

Chapter 1

General Provisions

Contents

1.0	Introduction	1
2.0	Enactment Authority	1
3.0	Jurisdiction	1
4.0	Purpose.....	1
5.0	Amendments and Revisions.....	2
6.0	Enforcement Responsibility	3
7.0	Review and Acceptance	3
8.0	Interpretation	3
9.0	Relationship to Other Standards or Permits	4
10.0	Variances.....	4
11.0	Acronyms	4

Tables

Table 1-1.	Examples of Minor and Major Revisions.....	2
------------	--	---

1.0 Introduction

The criteria and design standards presented in this document, together with all future amendments, comprise the *City of Woodland Park Drainage Criteria Manual* (hereafter called the “Manual”). The Manual has been developed by drawing on elements of the City of Colorado Springs Drainage Criteria Manual (Colorado Springs Manual) and the most current version of the Denver Urban Drainage and Flood Control District’s (UDFCD’s) Urban Storm Drainage Criteria Manual (UDFCD Manual). Because the City of Woodland Park (City) is a headwaters city in the mountains rather than a major metropolitan area, many sections of the Colorado Springs and UDFCD Manuals have been simplified for a smaller community, in a mountainous setting with significant existing development and infrastructure. In many sections of this Manual, the reader is directed to the Colorado Springs and/or UDFCD Manuals for additional guidance, especially for more complex and/or larger projects. In these cases, the Applicant should consult with the City Engineer to define specific criteria that will apply.

All drainage reports, plans, drainage system analyses, and drainage system designs shall comply with the criteria in this Manual. Drainage improvements shall be designed in conformance with the *City of Woodland Park Engineering Specifications* (2011). In addition, it is the responsibility of the owner, developer, planner, and designer (hereafter called “Applicant”) to ensure that the proposed improvements are consistent with other applicable documents such as the *City of Woodland Park Stormwater Management Program* (1996); land use master plans, transportation plans, utility plans, etc. and that all applicable permits are in place and have been complied with¹.

2.0 Enactment Authority

This Manual has been adopted by the Woodland Park City Council and was prepared under the direction of the Director of Public Works. This Manual shall apply to all new projects in the City of Woodland Park as of March 1, 2014.

3.0 Jurisdiction

This Manual shall apply to all land within the incorporated areas of the City of Woodland Park, including any public lands. This Manual shall apply to all storm drainage systems and facilities constructed in or on public rights-of-way, easements dedicated for drainage across public or private property, easements or tracts for public use, and to all privately owned and maintained stormwater conveyance, detention, retention, or water quality facilities.

4.0 Purpose

This Manual provides the policies and minimum design procedures and technical criteria for the planning, analysis and design of storm drainage systems within the City for the purpose of protecting public health, safety and welfare. All subdivisions, re-subdivisions, planned unit developments, or any other proposed construction within the City shall include adequate and appropriate storm drainage system planning, analysis, design and improvements. Such planning, analysis, and design shall conform with or exceed the criteria set forth herein. Storm drainage system planning, analysis, and design that require policies,

¹ The most up-to-date versions of these documents shall be used. The City expects to update the Drainage Master Plan in the near future (anticipated 2014). This and other documents may be periodically updated, and it is the responsibility of the Applicant to obtain the most recent versions of applicable master planning documents.

guidance, technical methods, or criteria not specifically addressed in this Manual shall follow the provisions of the UDFCD Manual and/or the Colorado Springs Manual. The Applicant shall consult with the City Engineer to determine how methods and/or criteria from these Manuals apply to their specific project. Because the UDFCD and Colorado Springs Manuals may be revised from time to time, the Applicant should obtain the latest versions from the UDFCD and Colorado Springs' websites or other means to assure that the most current versions of the criteria are being used.

5.0 Amendments and Revisions

When the provisions of this Manual are not adequate to provide clear guidance, it is the responsibility of the Applicant to seek guidance from the City or other appropriate party so that the intents of the criteria in this Manual are properly integrated into design. The application of methodologies or standards not defined in this Manual will not be accepted without an approved variance. Policies and criteria may be amended as new technologies are developed or if experience gained in the use of this Manual indicates a need for revision. All proposed changes must be approved in writing prior to implementation. Minor revisions require the approval of the Director of Public Works and may require a public notification process, depending on the implications of the change. The Director of Public Works will make reasonable accommodations and modify the proposed minor revision(s), as appropriate, based on comments received through the public notification process. Major revisions also require the approval of the City Council and a resolution or ordinance, as appropriate. The Director of Public Works shall monitor the performance and effectiveness of this Manual and recommend and implement amendments as needed to improve guidance or to better accomplish goals of the Manual.

Table 1-1. Examples of Minor and Major Revisions

Minor	Major
Grammar, typographic errors and formatting	Policy changes (such as storm frequency and freeboard requirements)
Submittal Requirements	Criteria changes (such as allowable flow depth, hydraulic grade line limits and maximum velocities)
Clarifications	
New Construction Details or Revisions	
Revisions to Recommended Parameters	
Revisions to Standard Methods	
Updating of Reference Document Versions	
Application of Manufactured Devices	
Material Specifications	
Adaptation to State and Federal Regulations that are not a Major Revision	
Application of Alternate Materials	

6.0 Enforcement Responsibility

The City Engineer or his/her designated representative (e.g. City consultant) is the designated official responsible for the review of all drainage reports and plans, drainage system analyses, drainage system designs and constructed improvements, for compliance with this Manual. The most recent version of this Manual, as available on the City's web site (<http://www.city-woodlandpark.org>), shall be the basis for enforcement. The City Engineer, or designated representative, shall have responsibility for enforcement of the criteria in this Manual.

7.0 Review and Acceptance

1. **All drainage submittals shall be reviewed for compliance with the criteria presented in this Manual and approved prior to their implementation.** Acceptance of submittals does not relieve the Applicant from the responsibility of ensuring that the design, calculations, plans, specifications, construction, and record drawings are in compliance with the intent of the criteria in this Manual.
2. **When appropriate, submittals shall be referred to other agencies having jurisdiction.** It is the responsibility of the Applicant to identify the appropriate referral agencies and provide the required documentation to acquire the necessary approvals and/or permits. Other review agencies may include Teller County, the Fountain Creek Watershed District (FCWD), state agencies (Colorado Water Conservation Board [CWCB], Colorado Department of Public Health and Environment [CDPHE], Colorado Department of Transportation [CDOT] etc.) and/or federal agencies (United States Army Corps of Engineers [USACE], United States Fish and Wildlife Service [USFWS], etc.).
3. **Submittals that impact FEMA-designated floodplains shall submitted to FEMA for review in accordance with the provisions of Chapter 5 of this Manual.**
4. **No considerations for public maintenance assistance will be given to facilities designed or constructed without provisions satisfying maintenance requirements specified in this Manual.** Public assistance with drainage and water quality infrastructure on private development projects will typically not be provided. For projects that include a public infrastructure component (storm sewer improvements, channel improvements, detention, etc.), City assistance with maintenance will be determined on a case-by-case basis.

8.0 Interpretation

In the interpretation and application of the provisions of the criteria in this Manual, the following shall govern:

1. The provisions shall be regarded as the minimum requirements for the protection of the public health, safety, and welfare of residents and property owners in Woodland Park and surrounding jurisdictions that adopt these criteria. Therefore, this Manual shall be liberally construed to further its underlying purposes of protection of the public good.
2. Whenever a provision of this Manual conflicts with any provision in any applicable law, ordinance, resolution, rule or regulation, containing requirements covering the same subject matter, the requirements that are more restrictive or impose higher standards shall govern.
3. The criteria in this Manual shall not abrogate or annul any easements, permits, drainage reports or construction drawings, recorded, issued, or accepted prior to the effective date of this Manual. All

submittals made prior to the effective date of this Manual, but not approved within six months of the effective date, may need to be revised to comply with this Manual at the discretion of the City Engineer. A determination by the City Engineer that a previous submittal must be revised to comply with the criteria in this Manual shall be documented in writing to the Applicant. All submittals made after the effective date of this Manual shall be prepared and submitted in compliance with the criteria in this Manual.

9.0 Relationship to Other Standards or Permits

If other entities that have jurisdiction impose more stringent criteria, this difference is not considered a conflict. If the state or federal government imposes stricter criteria, standards, or requirements, either through law or through conditions of a permit, these may be incorporated into the requirements after due process and public hearing(s), as needed, to modify this Manual.

10.0 Variances

Variance requests must be submitted in writing to the City Engineer and must, at a minimum, contain the following information:

- Identification of Applicant and project for which the variance will be applied.
- Recitation of criteria or standards from which the Applicant seeks a variance.
- Justification for not complying with the criteria in this Manual.
- Alternate criterion or standard that is proposed to comply with the intent of the criteria in this Manual and other applicable guidance documents.
- Supporting documentation, including necessary calculations, reference materials, software, specifications, etc., adequate to evaluate how the proposed variance satisfies the intent of the criteria in this Manual.

The variance request must be signed and stamped by a Professional Engineer licensed in the State of Colorado.

11.0 Acronyms

In this Manual, the following common acronyms may be used:

ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BCD	Baffle Chute Drop
BFE	Base Flood Elevation
BMP	Best Management Practice
CAP	Corrugated Aluminum Pipe
CAPA	Corrugated Aluminum Pipe Arch
CDOT	Colorado Department of Transportation
CDPHE	Colorado Department of Public Health and Environment
CEC	Consulting Engineers Council
CGIA	Colorado Governmental Immunity Act

CLOMA	Conditional Letter of Map Amendment
CLOMR	Conditional Letter of Map Revision
CMP	Corrugated Metal Pipe
CMPA	Corrugated Metal Pipe Arch
CRS	Colorado Revised Statutes
CSP	Corrugated Steel Pipe
CSPA	Corrugated Steel Pipe Arch
CWA	Federal Clean Water Act
CWCB	Colorado Water Conservation Board
DCIA	Directly Connected Impervious Area
DBPS	Drainage Basin Planning Study
EDB	Extended Detention Basin
EGL	Energy Grade Line
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
EURV	Excess Urban Runoff Volume
FAA	Federal Aviation Administration
FCWD	Fountain Creek Watershed Flood Control and Greenway District
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 Sloping Boulder
HDS	Hydraulic Design Series
HEC	Hydraulic Engineering Center
HEC-HMS	Hydraulic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydraulic Engineering Center River Analysis System
HERCP	Horizontal Elliptical Reinforced Concrete Pipe
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
LOMA	Letter of Map Amendment
LOMR	Letter of Map Revision
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
NWS	National Weather Service
P.E.	Professional Engineer (Licensed by the State of Colorado)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCBC	Reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe

ROW	Right-of-Way
SBA	Small Business Administration
SEO	Colorado State Engineer's Office
SFHA	Special Flood Hazard Area
SFIP	Standard Flood Insurance Policy
SPP	Structural Plate Pipe
SPPA	Structural Plate Pipe Arch
SWMM	Stormwater Management Model
TRC	Technical Review Committee
TWE	Tailwater Elevation
UDFCD	Urban Drainage & Flood Control District
UDSWMM	Urban Drainage Stormwater Management Model
USFWS	U.S. Fish and Wildlife Service
USACE	U.S. Army Corps of Engineers
WQCV	Water Quality Capture Volume

Chapter 2

Stormwater Management Principles

Contents

1.0	Introduction.....	1
2.0	Principles.....	1

1.0 Introduction

Principles, policies and criteria for effective management of stormwater drainage and water quality are necessary to protect and improve the general health, safety, welfare, and economic well-being of the City of Woodland Park, surrounding unincorporated areas, South Platte tributaries and the Fountain Creek watershed. Drainage affects all governmental jurisdictions and parcels of property, requiring a program that balances both public and private involvement. The City is a headwaters city, surrounded by a pristine mountainous environment and the way that drainage and water quality are managed in Woodland Park affect the surrounding environment and downstream drainageways. Sound management of drainage and water quality, as described in the Manual is consistent with the City's Comprehensive Plan desire to protect the mountain environment, wildlife, and scenic beauty surrounding Woodland Park.

When planning stormwater management facilities, certain underlying principles provide direction. The principles are made operational through policy statements (see Chapter 3). The policies are implemented through technical criteria and data, procedures, funding, construction, operation and maintenance for stormwater improvements. When considered in a comprehensive manner, on a regional level with public and private involvement, stormwater management facilities can be provided in a manner that will enhance the general health, safety and welfare of the region, while also providing economic, environmental and social benefits. The effectiveness of these policies will depend on their faithful and consistent application and integration into policies and practices in related areas such as land use and transportation planning and design.

