonpoint source pollution is contrasted with point source pollution in that it is not discharged from single discharge points such as storm sewers and wastewater treatment plants.

Non-Structural BMPs: Stormwater BMPs that focus on management of pollutants at their source by minimizing exposure to runoff, rather than treating runoff in constructed facilities. Non-structural BMPs are referred to as source controls in this manual.

NPDES: National Pollutant Discharge Elimination System, as described above.

Peak Runoff Rate: The highest actual or predicted flow rate (typically measured in cubic feet per second) for runoff from a site for a specific event.

Permeability: The ability of a material to allow the passage of a liquid, such as water through rocks or soil. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas impermeable material, such as clay, does not allow water to flow freely.

Permeable Pavement Systems (PPS): A general term to describe pavements designed to allow infiltration of water from the paved surface into subsurface layers. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the WQCV, and/or reduce effective imperviousness. Permeable pavement systems include permeable interlocking concrete pavement, concrete grid, pervious concrete, reinforced grass, and porous gravel.

Point Source Pollution: Pollutants from a single, identifiable source such as a factory, refinery, or place of business. In the context of TMDLs, point sources typically include NPDES-permitted sanitary wastewater treatment facilities, municipal separate storm sewer systems (MS4s), and confined animal feeding operations (CAFOs).

Pollutant (as defined by CDPS Regulation 6.3.0 [51]): Dredged spoil, dirt, slurry, solid waste, incinerator residue, sewage, sewage sludge, garbage, trash, chemical waste, biological nutrient, biological material, radioactive material, heat, wrecked or discarded equipment, rock, sand, or any industrial, municipal or agriculture waste.

Pollutant Load: The mass of pollutants carried in runoff, calculated based on flow volume multiplied by pollutant concentration. Pollutant loading has units of mass and is calculated over specific timescales such as day, month or year.

Porous Landscape Detention (PLD): Also known as a rain garden or bioretention facility, this stormwater quality BMP consists of a low lying vegetated area underlain by a permeable media with an underdrain. A shallow surcharge zone exists above the porous landscape detention for temporary storage of the WQCV.

Rain Garden: See definitions of Bioretention and Porous Landscape Detention (PLD).

Receiving Pervious Area (RPA): The pervious portion of a site that receives runoff from an upgradient impervious area prior to draining to the storm sewer system. RPA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Redevelopment: Improvements to an existing developed area, typically involving removal of existing structures and construction of new buildings and associated infrastructure. Depending on the scale of the redevelopment activity, post-development stormwater permit requirements may be triggered.

Retention Pond: A BMP consisting of a permanent pool of water designed to treat runoff by detaining water long enough for settling, filtering, and biological uptake. Also known as wet ponds, these ponds may also be designed to have an aesthetic and/or recreational value. These BMPs have a permanent pool of water that is replaced with stormwater, in part or in total, during storm runoff events. In addition, a temporary extended detention volume is provided above this permanent pool to capture storm runoff and enhance sedimentation. Retention ponds require a perennial supply of water to maintain the pool and are typically used on larger sites.

Retrofit: The creation or modification of a stormwater management practice, usually in a developed area, that improves or combines treatment with existing stormwater infrastructure.

Revised Universal Soil Loss Equation (RUSLE): An erosion prediction method originally developed for agricultural land use that can also be used for estimating erosion potential on construction sites and adjusting BMPs to reduce the estimated erosion. Factors included in this equation include rainfall-runoff erosivity, soil erodibility, slope length and steepness, surface cover management, and erosion control practice implementation.

Runoff: Water from rain, melted snow, or irrigation that flows over the land surface.

Sand Filter Extended Detention Basin: A stormwater quality BMP consisting of a sand bed and underdrain system. Above the vegetated sand bed is an extended detention basin sized to capture the WQCV. A sand filter extended detention basin provides pollutant removal through settling and filtering and is generally suited to off-line, on-site configurations where there is no base flow and the sediment load is relatively low.

Sediment Control Measures: Practices that reduce transport of sediment off-site to downstream properties and receiving waters. Sediment controls generally either provide filtration through a permeable media or slow or detain runoff to allow settling of suspended particles.

Separate Pervious Area (SPA): The pervious portion of a site that drains to the storm sewer system, but does not receive runoff from upgradient impervious areas. SPA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Sheet Flow: The portion of precipitation that flows overland in very shallow depths before eventually reaching a stream channel or other conveyance.

Site Management Practices: A combination of construction site management practices that help reduce pollutants leaving a construction site. These include practices such as construction sequencing and scheduling, vehicle tracking controls and street sweeping, and good management of practices associated with site construction such as stream crossing, temporary batch plants, dewatering operations and other measures.

Slotted Curbs: Curbs with slots or cut-out areas that allow stormwater to flow away from the curbed pavement into an adjacent landscape or turf area, as opposed to transporting runoff directly to a storm sewer system.

Source Controls: A variety of practices implemented to minimize pollutant transport in runoff by controlling pollutants where they originate and/or accumulate. Representative source controls include good housekeeping measures, landscape management practices, pet waste controls, public education regarding household hazardous waste, covering outdoor storage areas, etc.

Spill Prevention Control and Countermeasure (SPCC) Plan: A written plan prepared for an industrial, commercial or construction operation identifying measure to minimize the likelihood of a spill and to expedite control and cleanup activities should a spill occur. SPCC plans are legally required for certain types of operations.

Stormwater Management Plan (SWMP): A written plan required under state and federal stormwater discharge permits identifying measures that will be implemented to minimize the discharge of pollutants in stormwater. Requirements for SWMPs are legally specified in state and federal discharge permits. Requirements vary depending on whether the discharge permit is associated with municipal, industrial, or construction activities.

Structural BMPs: Engineered structures constructed to provide temporary storage and treatment of stormwater runoff.

Surface Water: Water that remains on the surface of the ground, including rivers, lakes, reservoirs, streams, wetlands, impoundments, seas, estuaries, etc.

Total Maximum Daily Load (TMDL): The maximum allowable loading of a pollutant that a designated waterbody can assimilate and still meet numeric and narrative water quality standards. Section 303(d) of the federal Clean Water Act requires states to identify waterbodies that do not meet federal water quality standards and establish TMDLs that result in attainment of stream standards.

Trash Rack: Grill, grate or other device installed at the intake of a channel, pipe, drain, or spillway for the purpose of preventing oversized debris from entering the structure. Trash racks may also serve a safety function.

Treatment Train: BMPs that work together in series to provide stormwater quality treatment.

Unconnected Impervious Area (UIA): The impervious portion of a site that drains over a receiving pervious area before discharging to the storm sewer system. UIA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Underdrain: A perforated pipe, typically 4- to 6-inches in diameter, placed longitudinally at the invert of a stormwater facility for the purposes of achieving a desired discharge rate and controlling nuisance ponding.

Water Quality Capture Volume (WQCV): The quantity of stormwater runoff that must be treated in stormwater quality BMPs in Denver. This volume is equivalent to the runoff from an 80^{th} percentile storm, meaning that 80 percent of the most frequently occurring storms are fully captured and treated and larger events are partially treated.

Waters of the United States: All waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters subject to the ebb and flow of the tide. Waters of the U.S. include all interstate waters and intrastate lakes, rivers, streams (including intermittent streams), mudflats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds. [See 40 CFR 122.2 for the complete definition.]

Watershed: A geographical area that drains to a specified point on a water course, usually a confluence of streams or rivers (also known as drainage area, catchment, or river basin).

Wet Pond: See definition of Retention Pond.

Wet Weather Flows: Water entering storm sewer systems as a result of precipitation events.

Wetlands: Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

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