2.0 Principles

The following principles for stormwater management shall guide the planning, design and implementation of stormwater facilities.

1. **Drainage is a regional phenomenon that does not respect the boundaries between governmental jurisdictions or between properties.** Systems that are planned and designed without considering regional implications can be ineffective and costly. Therefore, it is necessary to formulate programs that include public, private and multi-jurisdictional involvement. The governmental agencies involved must provide coordination, consistent standards, master planning, and possibly, joint-funding for key projects to achieve optimum results.
2. **A stormwater management system is a subsystem of the total urban infrastructure system.** Developing a stormwater system independent of considering how it relates to other infrastructure systems limits the potential for compatible integration and increases the probability of conflicts between the functions of different types of infrastructure. Stormwater management system planning and design must be compatible with local and regional comprehensive plans and must be coordinated with planning and designs for land uses, open space, utilities, wildlife, recreation, transportation corridors and other infrastructure.
3. **Development activity can greatly alter the amount and character of runoff resulting in significant impacts to man-made or natural systems.** Land development activities and supporting infrastructure (buildings, roads, schools, parking, etc.) have the potential to introduce significant changes to hydrology and water quality, including increased peak flow rates, runoff volumes and pollutant loadings that can cause negative impacts such as flooding, water quality degradation, erosion and sedimentation. These changes have the potential to damage man-made improvements as well as natural systems. Increased flow rates and runoff volumes typically result from increased runoff from impervious areas. Water quality degradation can result from

the mixing of runoff with pollutants associated with human activity, from increased sediment loads and/or from hydromodification effects of increased runoff on streams. Generally, the effects of development are most pronounced for runoff from the more frequent storm events, including those that may not have produced significant runoff prior to development. The increased frequency and volume of runoff from these events can significantly alter the hydrologic conditions in a watershed. Implementation of water quality features, channel stabilization measures and flood control detention are typically necessary to mitigate the adverse hydrologic and water quality effects of urbanization.

4. **Every urban area has a minor and a major drainage system, whether or not they are actually planned and designed.** The minor drainage system, sometimes referred to as the “initial 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.
5. **Handling runoff properly is largely 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 sewers 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.
6. **The diversion of storm runoff from one watershed or basin to another can introduce significant capacity, legal and social problems.** Drainage problems should not be transferred from one watershed or basin to another. Diversions should be avoided unless specific and prudent reasons justify and dictate such a transfer, and downstream damages are sufficiently mitigated.
7. **Resources to implement stormwater plans and improvements are limited. Drainage systems should be a multi-objective and multi-means effort.** The many competing demands placed upon space and resources require a stormwater management strategy that meets multiple objectives, including the preservation of ecological systems, water quality enhancement, groundwater recharge, recreation, wetland preservation, enhancement and creation, protection of landmarks/amenities, control of erosion and sediment deposition, and creation of open spaces.
8. **Natural systems possess a number of beneficial features that should be preserved and incorporated into the design of the stormwater management system.** Good designs incorporate the effectiveness of the natural systems rather than negate, replace or ignore them. Existing features such as natural drainageways, depressions, wetlands, floodplains, permeable soils, habitat, and vegetation provide for infiltration, help control the volume and rate of runoff, extend the travel time, prevent erosion, filter sediments and other pollutants, and recycle nutrients and support the ecology.
9. **Natural drainage systems respond to and are dependent upon the full range of hydrologic conditions and sources of water, including snowmelt, groundwater and the full range of rainfall events.** To be effective, the planning and design of stormwater systems must address all of these potential sources of water and the full range of potential rates of flow and volumes and how they may be altered by development activity.
10. **The stormwater management system must be designed, beginning with the outlet or point of outflow from the project, giving full consideration to potential impacts and the effects of off-site flows entering the system.** The design of the stormwater management system shall take into

account runoff from upstream sites and shall evaluate the downstream conveyance system to ensure that it has sufficient capacity to accept design discharges without adverse backwater or downstream impacts such as flooding, stream bank erosion, channel degradation, and sediment deposition. An assessment of potential downstream impacts should be based on quantifiable measures that relate to basin conditions immediately after project completion and with regard to future development and its timing.

11. **Poorly maintained systems may not function properly, reducing their effectiveness and reducing the benefits from the economic investment required to construct them.** Operation and maintenance procedures and activities must be developed and documented with the facility design, including the identification and acquisition of rights of access. Clear assignment of maintenance responsibilities must be identified and assigned to an established entity with the resources and understanding required to ensure proper ongoing maintenance.
12. **Floodplains, both regulated and unregulated, are areas of potential hazard due to high rates of runoff.** Modification of floodplains requires large investments in resources, and risks can increase when they are not properly managed. Flooding potential exists throughout the drainage system and is not limited to “regulatory” floodplains. In addition, flooding potential is not limited to regulated flows, and flow estimates may not accurately represent risk. It is not a question of *if* regulatory flows will be exceeded, but *when* they will be exceeded. The preservation of floodplains serves to reduce flood flows, minimize hazards, preserve habitat and open space, improve water quality, create a more livable environment, and protect the public health, safety, and welfare.
13. **Sufficient land rights must be reserved.** When space requirements are considered, the provision for adequate drainage becomes a competing use for space along with other land uses. If adequate provision is not made in a land use plan for drainage requirements, stormwater runoff can conflict with other land uses and impair or disrupt the functioning of other urban systems. Natural processes possess a prescriptive easement for intermittent occupancy by runoff. Encroachments into this easement can adversely affect adjacent properties and natural systems during inevitable periods of natural easement occupancy.
14. **Drainage law places certain obligations on those who cause or oversee modifications to the natural effects of the hydrologic cycle and the conveyance of runoff overland.** It is incumbent on individuals and agencies to safeguard the right of those potentially impacted by modifications to stormwater runoff to reduce the potential for impacts to public health, safety and welfare and to maintain the orderly development of human-made systems.

Chapter 3

Stormwater Management Policies

Contents

1.0	Introduction	1
2.0	Planning and Design	1
2.1	Reports and Plans	1
2.2	Early Planning	1
2.3	Integrated Comprehensive Planning	1
2.4	Multi-purpose Resource	1
2.5	Stormwater Master Plan	2
2.6	Site Design and Layout	2
2.7	Stormwater System Design Storms	2
2.7.1	Minor System	2
2.7.2	Major System	3
2.8	Detention Storage	3
2.8.1	Purpose and Planning Considerations	3
2.8.2	Locating Detention Storage Facilities	4
2.8.3	Previous Detention Approaches	4
2.8.4	Full Spectrum Detention	4
2.8.5	On-Site Detention	5
2.8.6	Rooftop and Underground Detention	5
2.9	Stormwater Quality and Runoff Reduction	5
2.9.1	Runoff Reduction	5
2.9.2	Best Management Practices	5
2.10	Drainageway Design Considerations	6
2.10.1	Major Drainageways	6
2.10.2	Minor Drainageways	7
2.11	Flood Flows	7
2.11.1	General	7
2.11.2	Floodplain Encroachment	7
2.11.3	Building Above Floodplains	7
2.12	Right-of-Way, Tracts and Easements	7
2.13	Basin Diversions	8
2.13.1	Intra-basin Diversions	8
2.13.2	Inter-basin Diversions	8
2.14	Groundwater Mitigation	8
3.0	Construction of Public Improvements	8
3.1	Minor Drainage System	9
3.2	Major Drainageway System	9
3.3	Major Drainageways in the City of Woodland Park	9
3.4	Master Plan Improvements	10
4.0	Stormwater Development Fees	10
5.0	Operations and Maintenance	10
5.1	Operation and Maintenance Plan	10
5.2	Owner Responsibility	10

5.3	Access	11
5.4	Private Detention Storage	11
5.5	Conveyance of Upstream Runoff	11
5.6	Easements on Residential Lots.....	11
6.0	Regulatory/Legal.....	11
6.1	Local Permits	11
6.2	Environmental Permitting	12
6.3	NPDES/CDPS Permits.....	12
6.4	Floodplain Regulations	12
6.5	Water Rights	13
6.6	Drainage Law	13
7.0	Hazard Minimization & Public Safety.....	13
7.1	Public Safety	13
7.2	Potential Hazards	13
7.3	Jurisdictional Dams and Reservoirs	13
8.0	Irrigation Canals or Ditches	14

1.0 Introduction

This chapter provides guidance on stormwater management policies and planning that should be considered in the early stages of projects in the City of Woodland Park (City) and summarizes concepts that are further developed in this Manual. Incorporating stormwater management in the initial stages of planning can lead to reduced infrastructure costs, better long-term function of stormwater management facilities, facilities with better maintenance access, and increased property values. To conduct initial feasibility studies or preliminary site analyses, it is important to have a clear understanding of stormwater management policies, regulatory requirements and criteria, site design practices for effective stormwater management, and existing site characteristics. Additional guidance for planning of the urban storm runoff system is also provided in the Planning Chapter of the UDFCD Manual.

2.0 Planning and Design

The following sections provide policies for addressing the impacts of urbanization and factors to consider when planning for stormwater management.

2.1 Reports and Plans

All project proposals shall receive full site planning and engineering analyses. Drainage reports and plans are required for all new development and redevelopment and shall be prepared in accordance with the City of Woodland Park Municipal Code (submittal requirements summarized in Chapter 4 of this Manual) and other applicable regulations.

2.2 Early Planning

Stormwater management planning is required in the initial planning stages of developments and redevelopments to ensure that adequate space is allocated for the required stormwater management facilities and that key issues are identified and adequately addressed. Planning efforts should include an assessment of sensitive site features and functions and identification of measures for preservation and enhancement of natural features and functions.

2.3 Integrated Comprehensive Planning

Drainage and water quality are important components of the City *Comprehensive Plan*(2010), and the City is in the process of developing an updated stormwater master plan that will replace the previous *City of Woodland Park Stormwater Management Program* that was completed in 1996. These plans, including updates and future plans in place at the time the project is being designed, should be consulted for all projects to assure that there is consistency between the proposed project and these planning documents.

2.4 Multi-purpose Resource

Drainageways and stormwater runoff can be urban resources that are amenities in urbanizing areas. When viewed as a resource, aesthetically pleasing, multi-purpose drainage designs can be integrated into developments, reconciling the competing demands for space during site development. For example, stormwater management facilities can be designed to fulfill recreational purposes and open space requirements along with stormwater runoff conveyance or detention storage. Additionally, facilities not intended primarily for stormwater management purposes may be designed to incorporate water quantity and quality benefits. For example, street medians, parking space islands, parking lots, landscaped areas, and other features can often be designed to provide stormwater management functions. Engineers are

encouraged to involve a landscape architect for effective, multi-functional integration of stormwater management with site landscaping.

2.5 Stormwater Master Plan

The City has conducted planning for drainage and water quality as a part of past plans, including the *Woodland Park Stormwater Management Plan* (1996). The City is currently developing an updated city-wide stormwater master plan that will replace the 1996 plan when it is completed. Developers, project planners and designers are required to incorporate master planned improvements into their development plans. In areas that have not yet been master planned, the developer must conduct analyses necessary to develop a plan that adheres to the criteria in this Manual. Where projects will be phased, development plans shall address the conditions that may occur in the period between development phases, including interim improvements, to comply with this Manual. Master plans will be updated and revised periodically by the City to accommodate changes that may occur within the City and to address additional drainage and water quality needs.

2.6 Site Design and Layout

Good site design and development layout are keys to effective stormwater management. Initial planning must identify important natural features and environmentally sensitive areas such as floodplains, riparian areas, wetlands and areas with soils that are conducive to infiltration. Protection of those areas should be incorporated into the site plan. Other site characteristics such as topography, geologic features, and soils may also present unique challenges for stormwater management planning. Stormwater quality facilities should be carefully planned and located to minimize directly connected impervious area, reduce runoff volumes and slow runoff rates. The incorporation of infiltration and stormwater conveyance into landscaped areas furthers the concept of designing stormwater management facilities that are aesthetically pleasing and effectively integrated within the site.

2.7 Stormwater System Design Storms

Stormwater systems are classified as minor or major systems based on the design storms that they designed to convey. Design requirements for each system are summarized below.

2.7.1 Minor System

The minor stormwater system shall be designed to convey runoff up to a storm event with a return period of 5 years (20% annual exceedence probability). The minor drainage system shall be designed to transport runoff with minimum disruption to the urban environment and to preserve and protect the natural environment.

In many areas minor storm drainage is conveyed in the curb, gutter and storm drain system of the street but in other areas, it is conveyed in roadside ditches/swales, which provide greater opportunities for infiltration and runoff reduction (but that require erosion protection on steep grades). Minor system design shall be based on runoff peak flows and volumes for fully developed conditions in the watershed. The design shall consider the effect of nuisance flows that result from excess irrigation, snowmelt and other sources and implement measures to minimize problems that may result from biological growth or decay, ice formation or other hazards.

Inlets, when needed, shall be located and designed to maximize collection or interception efficiency and with consideration of the proposed use in the vicinity of the inlet locations. Inlets in vehicular traffic or

parking areas are much different than inlets in landscaped or pedestrian traffic areas. Inlet types and grate designs must consider the setting of the inlet and potential inundation effects on adjacent property.

Underground storm drain systems, which convey stormwater runoff collected at inlets should be designed to facilitate proper function and ease of maintenance/repair. Storm drain design and layout should consider proximity to proposed structures, other utilities, and adjacent properties; depth of cover; traffic loading; proposed surface improvements; accessibility for future maintenance/repair; and other factors.

2.7.2 Major System

The major stormwater system shall be designed to convey runoff events up to a return period of 100 years (1% annual exceedence probability). The major drainage system shall be designed to convey runoff in a manner that minimizes health and safety hazards, damage to structures and natural systems, and interruption to traffic and services. Major storm flows typically are carried in the street system, swales/channels, storm drains and other facilities, provided that capacity exists when future development is considered. While the 100-year event is designated as the major event, larger events have occurred in the past and will occur again in the future. In cases with significant risk to public health, safety and welfare, events in excess of the major event may need to be considered and planned for.

2.8 Detention Storage

2.8.1 Purpose and Planning Considerations

Detention storage facilities serve a critical role in the management of increased runoff due to development and must be carefully integrated into early planning stages. Detention storage facilities shall be strategically located to mitigate the effects of increased runoff due to new development, redevelopment or expansion. Although the primary function of detention storage is attenuation of peak flow rates to allowable release rates, some volume reduction also occurs through infiltration into the pond bottom or evaporated as runoff is temporarily stored. Detention storage facilities should be designed to mitigate the full range of developed condition runoff rates by mimicking runoff rates from the upstream basin under undeveloped conditions up to the major storm event. Where site conditions allow, runoff reduction measures should be implemented to reduce the rate and volume of runoff from frequently occurring events in conjunction with detention storage. Runoff reduction and detention should be implemented in redevelopment projects to the extent practical, potentially as a part of street improvements in areas with space constraints.

Per City of Woodland Park Resolution No. 299, Series 1994, detention shall be provided for a low-flow, minor and major event. The low-flow event is based on retaining 75% of the 2-year runoff volume based on a 0.8 inch, one-hour storm. The minor event is the 5-year event with a one-hour storm depth of 1.1 inches, and the outlet must be designed to release 5-year flows at or below historic levels. The major event is the 100-year event with a one-hour storm depth of 2.1 inches, and flows from this event must be released at a rate not to exceed the historic discharge rate. The storage volumes from these events must be added together to determine the total detention storage volume. With approval of the City Engineer, the Water Quality Capture Volume (WQCV) may be substituted for the low-flow volume, and approaches such as Full Spectrum Detention, including providing the Excess Urban Runoff Volume (EURV), may be used to optimize the water quality and flood control benefits of detention facilities as discussed in the Storage Chapter.

Detention storage facilities have special design considerations and space allocation requirements. Sufficient space must be allocated to meet the criteria in this Manual and to allow for long-term maintenance and repair. Detention facilities should not be designed based only on minimum required

volume calculations or by assuming that retaining walls or steep slopes can be used to minimize the land area needed for the improvements. Generally, aesthetics and long-term operation and maintenance are severely compromised when required storage volumes and maintenance access are not integrated early in the planning stages. Detention designs that incorporate detention storage into the overall site and landscape plans can lead to multi-purpose facilities that are viewed as site amenities.

2.8.2 Locating Detention Storage Facilities

The location of a detention storage facility depends on its intended function within the drainage system. Most of the development or redevelopment that occurs in Woodland Park will require detention so that existing storm drain capacity is preserved or improved and/or to avoid causing/contributing to downstream flooding and/or channel erosion and degradation. When detention facilities can be located where upstream sediment loads are well managed (e.g., by BMPs, upstream stabilization, sediment forebays, etc.), maintenance costs may be lowered due to less frequent sediment removal requirements. Detention storage facilities should be designed to be multi-purpose, aesthetically pleasing, safe and maintainable community assets.

To the extent feasible, detention storage facilities should be located to avoid classification as jurisdictional dams by the Office of the State Engineer. The criteria for non-jurisdictional dams are defined in the *Rules and Regulations for Dam Safety and Dam Construction* (State of Colorado Department of Natural Resources, Division of Water Resources Office of the State Engineer 2007). Jurisdictional dams must be reviewed and approved by the State Engineer and may require special design and construction considerations, potentially increasing their costs. Jurisdictional dams require an ongoing inspection and maintenance program.

2.8.3 Previous Detention Approaches

Past detention storage approaches that allowed flows from development to be conveyed long distances before being attenuated in detention facilities have resulted in degradation of the natural functions of drainageways, difficulties in effective implementation and economic burden to the public to stabilize degraded streams. Detention in headwaters areas, including providing the low-flow retention volume, the WQCV or EURV is critical to the stability of downstream drainageways. Detention facilities that do not provide mitigation for the more frequent runoff events and systems that do not include volume reduction practices can result in significant downstream impacts due to erosion and sedimentation.

2.8.4 Full Spectrum Detention

Full spectrum detention is a relatively new approach to stormwater detention that effectively limits peak flow rates to predevelopment levels and reduces the volume of stormwater runoff when used in conjunction with minimizing directly connected impervious area and other volume reduction practices. Placing full spectrum detention ponds for site-level detention will often not be feasible for a single-site development; however, for multiple lots or larger developments, full spectrum detention is a viable option, in conjunction with bioretention, extended dry detention, a sand filter or permeable pavement with detention storage in the aggregate. In addition to reducing runoff rates, full spectrum detention can also provide water quality benefits, primarily through sedimentation. The full spectrum detention approach, as defined in Chapter 13 of this Manual, maybe implemented as an alternative to the standard Low-Flow/5-year/100-year criterion specified by City of Woodland Park Resolution No. 299, Series 1994.

Although full spectrum detention is expected to more effectively mitigate increases in peak flow rates and runoff volumes for the full range of runoff events, it generally will not eliminate the need for channel stabilization downstream. To maximize the benefits of this approach, it must be implemented throughout

a drainage basin and downstream floodplain storage must be preserved. Alternative detention approaches will be evaluated on a case-by-case basis, depending on the facility's ability to achieve results similar to full spectrum detention and/or the City's existing Low-Flow/5-year/100-year criterion.

2.8.5 On-Site Detention

When development or redevelopment is proposed within a basin where downstream facilities are inadequate to pass project flows, on-site detention may be required. Requirements for on-site detention are described more fully in Chapter 13. The appropriateness of on-site detention will be evaluated on a case-by-case basis. In many cases, on site detention for small-scale developments can be accomplished by integrating a relatively small amount of additional storage into water quality facilities such as permeable pavements, bioretention area, sand filters and/or landscape depression storage.

2.8.6 Rooftop and Underground Detention

Rooftop and underground detention for flood control are prohibited, except as approved by the variance process in this Manual. Variances for rooftop or underground detention may be considered when there are severe space limitations or when the downstream system capacity is very limited; however, underground and rooftop detention systems should be avoided when practical, due to difficulties in ensuring adequate inspection and maintenance in locations that may not be easily accessible. Underground stormwater quality facilities may be allowed on a case-by-case basis at the discretion of the City Engineer, and in all cases an agreement stating the maintenance responsibility, frequency and process to rectify poor or delayed maintenance shall be established with the City.

2.9 Stormwater Quality and Runoff Reduction

Stormwater quality management approaches should include a combination of runoff reduction practices and structural and non-structural Best Management Practices (BMPs) to provide the WQCV.

2.9.1 Runoff Reduction

Whenever practical, site planning and design techniques should reduce imperviousness, minimize directly connected impervious area and increase infiltration in order to decrease the rate and volume of stormwater runoff from a site. A series of BMPs should be implemented to meet the goals of this Manual, both in terms of runoff reduction and pollutant concentration and load reduction. BMPs that provide for infiltration as well as water quality treatment have the ability to conjunctively address runoff quantity (for frequently occurring storm events) and quality and may be some of the most cost-effective practices. Volume 3 of the UDFCD Manual should be consulted for a detailed discussion regarding the implementation of runoff reduction practices.

Stormwater runoff volume reduction is beneficial to accomplishing overall stormwater management goals and can potentially reduce the overall cost of stormwater management features in development. Stormwater volume reduction is not currently required by regulation or permit in Woodland Park; however, it is anticipated that future regulations and permit requirements will likely heavily emphasize infiltration, evapotranspiration and/or capture/reuse of excess urban runoff where site conditions are conducive. Capture and reuse of urban runoff is constrained by Colorado Water Law.

2.9.2 Best Management Practices

All new developments and redevelopments are required to address stormwater quality during construction and post-construction conditions, as described in Volume 3 of the UDFCD Manual. Planning and design

of post-construction (permanent) water quality BMPs is best addressed hand-in-hand with stormwater conveyance and detention storage requirements for a site.

2.10 Drainageway Design Considerations

Design considerations for major and minor drainageways are discussed separately below.

2.10.1 Major Drainageways

A major drainageway is defined as any channel draining a tributary area of approximately 130 acres or more. The 130-acre threshold for defining a major drainageway is approximate in Woodland Park and may vary depending on specific site conditions, including the density of upstream development, opportunities for detention embankment construction, street-channel crossing locations, the quality of natural channel features downstream, and the capacity of the downstream system. As discussed in Section 3.3, there are several major drainageways that run through parts of the City. These include Trout Creek and Loy Gulch in the Upper South Platte watershed, and Fountain Creek and tributaries in the Fountain Creek Watershed.

Major drainageways shall be preserved in their natural state or restored where already degraded, to the extent practical, and stabilization measures shall be designed to complement and enhance their natural character. Preserving natural channels provides ecological and hydrologic benefits such as riparian habitat, flood storage and opportunity for groundwater recharge, and usually reduces the overall cost of improvements. Natural channels can also be valuable amenities when integrated into open space areas.

Key considerations for major drainageway design include preserving or restoring the natural character of the channel, limiting velocities to non-erosive levels, planning for maintenance access, and evaluating and mitigating potential safety hazards. To the extent practical, major drainageway channels shall be constructed to provide a natural, smooth transition from the channel to the natural topography. Bank slopes greater than 4:1 for major drainageway channels should be avoided due to stability/erosion concerns and maintenance access. Retaining walls may be used with approval of the City Engineer when appropriate due to space and/or side slope constraints; however, retaining walls are generally discouraged for “natural” channel sections. Varying side slopes and the channel cross section throughout the channel reach is encouraged to provide a less structural, more natural appearance. Channelizing natural drainageways should be avoided when feasible and usually increases flow rates and reduces floodplain storage, causing higher downstream peaks and higher drainage costs, ultimately degrading the environment.

In some cases, it is not feasible to construct a natural, open channel major drainageway due to constraints which may include space limitations due to private property, existing severe erosion problems (e.g. some reaches of Fountain Creek), other infrastructure, etc. In these cases, a channelized or closed conduit solution may be the most practical choice for providing conveyance of flood flows and protecting infrastructure, especially in areas with constrained right of way.

When full spectrum detention and upgradient volume reduction practices are implemented, peak flows entering major drainageways will be reduced, and as redevelopment activities occur in Woodland Park, with facilities that address water quality and detention, better management of runoff will improve the stability of drainageways. Controlling runoff from developed areas so that detention releases more closely approximate predevelopment conditions is critical for implementing “natural” channel designs for major drainageways. However, even with implementation of volume reduction measures and full spectrum detention in the tributary watershed, some channel stabilization work is still typically required.

2.10.2 Minor Drainageways

A minor drainageway is defined as any conveyance that drains a tributary area of less than approximately 130 acres. Minor drainageways typically require significant modifications to accommodate developed flows, especially if adequate detention is not provided for upstream, and in many cases minor drainageways in urbanized areas have been channelized or are in storm drains. Surface conveyances are encouraged and should be considered in areas as storm drains age and require replacement.

2.11 Flood Flows

2.11.1 General

Flood risk evaluation and delineation of the regulatory floodplain and floodway shall be based on a runoff event with a return period of 100 years (annual exceedence probability of 1%). Flood flows shall be based on fully-developed, future land use conditions. Effects of detention storage facilities on flood flow rates can be considered, provided that the detention facilities have been implemented in compliance with approved master plans and have adequate assurances for long-term operation and maintenance (typically publicly owned and/or maintained facilities). Effects of on-site detention practices shall not be taken into account for determination of flood flows because long-term operation and maintenance of private, on-site facilities is not assured. Where critical facilities, such as hospitals, fire stations, wastewater and water treatment plants, police stations, electrical sub-stations or other facilities, provide important public services and emergency response capabilities, protection from a more severe storm event, such as the 500-year event, should be considered. The City recently adopted Floodplain regulations for critical facilities in accordance with CWCB requirements. For the purposes of floodplain delineation, flood flows shall be evaluated as described in Chapter 5 of this Manual.

2.11.2 Floodplain Encroachment

Encroachment into the regulatory floodplains is strongly discouraged, and encroachment into unregulated floodplains is undesirable. When considering requests for floodplain filling or relocation, the impacts to adjacent properties, channel hydraulics, channel aesthetics, flood storage, and riparian habitat shall be evaluated and mitigated. Alterations to floodplains must acknowledge that anticipated flood flows may not be accurately estimated and that less frequent (more extreme) events will occur. Any alteration of the regulatory floodplain must be reviewed by the Floodplain Administrator and approved by FEMA according to the local floodplain regulations.

2.11.3 Building Above Floodplains

When developing adjacent to floodplains, a minimum of 1 foot of freeboard shall be provided above the established Base Flood Elevation (BFE). For approximate floodplains without BFEs, the Applicant shall conduct analyses to determine the estimated 100-year flood elevation. While minimum freeboard required is 1.0 foot above the 100-year flood elevation, the Applicant is strongly encouraged to provide additional freeboard due to uncertainties associated with approximate (Zone A) floodplains. The analyses shall be reviewed and approved by the City Engineer.

2.12 Right-of-Way, Tracts and Easements

All developments must include the allocation of space for drainage facility construction and maintenance, which includes the preservation of natural systems and the conveyance of adequate right-of-way and/or easements or tracts through the execution of appropriate legal documents. Right-of-way for floodplains

must also account for potential increases in flood flows due to development and for the preservation of floodplains and their natural functions.

2.13 Basin Diversions

2.13.1 Intra-basin Diversions

Some intra-basin diversion of runoff may occur within major basins, as sub-basin boundaries are changed with a development. Those diversions should be minimized and, to the extent possible, historic outfall locations to natural drainageways shall be maintained. When a diversion is necessary, any potential adverse impacts that result shall be mitigated with proper stormwater management design and adequate right-of-way.

2.13.2 Inter-basin Diversions

Inter-basin diversion of runoff from one major drainageway basin to another major drainageway basin shall be avoided unless specific and prudent reasons justify and dictate a diversion. These diversions must be part of a master plan that fully recognizes the potential impacts and provides for adequate mitigation measures.

2.14 Groundwater Mitigation

Shallow groundwater has the potential to adversely impact the construction, capacity, long-term function, and maintainability of stormwater management facilities. It is the Applicant's responsibility to perform investigations and analyses to quantify potential effects of shallow groundwater and to implement facility designs that are effective under such conditions. For facilities that are intended to be dry between runoff events, seasonally high groundwater should be at least three feet below the bottom of the facility so that the bottom of the facility does not become inundated as groundwater fluctuates throughout the year. For facilities designed for infiltration, a minimum separation from the annual high groundwater table of at least 5 feet is recommended.

It is also important to note that for infiltration-based BMPs, the groundwater beneath the site is the receiving water for stormwater that is infiltrated. Therefore, infiltration-based BMPs are not recommended for land uses that generate significant loads of dissolved pollutants or for "hot spot" areas such as drive-through lanes, fueling areas, etc.

Other groundwater related issues may occur when groundwater or subsurface flows increase as a result of development and urbanization. In such cases, foundation drains and sump pumps are often installed to collect and discharge these flows to the surface. If discharged quantities are excessive or continuous, icing and algae can create nuisance conditions. Mitigation of these problems typically requires an additional collection system, which may ultimately discharge into the storm drain system. These additional flows have the potential to affect the capacity of the storm drain system. During wet weather, runoff in the storm drain system may surcharge the subsurface collection system.

3.0 Construction of Public Improvements

When drainage reports or other applicable reports or studies identify public improvements that are necessary to properly manage stormwater runoff, mechanisms for funding the improvements are required. Funding mechanisms should equitably distribute the construction and maintenance costs in proportion to the benefits received. Applicants are required to construct, or guarantee to construct, stormwater

management facilities that are necessary to serve their subdivision or development. Such facilities may include improvements to convey off-site flows through the property and participation in the stabilization or improvement of the major drainageway system. Public improvements typically consist of the street/minor drainage system and the major drainageway system, as described in the remainder of this section.

3.1 Minor Drainage System

The minor (or local) drainage system, to convey the 5-year event, must be designed and constructed with all new development and redevelopment. The minor drainage system consists of curb and gutter, inlets and storm drains, culverts, bridges, swales, ditches, channels, detention facilities, and water quality BMPs within the subdivision or development. The minor drainage system also includes facilities required to convey the minor and major storm runoff to the major drainageway system and those facilities necessary to convey off-site flows across or through the developing property. The drainageway improvements may be master planned or may require the preparation of detailed analysis by the Applicant. It is the responsibility of the Applicant to demonstrate that improvements on the site will be protected from minor and major storm flows, flooding, channel degradation and bank erosion. Conveyance of off-site runoff is discussed in detail in Chapter 6, Hydrology.

3.2 Major Drainageway System

The major drainageway system consists of channels, storm drains, bridges, culverts, detention facilities, and water quality BMPs generally serving a tributary area of approximately 130 acres or greater and, in many cases, more than one subdivision or development. Major drainageway systems within proposed developments must be designed and constructed as part of the new development or redevelopment.

3.3 Major Drainageways in the City of Woodland Park

The City of Woodland Park has three major drainageways within its City limits. These drainageways include Trout Creek, which flows south to north; Fountain Creek, which flows north to south; and Loy Gulch, a tributary of Trout Creek, which flows east to west.

1. Trout Creek drains a total area of approximately 24 square miles to the downstream City boundary and is a part of the South Platte River Basin. Tributaries of Trout Creek include Lovell and Loy Gulches. The drainage area is comprised of land uses including public, commercial, residential, and forest.
2. Fountain Creek drains a total area of approximately 5.5 square miles to the downstream City boundary. Fountain Creek, located within the Arkansas River Basin, is subject to more intense rainfall than Trout Creek, in the South Platte River Basin. The drainage area is comprised of land uses including agricultural, public, commercial, business, residential, and forest.

3. Loy Gulch, a tributary of Trout Creek, drains a total area of approximately 6.6 square miles to the downstream City boundary. The drainage area is comprised of land uses including commercial, residential, and forest.

3.4 Master Plan Improvements

Development and redevelopment projects must be designed and constructed in accordance with the *City of Woodland Park Engineering Specifications* (2011). Improvements must be in conformance with the most current versions of stormwater and drainage master plans and the City Comprehensive Plan. Responsibility for these improvements, which may serve multiple ownerships or projects, shall be determined through discussion and negotiation during the preparation of Preliminary and Final Drainage Reports and Plans.

4.0 Stormwater Development Fees

A current schedule of stormwater-related development fees is available from Public Works. The stormwater fee program was established via Ordinances 633 (1994) and 645 (1995) and was amended in 1996 via Ordinance 674.

5.0 Operations and Maintenance

Maintenance activities, including routine maintenance, restorative maintenance, rehabilitation and repair, are required to ensure the long-term function and effectiveness of stormwater management infrastructure. Such tasks are necessary to preclude the facility from becoming ineffective and to avoid reduced conveyance capability, unsightliness, and malfunction. Site plans and projects must incorporate provisions for adequate access and space to perform maintenance activities for all stormwater management facilities. Routine maintenance of facilities may include removal of debris and sediment, trash rack clearing, mowing, noxious weed control, etc. Non-routine restorative maintenance activities include repairs to or replacement of structures and other improvements necessary to retain the effectiveness of the system. All facility designs shall be held to the same standards, regardless of the organization or entity that has accepted responsibility for maintenance.

5.1 Operation and Maintenance Plan

The design of all stormwater management facilities must be performed with access and short-term and long-term operation and maintenance being priority considerations. An Operation and Maintenance Manual (O&M Manual) must be developed and approved concurrent with the design and shall define O&M plans and those entities responsible for the maintenance and management of stormwater facilities. The purpose of the O&M Manual is to provide guidance and standard forms for those responsible for the long-term inspection and maintenance of the facilities. Water quality BMPs require an Inspection and Maintenance Plan as described in Volume 3 of the UDFCD Manual.

5.2 Owner Responsibility

The property owner shall be responsible for the all maintenance, rehabilitation and repair of stormwater facilities located on the property unless another party accepts such responsibility in writing and responsibility is properly assigned through legal documentation. Maintenance responsibility shall be defined on final plats and final development plans or by maintenance agreements.

5.3 Access

Drainage easements, tracts and access easements, or public right-of-way shall be provided for all stormwater management facilities that convey public stormwater runoff or that will be maintained by a public entity. In general, easements are required for detention facilities, structural water quality enhancement BMPs, storm drains, swales, channels, parking lot areas that convey runoff from adjacent properties (blanket type easements), culverts, major drainageways, and floodplains. Drainage easements shall be granted for inspection and maintenance purposes and shall be shown on the drainage plans, Final Plat, and Site Improvement Plans, as applicable. Maintenance access for all facilities must be adequate for the anticipated maintenance vehicles and equipment. Public stormwater runoff shall be defined as surface waters resulting from rainfall, snowmelt or groundwater seepage that originates on privately or publicly owned property and combines with other surface waters from publicly owned property.

5.4 Private Detention Storage

When detention storage facilities receive runoff only from private parcels, but release flows into a public system or onto public right-of-way, easements shall be provided for access, inspection and maintenance.

5.5 Conveyance of Upstream Runoff

Developing properties shall convey runoff from upstream properties across their site within dedicated drainage easements or tracts in accordance with approved drainage plans. This may require the conveyance of developed runoff if the approved plan includes downstream detention storage facilities.

5.6 Easements on Residential Lots

Drainage leaving individual residential lots can combine with other privately owned residential lots and contribute to excess runoff entering adjacent lots, creating the potential for saturated ground, local flooding and a general nuisance. Subdivision plans shall limit the amount of runoff from residential lots so that runoff does not unduly impact adjacent lots. Easements shall be provided along lot lines or through tracts so that these flows can be conveyed safely. Drainage easements are allowed at a width of 10 to 20 feet (total width) along residential lot lines (typically centered on the lot line, with equal portions on each lot). Swales placed within these easements may only accept a limited amount of drainage and must remain free of obstructions such as fences, excessive vegetation and/or debris. Maintenance of swales within any easements is the sole responsibility of the property owners.

6.0 Regulatory/Legal

6.1 Local Permits

The construction of stormwater management facilities may require one or more of the following permits:

1. **Flood Hazard Development Permit.** Projects that include work within designated 100-year floodplain limits of drainageways require a Flood Hazard Development Permit. Consult Chapter 5, Floodplain Management, of this Manual for additional details.
2. **Zoning Development Permit.** A Zoning Development Permit is required for any substantial clearing, grading or excavation of any area over one thousand five hundred (1,500) square feet, or a driveway of any size, on lands contemplated for development. Applicants must also obtain a Zoning Development Permit to begin any construction, moving, alteration or renovation of any

building or other structure, aside from ordinary repairs. The Zoning Development Permit defines the type of use and type of occupancy for land and structures. Zoning Development Permits are valid for one year from the date of issue and must be renewed if construction has not started within that time period.

3. **Right-of-Way Access/Street Cut Permit.** Projects that include use of or construction in the public right-of-way must obtain a Right-of-Way Access/Street Cut Permit.
4. **Grading Permit.** A grading and erosion control plan must be submitted and approved prior to the start of land-disturbing activities. A Grading Permit is required for development and redevelopment activities with more than 7,500 ft² of disturbance per Chapter 18.41 of City Zoning Regulations.

6.2 Environmental Permitting

In addition to local permitting processes, the construction of stormwater management facilities often requires permitting through the Colorado Department of Public Health and Environment Water Quality Control Division with regard to stormwater management during construction and construction dewatering; permitting through the United States Army Corps of Engineers (USACE) relative to Section 404 of the Clean Water Act (wetlands permitting); and through the United States Fish and Wildlife Service regarding threatened and endangered species. It is strongly recommended that initial project planning incorporate input from the appropriate agencies to determine permitting process requirements because these processes can be complex and time consuming. It is the responsibility of the owner or developer to anticipate and comply with all permit requirements for a project.

Compliance with state or federal permitting requirements does not replace the need to fully comply with local regulations, standards, or criteria. If necessary, joint discussions between all regulatory agencies shall be initiated in project planning stages and continued as needed.

6.3 NPDES/CDPS Permits

Permit holders under the National Pollutant Discharge Elimination System (NPDES) Program requirements of the Federal Clean Water Act, and regulations promulgated by the Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Division (Colorado Discharge Permit System [CDPS]) comply with permit requirements, which includes requiring permanent post-construction water quality enhancement BMPs with development or redevelopment. Currently, the City of Woodland Park falls below the size threshold requiring a Municipal Separate Storm Sewer (MS4) permit through CDPHE (generally population greater than 10,000); although, with current EPA Rulemaking it is anticipated that the City of Woodland Park will be required to obtain coverage under and comply with a MS4 permit as the federal regulations are implemented at the state level. In addition, CDPS coverage for Stormwater Discharges Associated with Construction Activities is required for all projects with an area of disturbance of greater than or equal to 1.0 acre.

6.4 Floodplain Regulations

The City of Woodland Park participates in the National Flood Insurance Program (NFIP) and implements and enforces floodplain development regulations that meet or exceed the minimum standards provided in 44 Code of Federal Regulations, Part 60.

6.5 Water Rights

It is the responsibility of the owner/developer to recognize that certain stormwater management facilities may impact water rights. The integrity of water rights shall be preserved in the planning, design, and construction of stormwater drainage facilities according to Colorado law and the rules administered by the Office of the State Engineer.

6.6 Drainage Law

The general principles of Colorado drainage law and specific Colorado Revised Statutes guide and affect many aspects of stormwater management, including, but not limited to, private and municipal liability, maintenance and repair of drainage improvements, construction of drainage improvements by local governments, financing of drainage improvements, floodplain management, irrigation ditches, dams and detention facilities, water rights, and water quality. The Drainage Law Chapter of the UDFCD Manual provides an outline of the general principles of Colorado drainage law and should be consulted for general reference.

7.0 Hazard Minimization & Public Safety

7.1 Public Safety

Public safety shall be an essential objective when planning, designing and maintaining stormwater facilities.

7.2 Potential Hazards

Stormwater facilities shall be designed with careful consideration of the potential hazards associated with the use, operation and maintenance of the facility and shall include appropriate design features to minimize these risks.

7.3 Jurisdictional Dams and Reservoirs

Dam safety issues and hazards may be associated with water storage facilities due to the risks associated with dam failure, emergency spillway locations, and downstream flow paths. Jurisdictional dams are classified by the State Engineer as low, moderate, or high hazard structures depending on the risks dams pose to downstream property and public safety. Currently, there are no jurisdictional drainage dams maintained by the City of Woodland Park¹.

Due to the potential liabilities and regulatory and administrative requirements, the creation of jurisdictional dams is strongly discouraged. The creation of a jurisdictional dam shall not be allowed, unless special approval is obtained. Detention pond embankment heights shall be limited, and other elements of pond design shall be considered to avoid the creation of a jurisdictional dam.

¹ The City owns jurisdictional water supply dams; however, these structures are located outside of City limits.

8.0 Irrigation Canals or Ditches

Irrigation ditches and reservoirs have historically intercepted the storm runoff from rural and agricultural basins. Urbanization of the basins, however, has increased the rate, quantity and frequency of stormwater runoff and can have negative effects on water quality. Irrigation ditches are designed with flat slopes and have limited carrying capacity, decreasing in the downstream direction. In addition, certain ditches are abandoned after urbanization and, therefore, cannot be successfully utilized for storm drainage. Currently, there are no ditches or canals in the City of Woodland Park. If an irrigation ditch or canal is involved in the design of a project, the Applicant shall consult the Colorado Springs Manual for applicable policies.

Chapter 4

Submittals

Contents

- 1.0 Introduction..... 1**
- 2.0 Overview of Submittal Requirements 1**
 - 2.1 Preliminary Drainage Report (PDR) 1
 - 2.2 Guidelines for a Final Drainage Report (FDR) 6
 - 2.3 Drainage Report for Re-subdivisions 7
 - 2.4 Stormwater Management Facility Operation and Maintenance 8
 - 2.5 Erosion and Stormwater Quality Control Plan/Stormwater Management Plan (SWMP) 8
 - 2.6 Construction Plan Drainage Statements and Notes 8

Tables

Table 4-1. Guidelines for a Preliminary Drainage Report (PDR) 3

Table 4-2. Preliminary Drainage Plan Drawing Requirements.....6

1.0 Introduction

This chapter describes the drainage submittal, review and approval process for development and redevelopment projects in Woodland Park, including requirements for stormwater-related submittals such as drainage reports and construction drawings for stormwater management facilities. The Applicant must prepare the required submittals in compliance with previously approved governing documents and the criteria in this Manual. The requirements presented in this chapter are the minimum necessary and will be used to evaluate the adequacy of submittals. Depending on site-specific conditions, additional studies and submittals may be necessary.

Plans for addressing stormwater management issues for each phase of a project may include a Preliminary Drainage Report and/or a Final Drainage Report. In some cases, a Drainage Letter Report may be sufficient. Requirements for each of these documents are described in the remainder of this chapter. Title 1, Policies and Procedures, of the *City of Woodland Park Engineering Specifications* (2011) provides detailed information on procedures and required submittals for subdivisions and other developments in Woodland Park.

2.0 Overview of Submittal Requirements

All reports shall be prepared in the appropriate format and properly bound. The drawings, figures, and tables shall be bound with the report or included in a pocket attached to the report. The reports shall contain appropriate analyses and information as described herein, prepared under the supervision of and certified by a Professional Engineer licensed in Colorado. The Applicant must also provide an electronic copy of all submittal materials in PDF format when hard copy submittals are delivered to the City.

2.1 Preliminary Drainage Report (PDR)

A Preliminary Drainage Report (PDR) shall accompany Preliminary Plat submittals. The purpose of the PDR is to identify a conceptual plan and identify specific solutions for on-site and off-site existing and future conditions resulting from the development of the proposed project. The PDR should address any existing drainage and/or water quality problems associated with the project site and proposed measures to address existing problems and accommodate the planned development without adversely affecting neighboring properties.

The proposed improvements must be consistent with any previously approved master plans and the *City of Woodland Park Engineering Specifications* (2011). Analysis of drainage basin hydrology and hydraulics shall be based on the best available site information and land use plans. Specific improvements, including open channels, storm sewers, grading, site stabilization, catch basins, culverts and other improvements, will be located and sized to meet requirements of the minor and major drainage systems. Drainage easements and tracts necessary to access and maintain the proposed improvements must be identified.

A typical PDR consists of a narrative portion and appendices with supporting calculations and other pertinent information. The narrative should lead the reader logically through the entire analysis and design process and provide a clear picture of stormwater management issues. The narrative portion shall provide detailed discussion regarding the general location and description of the site, off-site and on-site drainage basins and subbasins, drainage design criteria, stormwater management facility design, and conclusions. Discussion of methodology, assumptions, input, and a summary of results shall be provided in the narrative for all hydrologic or hydraulic modeling efforts. Peak flow rates, storage volumes, critical water surface elevations, and stormwater management facility sizes shall also be summarized and

discussed in the report narrative. The appendices must provide the appropriate backup information and calculations, but the reader should not have to review information contained in the appendices to have a clear and thorough understanding of the project and the stormwater management analysis and facility designs.

The guidelines for a typical PDR are summarized in Table 4-1, which can be used as a checklist for completeness for PDR submittals.

If it is determined during the development review process that the project is of sufficient size or complexity, a PDR may be required in advance of the final drainage report. This may also be done at the developer's request. Two copies of the PDR shall be submitted. The drainage report shall be a stand-alone document. When references are made or assumptions are based on previously approved submitted reports, the drainage report must include the appropriate excerpts, pages, tables, and maps containing the referenced information.

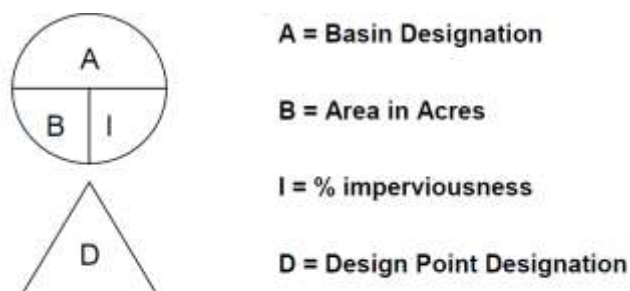
Table 4-1.Guidelines for a Preliminary Drainage Report (PDR)

	Cover Sheet	Project Name, Owner/Developer/Applicant and Address, Engineer, Submittal Date/Revision Date(s)
	Letter of Transmittal	Must include Professional Engineer's Stamp/Certification
	Certification Statement	The report shall contain a certification page with the following statement: “This report and plan for the preliminary drainage design of <u>(Name of Development)</u> was prepared by me (or under my direct supervision) in accordance with the provisions of City of Woodland Park Drainage Design and Technical Criteria and was designed to comply with the provisions thereof. I understand that City of Woodland Park does not and will not assume liability for drainage facilities designed by others.” SIGNATURE: _____ Registered Professional Engineer State of Colorado No. _____ (Affix Seal)
	Report Contents	I. General Location and Description A. Location a. City and county, and local streets within and adjacent to the subdivision b. Township, range, section, ¼ section c. Major drainageways and existing facilities d. Names of surrounding platted developments B. Description of property a. General project description, including proposed land use b. Area in acres c. Ground cover (type of trees, shrubs, vegetation) d. General topography e. General soil conditions, hydrologic soil group f. Major drainageways and drainage facilities II. Drainage Basins and Subbasins A. Major basin descriptions a. Reference should be made to major drainageways planning studies; such as drainage basin planning studies, flood hazard delineation reports, and flood insurance studies or maps, if available 1. A floodplain statement shall be provided indicating whether any

		portion of the development is in a designated floodplain as delineated on the current FEMA mapping b. Major basin drainage characteristics c. Identification of all nearby irrigation facilities and other obstructions which could influence or be influenced by the local drainage B. Sub-basin description a. Discussion of historic drainage patterns of the property in question b. Discussion of off-site drainage flow patterns and their impact on the development III. Drainage Design Criteria A. Development criteria reference a. Reference all criteria, master plans, and technical information used for report preparation and design; any deviation from such material must be discussed and justified b. Discussion of previous drainage studies (i.e., PDR, DBPSs, master plan, flood insurance studies) for the site in question that influence or are influenced by the drainage design and how the studies affect drainage design for the site B. Hydrologic criteria a. Identify design rainfall b. Identify runoff calculation method c. Identify design storm recurrence intervals d. Identify detention discharge and storage calculation method IV. Drainage Facility Design A. General concept a. Drainage concept and typical drainage patterns b. Discussion of compliance with off-site runoff considerations c. Discussion of anticipated and proposed drainage patterns d. Discussion of the content of tables, chart, figures, plates or drawings presented in the report B. Specific details a. Presentation of existing and proposed hydrologic conditions including approximate flow rates entering and exiting the project site with all necessary calculations
--	--	---

		b. Existing stormwater conveyance and storage facilities c. Proposed stormwater conveyances, including storm drain pipes, inlets, and open channels d. Detention/water quality facility volumes, water surface elevations, release rates, and outfalls e. Discussion of the drainage impact of site constraints such as streets, utilities, existing and proposed structures f. Relationship to both upstream and downstream properties and impact of the project on these properties; include discussion of off-site drainage flow patterns g. Maintenance responsibility, access and aspects of the preliminary design h. Compliance with other local, state and federal requirements, if any i. Water quality measures implemented to treat stormwater, including Water Quality Capture Volume(WQCV) or Excess Urban Runoff Volume (EURV) j. Structural and non-structural best management practices (BMPs) that will be part of the stormwater management design C. Conclusions a. Compliance with Standards b. Justification for any requested waiver(s) c. Effectiveness of drainage design to control damage from storm runoff d. Influence of proposed development on upstream and downstream properties e. Water quality treatment D. References E. Appendices
--	--	--

Table 4-2 Summarizes PDR drawing requirements. The following symbols should be used to define basins and design points:



A summary runoff table should be included on the PDR plan sheets that lists design points, identifies contributing drainage basins to each design point, quantifies contributing drainage areas and provides 5- and 100-year design peak flow rates.

A detention basin summary table should be included on the PDR plan sheets that provide storage volumes (WQCV/EURV and/or detention volumes) and water surface elevations and release rates corresponding to storage volumes and release rates. A rating curve showing stage-storage-discharge relationships for detention and/or water quality features shall be provided on PDR plan sheets for storage facilities designed to impound more than 1 acre-foot of runoff.

Table 4-2. Preliminary Drainage Plan Drawing Requirements

Preliminary Drainage Plan Contents	
	24" x 35" in size at a scale of 1" = 20' to 1" = 200'
	Vicinity map at a scale no smaller than 1" = 2000'
	Title Block, Including name of project, address, engineering firm, P.E. stamp.
	Legend, north arrow, scale, date of preparation and benchmark.
	Boundaries of entire development of project.
	Existing (dashed or screened) and proposed (solid) contours with 2-foot maximum interval, extending a minimum of 100 feet beyond property lines. In terrain greater than 10% slope, 10 foot intervals are allowed.
	Proposed development site plan/improvements.
	All existing and proposed drainage facilities (e.g. detention facilities, storm sewers, swales, riprap, outlet structures, irrigation ditches, culverts, cross pans).
	Major basin and sub basin boundaries, including off-site basins.
	Floodplain boundary based on the most current information.

2.2 Guidelines for a Final Drainage Report (FDR)

The Final Drainage Report (FDR) serves to finalize the planned improvements identified the Preliminary Drainage Report and to present the design details for the proposed improvements. The FDR must also identify changes to the preliminary design concepts that were incorporated due to review comments.

The analyses included in the FDR provide the background for the design that is incorporated into construction plans for the proposed project and shall include calculations that support the location and sizing of all drainage features required to properly convey on-site and off-site surface runoff, including grading, streets profiles, pond grading and outlet designs, street sections, storm sewer and channel profiles and water quality features, etc.

The Final Drainage Report and Plan shall incorporate all of the information outlined in Table 4-1 for preliminary reports and plans, updated to reflect comments and revisions. The following information also shall be provided:

- a. Detention storage and outlet design and details.
- b. Storm drain system design, and hydraulic calculations including hydraulic grade line (HGL) and energy grade line (EGL) computations, pipe and inlet locations, types and sizes.
- c. Locations of storm drain system outfalls, energy dissipation features (if required), and details.
- d. Water quality features and details.

The report also must include the following certification statement signed and stamped by a registered Professional Engineer in Colorado.

“This report and plan for the final drainage design of (Name of Development) was prepared by me (or under my direct supervision) in accordance with the provisions of City of Woodland Park Drainage Design and Technical Criteria for the owners thereof. I understand that City of Woodland Park does not and will not assume liability for drainage facilities designed by others.”

SIGNATURE: _____

Registered Professional Engineer State of Colorado No. _____

2.3 Drainage Report for Re-subdivisions

When a portion of previously platted land is re-subdivided and the proposed division of lots is consistent with previously approved reports for the property, a modified drainage report format may be submitted with approval. In this situation a “Letter Type” drainage report rather than a complete Final Drainage Report may be proposed.

A “Letter Type” drainage report may be used only for re-subdivision or re-plat when a complete drainage report has previously been approved by the City/County Engineer and significant changes from such report are not proposed. If a complete drainage report has not been approved in the past, a full drainage report will be required.

The “Letter Type” drainage report must include the following:

1. Cover sheet or statement stating the name and purpose of the report. This shall include the date of preparation and the name of the previous subdivision.
2. Engineer’s certification.
3. Body of the report shall include:
 - a. General property description with acreage
 - b. General existing drainage characteristics (on and off site)

- c. General proposed drainage characteristics (on and off site)
 - d. Hydrologic calculations including areas, runoff coefficients, time of concentration, rainfall intensity, and runoff.
4. A site map showing the general vicinity of the project.
5. A drainage plan indicating site and adjacent property as platted with name and filing. Indicate storm runoff routing and rates if applicable.
6. Drainage fees (cash or letter of credit) shall be determined in accordance with the latest drainage ordinances/resolutions and applicable basin fees.

2.4 Stormwater Management Facility Operation and Maintenance

All projects should be planned, designed and constructed acknowledging that maintenance is essential to the effectiveness of stormwater improvements. Designs should provide adequate maintenance access and implement concepts that reduce maintenance requirements. Detention ponds, open channels, post-construction water quality BMPs, and other stormwater management facilities require proper maintenance in order to ensure that they function as designed. Each project must include an Operation and Maintenance (O&M) Manual developed in conjunction with the final design to ensure that maintenance considerations have been incorporated into project designs and to document how those provisions must be implemented. Although many common maintenance provisions apply to projects, each O&M Manual must also identify the unique features of each project that need to be addressed.

The O&M Manuals should provide guidance and standard forms for those responsible for the maintenance of stormwater management facilities. The O&M Manual must be submitted for acceptance with the construction drawings. For small projects, the O&M Manual may be a short and simple document identifying maintenance activities and methods, maintenance frequency, triggers for maintenance (scheduled and unscheduled) and documentation requirements. For larger projects, a more comprehensive O&M Manual addressing multiple facets of the drainage system (detention, channels, water quality facilities, etc.) is required.

2.5 Erosion and Stormwater Quality Control Plan/Stormwater Management Plan (SWMP)

A Stormwater Management Plan (SWMP) that addresses erosion control and stormwater quality during the construction phase and extends through final stabilization of this site is required. Volume 2 of the Colorado Springs Manual provides criteria and guidance on construction-phase (and post-construction) stormwater quality management. The SWMP shall address each phase of construction and shall be an integral part of the overall site development plans. Erosion control measures shall be sufficient to control the runoff from the design rainfall. For sites disturbing more than 1 acre (or smaller sites that are a part of a larger common plan of development) coverage under the CDPHE General Permit for Stormwater Discharges Associated with Construction Activities will be required in addition to local requirements.

2.6 Construction Plan Drainage Statements and Notes

All construction plans shall contain the following statements and notes:

1. Detailed Drainage Construction Plans and Specifications Engineer's Statement: "These detailed plans and specifications were prepared under my direction and supervision. Said detailed plans and specifications have been prepared according to the established criteria for detailed drainage plans and specifications, and said detailed plans and specifications are in conformity with the master plan of the drainage basin. Said detailed drainage plans and specifications meet the

purposes for which the particular drainage facility(s) is designed. I accept responsibility for any liability caused by any negligent acts, errors or omissions on my part in preparation of the detailed drainage plans and specifications.”

2. Required Note: “Plan review by The City of Woodland Park is provided only for general conformance with Design Criteria. The City of Woodland Park is not responsible for the accuracy and adequacy of the design, dimensions, and/or elevations which shall be confirmed at the job site. The City of Woodland Park, through the approval of this document, assumes no responsibility for completeness and/or accuracy of this document.”

Chapter 5

Floodplain Management

Contents

1.0	Introduction	1
2.0	Floodplain Management and Regulation	1
2.1	City Code.....	1
2.2	Floodplain Management	1
2.3	Level of Flood Protection	2
2.3.1	Standard Level of Protection	2
2.3.2	Higher Level of Protection	2
2.4	National Flood Insurance Program.....	2
2.5	Colorado Water Conservation Board.....	3
2.6	Floodplain Development Regulations	3
2.7	Unstudied or Unmapped Floodplains	3
3.0	Sources of and Use of Existing Floodplain Information	4
3.1	FEMA Flood Insurance Rate Maps (FIRMs) and Flood Insurance Study (FIS)	4
3.2	Major Drainageways with FEMA Mapping in Woodland Park	5
3.3	Woodland Park Drainage Master Plan and Stormwater Management Plan.....	6
3.4	Other Floodplain Information.....	6
3.5	Confirmation of Floodplain Data.....	6
4.0	Construction in or Development Adjacent to Floodplains.....	6
4.1	Floodway	6
4.2	Floodplain Fringe and Encroachments	7
4.3	Subdivision Platting and Floodplains	7
4.4	Freeboard Requirements	8
5.0	FEMA Map Revisions and Amendments	8
5.1	General	8
5.2	Conditional Letter of Map Revision (CLOMR)	9
5.3	Conditional Letter of Map Revision Based on Fill (CLOMR-F).....	9
5.4	Letter of Map Revision (LOMR).....	9
5.5	Letter of Map Revision Based on Fill (LOMR-F)	9
5.6	Conditional Letter of Map Amendment (CLOMA).....	9
5.7	Letter of Map Amendment (LOMA)	9
5.8	Physical Map Revision	9
6.0	Floodplain Study Guidelines.....	10
6.1	Requirement	10
6.2	Incorporation into Other Submittals	10
6.3	Floodplain Study Outline.....	10
6.4	Agency Review Requirements	11
6.5	Conceptual Review.....	11
7.0	Floodproofing.....	11

Figures

Figure 5.1. Trout Creek Floodplain Near Northern City Limits	12
Figure 5.2. Trout Creek Floodplain Including Confluence with Loy Gulch.....	13
Figure 5.3. Loy Gulch Floodplain and Upper Trout Creek.....	14
Figure 5.4. Loy Gulch, Paint Pony Creek and Lovell Gulch Floodplains	15
Figure 5.5. Upper Trout Creek, Including Detailed (Zone AE) Mapping	16
Figure 5.6. Upper Trout Creek Approximate (Zone A) Floodplain Mapping	17
Figure 5.7. Upper Fountain Creek Floodplain Mapping.....	18
Figure 5.8. Upper Fountain Creek Floodplain Mapping (Continued)	19

1.0 Introduction

Nature has claimed a prescriptive easement for floods, via its floodplains, that cannot be denied without public and private cost (White 1945). Flooding can result in loss of life, increased threats to public health and safety, damage to public and private property, damage to public infrastructure and utilities, and economic impacts to residents. In contrast, natural floodplains provide many benefits, including natural attenuation of flood peaks, water quality enhancement, groundwater recharge, wildlife habitat and movement corridors, and opportunities for recreation.

Floodplains have been created and recreated over millennia and are the result of a complex interaction between hydrologic forces, vegetation, wildlife activity and geologic features. Changes to any of the factors that contribute to their natural function and dynamic adjustment to natural phenomenon may have far-reaching consequences and must be thoroughly evaluated.

As a matter of public health and safety, it is desirable to minimize risks associated with potential flooding. The most effective means of minimizing these risks is to preserve flood-prone areas and to avoid alterations to flood flows and floodplains.

This chapter describes policies, practices, and procedures for floodplain management. The requirements presented in this chapter apply to development within and adjacent to floodplains.

2.0 Floodplain Management and Regulation

2.1 City Code

Title 20 of the Woodland Park Code of Ordinances (City Code) addresses Flood Damage Prevention Regulations, including the statutory authority and the basis for the regulations, administrative procedures for Flood Hazard Development Permits, variance procedures and procedures/requirements for flood hazard reduction. The City Code provides the basis for floodplain and floodway regulation in Woodland Park, and this chapter provides information that can be used to develop plans that will be compliant with the City Code. To the extent that there are differences between the recommendations in this chapter and the requirements of Title 20, Title 20 requirements shall prevail.

2.2 Floodplain Management

Floodplain management is generally defined as a comprehensive program of preventative and corrective measures to reduce losses associated with flooding. Floodplain management measures may include, but are not limited to, land use regulations (including new development and construction policy), construction of flood control projects, floodproofing, floodplain preservation, acquisition of flood-prone properties, education, and implementation of early warning systems. These measures must be implemented in a consistent manner to be of value. Some of the objectives of floodplain management are to:

- Adopt effective floodplain regulations,
- Improve local land use practices, programs and regulations in flood-prone areas,
- Provide a balanced program of measures to reduce losses from flooding including floodplain and land use regulation, capital improvements, floodplain preservation, public education, flood insurance and others,

- Reduce reliance on local, state and federal disaster relief programs,
- Minimize water quality impacts, and
- Foster the creation or preservation of greenbelts, with associated wildlife and other ecological benefits.

2.3 Level of Flood Protection

2.3.1 Standard Level of Protection

The standard of practice, as defined by FEMA, requires implementation of floodplain management criteria within the “regulatory” 100-year (Base Flood) floodplain. The regulatory 100-year floodplain is the land area that will be inundated or flooded based on the stormwater runoff produced by the 100-year storm event as delineated on adopted FIRMs. The 100-year storm event is defined as the rainfall event that has a 1% probability of being equaled or exceeded in any given year. The flood flows used to determine floodplains shall be estimated using the methods defined in the Hydrology Chapter of this Manual, accepted published documents, and sources and methods otherwise approved by FEMA. Discharge flow rates in excess of the 100-year estimate can and will occur, but with lower probability. In those instances, the depth of flow and floodplain width will typically be greater than indicated on the floodplain maps.

It is important to note that flooding occurs outside of the regulatory floodplains both beyond their width and upstream where mapping has not been provided. These areas must also be managed to preserve adequate space for flooding and to protect property and public safety.

2.3.2 Higher Level of Protection

In some cases, a higher level of protection should be provided for flooding events in excess of the 100-year event. A higher level of protection should be considered for facilities and access routes that are critical for the protection of public health, safety, and welfare, or where flooding in excess of the 100-year storm event flooding is likely to result in loss of life, significant damage to utilities and infrastructure, or result in hazardous materials being transported in flood waters. The event for which protection should be provided should be determined on a case-by-case basis and be appropriate to the consequences of incurring the potential hazards. The Colorado Water Conservation Board (CWCB) has suggested that the 500-year flood event could be appropriate for evaluating risk to “critical facilities.” Critical facilities are structures or related infrastructure that, if flooded, may result in significant hazards to public health and safety or interrupt essential services and operations for the community at any time before, during and after a flood.

2.4 National Flood Insurance Program

The National Flood Insurance Program (NFIP) is a federal program enabling property owners to purchase insurance protection against losses from flooding. Participation in the NFIP is based on an agreement between local communities and the federal government, which states that if a community will implement and enforce measures to reduce future flood risks to new construction in Special Flood Hazard Areas (SFHAs) or “designated floodplains,” the federal government will make flood insurance available within the community. In the past, the national response to flooding disasters was generally limited to constructing flood control projects and providing disaster relief to flood victims after a flood occurred. This did not reduce losses or discourage unwise development in flood-prone areas. Additionally, the

public could not buy flood coverage from private insurance companies. Faced with mounting flood losses and escalating costs to the general taxpayers, Congress created the NFIP. The City of Woodland Park and Teller County participate in the NFIP and have agreed to adopt and enforce floodplain development regulations that meet or exceed the minimum outlined in 44 Code of Federal Regulations, Part 60. If the communities do not enforce the regulations that have been adopted, the community can be put on probation or suspended from the program. If suspended, the communities become “non-participating” and flood insurance policies cannot be written or renewed.

2.5 Colorado Water Conservation Board

The CWCB is the State Coordinating Agency of the NFIP. The Flood Protection Program of the CWCB assists in the prevention of and recovery from flood disasters. The CWCB is responsible for technical review and approval of all reports and maps that are normally used by local governments for regulatory, floodplain administration, and insurance purposes. The CWCB review and approval process is officially known as floodplain designation. Designation and approval of the existing floodplain mapping enhance a community’s ability to regulate 100-year floodplains more effectively. State enabling law for local zoning and subdivision regulation requires that technical information used for regulation of flood-prone areas be designated and approved by the CWCB.

2.6 Floodplain Development Regulations

The governing regulation for floodplains within the City of Woodland Park is contained within Title 20 of the City of Woodland Park Municipal Code (City Code). The relationship between floodplains and development activity is also discussed in several other articles of Title 17 of the City Code, which addresses subdivision of land including preliminary and final plat requirements, and Title 18, which addresses zoning. The detailed requirements defined in the applicable codes are not reproduced in this chapter. For modifications to the SFHA and other floodplains regulated by the City, a Flood Hazard Development Permit is required.

2.7 Unstudied or Unmapped Floodplains

There are a number of small channels and streams within the City that do not have FEMA-designated SFHAs. Some of these are headwaters reaches where FEMA mapping has not been extended all the way upstream. Typically FEMA maps floodplains for drainageways around urbanized areas that have a tributary drainage area of one square mile or greater. The potential for loss of life and/or property along these streams exists, just as it does along those channels or streams where floodplain limits or SFHAs have been identified. In general, these unstudied or “non-regulatory” floodplains will be managed in a similar manner as floodplains within the SFHAs. Management of these floodplains includes the preservation of right-of-way and natural features, and the mitigation of safety hazards. However, the FEMA process for mapping and map revision procedures is not required.

A significant number of flood insurance claims result from areas outside of regulatory floodplains. By definition, flooding occurs whenever rainfall causes water to inundate the surface of the ground. While this occurs frequently without consequence, a failure to adequately accommodate these conditions can result in significant flood losses.

Floodplain limits and water surface elevations must be determined for these unstudied drainageways when development, including but not limited to, home construction, channel modification, grading and earthmoving, other construction activities, or storage is proposed. In general, where floodplain

information is unavailable, the applicant will be responsible for delineating the floodplain, based on fully-developed conditions in the watershed, consistent with the requirements outlined in this Manual.

3.0 Sources of and Use of Existing Floodplain Information

3.1 FEMA Flood Insurance Rate Maps (FIRMs) and Flood Insurance Study (FIS)

The purpose of FIRMs is to identify flood-prone areas, by approximate or more detailed methods, and to establish flood risk zones for insurance rate purposes within those flood-prone areas. FIRMs are generally based on watershed conditions at the time the engineering analyses and accompanying survey were completed. In addition, detailed contour mapping may not have been available or used in the preparation of the original FIRMs. It is notable that there are differences between FIRMs and observed flood paths and some drainageway alignments in Woodland Park, and FIRM maps may not accurately reflect actual floodplains. In some cases modifications to drainageways have occurred that are not yet reflected on FIRMs.

The information provided on the FIRMs and in the FIS is not based on consideration of changes that may have occurred since the study was completed or may occur due to future development in the watershed. Therefore, this information should not be solely relied upon as the actual limits of the 100-year floodplain or to identify areas prone to flooding. Further investigation of the assumptions, methodologies, and mapping that was used to produce the flood information on the FIRMs should be performed by a Professional Engineer registered in the State of Colorado. In some cases, the FIRMs are the only source of information available and can be used as an aid, but additional investigation and analyses may be required to define the actual floodplain limits on a particular parcel of land, especially when FIRMs are believed to be out-of-date and/or inaccurate.

FIRMs, however, are the official regulatory maps published by FEMA for flood insurance purposes and, therefore, must be used when determining limits of the SFHA, and for complying with the floodplain regulations, as discussed previously. Important characteristics of FIRMs include:

1. Detailed Studies. FIRMs contain SFHA designations that were developed through a detailed study or by approximate methods. For drainageways that have a detailed study, Base Flood Elevations (BFEs, corresponding to 100-year water surface elevations) are provided on the maps and information is available in the FIS regarding floodplain and floodway widths, drainage areas, and peak discharges at select locations. In most cases, the BFEs can be used in conjunction with detailed topographic information to produce a reasonable estimate of the floodplain limits on a particular parcel of land, as long as it can be verified that the topographic information and the BFEs are referenced to the same vertical datum.
2. Approximate Zones. SFHA designations that were developed by approximate methods (Zone A) are generally less accurate and BFEs are not provided. Typically, there is no published information regarding peak flow rates used to calculate the approximate limits. As a result, making floodplain determinations and correctly delineating the floodplain on a specific property is more difficult. When a project is adjacent to a Zone A floodplain, floodplain limits must be developed using topographic mapping and an acceptable level of hydrologic and hydraulic analysis or a registered Professional Engineer must certify that flooding is unlikely. Procedures for making floodplain estimations in Zone A areas are outlined in the FEMA publication *Managing Floodplain Development in Approximate Zone A Areas*; however, the applicant's engineer should consult with the governing jurisdiction prior to selection of methodology or level

of detail to confirm that they are reasonable and appropriate.

3. **Map Revisions.** FIRMs are often updated due to development or construction projects, changes in hydrology, the use of better topographic information, or other factors that affect the accuracy of the current SFHA limits. In most cases, the updates occur through a process called a Letter of Map Revision (LOMR). A LOMR provides revised floodplain information for a particular area, which supersedes the previous information and becomes the effective SFHA designation. However, the LOMR is a separate document, and the FIRMs typically are not re-published with the changes resulting from a revision. When reviewing FIRMs, it is important to determine whether any LOMRs have been completed for the area in question since these changes (LOMRs) may not yet be shown on the FIRM.
4. **Map Availability.** Current copies of the FIRMs and LOMR information are available for review in the office of the Floodplain Administrator. Maps can also be acquired through the FEMA Region 8 Office in Denver, or on-line at www.fema.gov. Figures for floodplains along major drainageways in Woodland Park are included as Figures 5-1 through 5-8 at the end of this chapter. Users of the Manual must check for current FEMA mapping, recent CLOMRs/LOMRs affecting reaches of interest and any updated hydrologic information since the date of the FIS.

3.2 Major Drainageways with FEMA Mapping in Woodland Park

The City of Woodland Park has three major drainageways within its City limits. These drainageways include Trout Creek, which flows south to north, Fountain Creek which flows north to south, and Loy Gulch, a tributary of Trout Creek, which flows east to west.

Per the FIS, Trout Creek drains a total area of approximately 24 square miles to the downstream City boundary shown on the FIRM and is a part of the South Platte River Basin. Tributaries of Trout Creek include Lovell and Loy Gulches. The drainage area is comprised of land uses including public, commercial, residential, and forest. According to the FIS, peak flows for the 10-yr, 50-yr, 100-yr, and 500-yr events are approximately 230 cfs, 340 cfs, 380 cfs, and 500 cfs, respectively. Trout Creek has an average gradient of 0.02 ft/ft (2 percent) through the City.

Loy Gulch, a tributary of Trout Creek, drains a total area of approximately 6.6 square miles to the downstream City boundary shown on the FIRM, according to the FIS. The drainage area is comprised of land uses including commercial, residential, and forest. According to the FIS, peak flows for the 10-yr, 50-yr, 100-yr, and 500-yr events are approximately 90 cfs, 140 cfs, 160 cfs, and 200 cfs, respectively. Loy Gulch has an average gradient of 0.03 ft/ft (3 percent) through the City. Figures 5-1 through 5-6 provide effective FEMA floodplain mapping for Trout Creek and Loy Gulch as of the date of this Manual.

Fountain Creek drains a total area of approximately 5.5 square miles to the downstream City boundary shown on the FIRM, according to the FIS. Fountain Creek, located within the Arkansas River Basin, is subject to more intense rainfall than Trout Creek, in the South Platte River Basin. The drainage area is comprised of land uses including agricultural, public, commercial, residential, and forest. According to the FIS, peak flows for the 10-yr, 50-yr, 100-yr, and 500-yr events are approximately 80 cfs, 120 cfs, 130 cfs, and 180 cfs, respectively. Fountain Creek has an average gradient of 0.03 ft/ft (3 percent) through the City. Figures 5-7 and 5-8 provide effective FEMA floodplain mapping for Fountain Creek as of the date of this Manual.

3.3 Woodland Park Drainage Master Plan and Stormwater Management Plan

The City of Woodland Park worked with consultants to create the City of Woodland Park Drainage Master Plan and Stormwater Management Plan in 1996. These plans, which will periodically be updated by the City, define drainage and stormwater management planning for many portions of the City and should be referenced and consulted for proposed construction activities with potential to affect floodplains, drainage and/or stormwater quality management. The City is currently in the process of creating an updated city-wide drainage and stormwater master plan, and Applicants should be sure they are using the most current planning documents.

3.4 Other Floodplain Information

Floodplain data may be obtained from other sources, including the Colorado Water Conservation Board, special districts that have completed floodplain studies and mapping, other local government initiated studies, and studies that have been prepared by private property owners or developers. In some cases, the information may be used as a basis for floodplain delineation for permitting and land development purposes, but the accuracy of all such information must be verified and the use of the information approved by the City.

3.5 Confirmation of Floodplain Data

Prior to using any published floodplain information for design or planning purposes, the source of the data, accuracy, modeling methodology, assumptions, and other considerations must be investigated. Many factors can change floodplain limits; therefore, floodplain data is periodically updated to reflect changes due to floodplain modifications or the use of better technical data. The applicant is solely responsible for acquiring or developing accurate floodplain information for design and planning purposes.

4.0 Construction in or Development Adjacent to Floodplains

The following sections identify the two areas within the SFHA floodplains with BFEs that are defined for regulatory purposes and discuss additional issues related to development adjacent to floodplains.

4.1 Floodway

The floodway is defined as the stream channel and that portion of the floodplain that must be preserved in order to discharge the base flood without cumulatively increasing the water surface more than a designated height. The floodway is based on a maximum increase in the flood elevation of 1.0 foot. The floodway limits are typically generated through hydraulic modeling by assuming an equal loss of conveyance on both sides of the floodplain. The floodway can't be identified by visual inspection on a specific site or stream reach. The floodway is defined for regulatory purposes, and development in or use of the floodway is severely restricted. In most cases, projects that encroach upon the floodway require a "no rise" certification for existing structures, and conveyance improvements are needed to balance fill activities so that no rises in 100-year BFEs adversely affect insurable structures.

It is notable that 1.0-foot rise floodways are being replaced by 0.5-foot-rise floodways as large map revision projects occur (typically Physical Map Revisions [PMRs] and not CLOMRs/LOMRs for specific reaches). Applicants should consult with the City Engineer and CWCB to determine applicable floodway rise criteria.

4.2 Floodplain Fringe and Encroachments

The floodplain fringe is the portion of the 100-year floodplain that is not within the floodway. Although development and other forms of encroachment may be considered in the floodplain fringe, developers do not have an inherent right to fill in the floodplain fringe.

Encroachments into the floodplain fringe reduce beneficial floodplain storage areas, and the cumulative effect of such encroachments can have significant impacts on downstream properties. Encroachment evaluations are only based on flood depth and do not consider impacts to channel stability as a result of increased channel velocity. Reduction of floodplain storage areas can increase peak flow rates and associated BFEs downstream, even though theoretically there may be limited impact at the site where the encroachment occurs. For this reason, encroachment into the floodplain fringe is contrary to the objective of minimizing damage to life and property and to the objective of maintaining floodplains as open space. Therefore, encroachments into the floodplain fringe are discouraged and will be considered on a case-by-case basis. When considering requests involving floodplain fringe encroachment, at a minimum, the following shall be considered:

- Impacts to adjacent properties. If the encroachment creates a rise in the BFE on properties other than that of the applicant, the applicant will be required to obtain floodplain easements for the additional floodplain property. FEMA typically will not allow any encroachment that causes a rise on an existing habitable structure.
- Channel hydraulics and design. If the encroachment creates a significantly narrow channel, with steep side slopes and undesirable velocities, mitigating channel improvements may be required, or the floodplain encroachment may not be supported.
- Channel stability, aesthetics and land use. If the fringe encroachment significantly impacts the functions, stability or aesthetics of the natural drainageway, and the resulting channel improvements create a drainageway that is not deemed compatible with the surrounding land uses, the floodplain fringe encroachment may not be supported.
- Threatened and Endangered Species. FEMA requires that the U.S. Fish and Wildlife Service (USFWS) sign-off for threatened and endangered species for CLOMRs. If there is no effect, the USFWS provides a letter of concurrence of “no taking.” If habitat for threatened and endangered species is affected, a CLOMR review may not begin until a permit is issued by the USFWS, which can delay the CLOMR and project schedule.

4.3 Subdivision Platting and Floodplains

Platted lots should be located outside of the 100-year floodplain limits. Subdivision layout should also consider these factors: the size of the tributary watershed and higher degrees of protection where 500-year floodplains have been identified; the stability of the drainageway and anticipated improvements in the floodplain; access and trail requirements adjacent to the floodplain; the proximity of steep or vertical banks relative to the location of lot lines; the potential for the channel to migrate horizontally over time; the topography of the proposed lots; and the differences in elevation between the flooding elevation and potential structure locations. Lot lines should not be placed within or immediately adjacent to the floodplain limits without consideration of these factors.

Additional considerations include:

1. Actual Floodplain Limits. The floodplain limits used for subdivision layout must be based on existing or proposed floodplain information that has been verified for accuracy, or floodplain limits must be developed through detailed hydrologic and hydraulic analyses, based on fully-developed conditions in the upstream watershed.
2. FEMA SFHAs. In addition to the physical floodplain limits, FEMA-designated SFHA boundaries must be considered in subdivision layout, where applicable. When the SFHA boundary accurately represents the proposed floodplain limits, lots should be platted so that they are outside of the SFHA. There are cases, however, where the SFHA is much wider than the actual or proposed floodplain. This situation frequently arises in locations where the SFHA was delineated using approximate methods or where improvements are proposed to confine the floodplain. In this case, platted lots should be outside of the SFHA and the actual floodplain, whichever is more restrictive. In some cases and only with the approval of the City Engineer, portions of platted lots that will not contain habitable structures (or significant obstructions to flow) may be within the SFHA. This would most typically be the case when detailed analysis shows a narrower floodplain and/or floodway than approximate or older FEMA mapping. Although outside of the actual floodplain, if lots are partially or totally within the SFHA, owners can be burdened with mandatory flood insurance purchase requirements.

4.4 Freeboard Requirements

A minimum vertical clearance, or freeboard, shall be provided between the 100-year BFE and structures and other applicable facilities which may be impacted by the floodplain. Freeboard is required to allow for uncertainty in the floodplain modeling, changes to the drainageway (i.e., increased invert due to sedimentation or increased vegetation), and to provide an additional factor of safety for structures and facilities which would result in damages or hazards during inundation. A minimum of 1 foot of freeboard shall be provided between the 100-year BFE and the lowest finished floor elevation of all structures (this includes basements). The required freeboard should be contained within the floodplain tract and/or easement. For development/fill in an Approximate Flood Zone (Zone A), a minimum of 1.5 foot of freeboard shall be provided for structures unless detailed analysis is submitted and approved. For Critical Facilities, greater freeboard is recommended and may be required as a part of recent CWCB regulations that will be integrated into the City Code.

5.0 FEMA Map Revisions and Amendments

5.1 General

FEMA FIRMs are the official regulatory maps that must be used for implementation and enforcement of the floodplain development regulations, which are generally discussed in this chapter. Additionally, the maps show projected flooding elevations, flood velocities, floodway dimensions, and flood risk zones used for insurance purposes. Maps must be updated to correct non-flood-related features, include analyses based on better ground elevation data, reflect changes in ground elevations within the floodplain, provide revised flooding data, and reflect flood control projects or other construction in the floodplain. Detailed information, revision request forms, technical requirements for map revisions or amendments, and construction requirements are included in the NFIP Regulations in 44 Code of Federal Regulations or are available through FEMA. The following sections provide brief descriptions of the various types of map revisions or amendments and how the requirements impact proposed projects.

5.2 Conditional Letter of Map Revision (CLOMR)

A CLOMR is prepared to allow FEMA to comment on a proposed project or the use of better data that would affect the hydrologic or hydraulic characteristics of a flooding source and thus result in the modification of the existing regulatory floodway, BFEs, or SFHA limits. A CLOMR is required by FEMA, prior to construction, for projects or construction in the floodway that will result in an increase in the BFEs. At the discretion of the Floodplain Administrator, a CLOMR may also be required for other projects when it is important to ensure that the SFHA will be revised based on a proposed project or the use of better data.

5.3 Conditional Letter of Map Revision Based on Fill (CLOMR-F)

A CLOMR-F is prepared to allow FEMA to comment on whether a proposed project involving the placement of fill outside of the regulatory floodway would exclude an area from the SFHA based on elevation. A detailed technical review generally is not required for a CLOMR-F application, as it primarily involves comparison of finished floor and lowest adjacent grades with . A CLOMR-F may also be required for a project when it is important to ensure that the SFHA will be revised based on a proposed project that involves fill in the floodplain fringe.

5.4 Letter of Map Revision (LOMR)

A LOMR is an official revision, by letter, to an effective FIRM. A LOMR may change flood insurance risk zones, floodplain and/or floodway boundary delineations, planimetric features, and/or BFEs. The LOMR may be based on the use of better data or as-built conditions reflecting flood control or other construction projects. The LOMR must be completed and issued in order to revise the effective SFHA.

5.5 Letter of Map Revision Based on Fill (LOMR-F)

A LOMR-F is a document issued by FEMA that officially removes a property and/or structure from the SFHA. 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.

5.6 Conditional Letter of Map Amendment (CLOMA)

A CLOMA is FEMA's comment on a proposed structure or group of structures that would, upon construction, be located on existing natural ground above the BFE. Generally, a CLOMA involves parcels, portions of parcels, or individual structures that were inadvertently included in the SFHA.

5.7 Letter of Map Amendment (LOMA)

A LOMA is a document issued by FEMA that officially removes a property and/or structure from the SFHA. A LOMA establishes a property's or structure's location in relation to the SFHA.

5.8 Physical Map Revision (PMR)

A PMR is an official republication of a map to change flood insurance zones, floodplain delineations, flood elevations, floodways, and planimetric features. A community can submit scientific and technical data to FEMA to support the request for a map revision. The data will be analyzed, and the map will be revised if warranted.

6.0 Floodplain Study Guidelines

6.1 Requirement

When a project will modify the SFHA or any other floodplain regulated by the City, a Flood Hazard Development Permit is required, which must be supported by a floodplain study. This section presents general guidelines for preparing a floodplain study. Activities or projects that may potentially affect floodplains are not limited to new development. Other activities include, but are not limited to, bridge or culvert construction, utility installation, channel stabilization projects, trail crossing construction, and proposed storage of equipment or materials.

6.2 Incorporation into Other Submittals

In some cases, the floodplain study will be an independent document; however, the floodplain study results are often incorporated into drainage reports for development projects or form the basis for CLOMR or LOMR submittals to FEMA.

6.3 Floodplain Study Outline

A floodplain study must be certified by a Professional Engineer registered in the State of Colorado. The study must address the following items through detailed analysis or through reference to the current drainage master plan:

1. A description of the site.
2. A description of the major drainage basin.
3. The identification of drainage master plan reports, Flood Hazard Area Delineation (FHAD) studies, or FISs with a discussion of the applicability of published information or data to the proposed activity or modification.
4. Hydrologic analysis, including a narrative on the source of peak flow rates used for design. The flow rates used should be those generated for each storm event included in previous studies under future or revised development conditions for the entire watershed, unless the floodplain modification study is for a CLOMR/LOMR application, in which case, the FIS discharges should be used.
5. Characteristics of the proposed channel including, but not limited to, slope, roughness, depth, velocity, Froude Number, centerline alignment and stationing, and cross-sections. Existing topographic mapping may be utilized if it has been field-verified to determine that it has not changed significantly since mapping. The profile and plan shall be given for existing conditions and for the proposed channel alignment, including the cross-section locations.
6. A description of the method of hydrologic and/or hydraulic analysis (such as HEC-HMS or HEC-RAS) and its application in the study.
7. Identification and discussion of all input parameters and basis for input parameters.
8. Discussion of the results and conclusions of the hydraulic analysis. This shall include a narrative summary of the results, printed comprehensive output file free of modeling errors, and an electronic file of the modeling effort for review.

9. The delineation of the existing and proposed floodplains and water surface profiles for both conditions, including cross-section locations.
10. A description of potential impacts to other properties in the vicinity of the modification or activity and to downstream properties adjacent to the floodplain.
11. A description of measures proposed to mitigate potential impacts.
12. A conceptual design for the channel including bank protection, drop structures, culverts, bridges, and hardened trickle channel or low-flow channel.
13. A channel stability analysis if there is a change to the hydraulic characteristics of the drainageway or the stability of the bed and banks or if there is a change to the soils. This may include an analysis of sediment transport and fluvial morphology.

6.4 Agency Review Requirements

Requests to modify the floodplain must be reviewed by multiple agencies, depending on the existing mapping of the flood hazard area and the extent of the modifications proposed, but in general conformance with the following:

1. City of Woodland Park. Issues related to floodplain management should be coordinated with any land use applications to the Planning Department and the Woodland Park City Engineer.
2. CWCB. The CWCB is the State Coordinating Agency of the NFIP and is responsible for technical review and approval of all reports and maps that are normally used by local governments for regulatory, floodplain administration, and insurance purposes.
3. FEMA. FEMA administers the NFIP. FEMA publishes Flood Hazard Boundary Maps and FIRMs that show floodplain boundaries for major drainageways. FEMA reviews applications to modify these FEMA designated floodplains. Floodplain modifications that impact a FEMA-designated floodplain must be submitted to FEMA for review and approval via a CLOMR/LOMR process.

6.5 Conceptual Review

Floodplain modifications must be permitted and approved by the agencies listed previously, depending on the proposed modification and site location. All projects or proposed modifications should be discussed with these agencies, in concept, prior to commencement of efforts required to produce the floodplain study.

7.0 Floodproofing

In areas where structures may be within an existing floodplain or where local flooding may be expected, floodproofing can provide protection against flooding or reduce flood damage. For more information on floodproofing, see the technical bulletins provided by FEMA as part of the NFIP and Volume 2 of the UDFCD Manual.

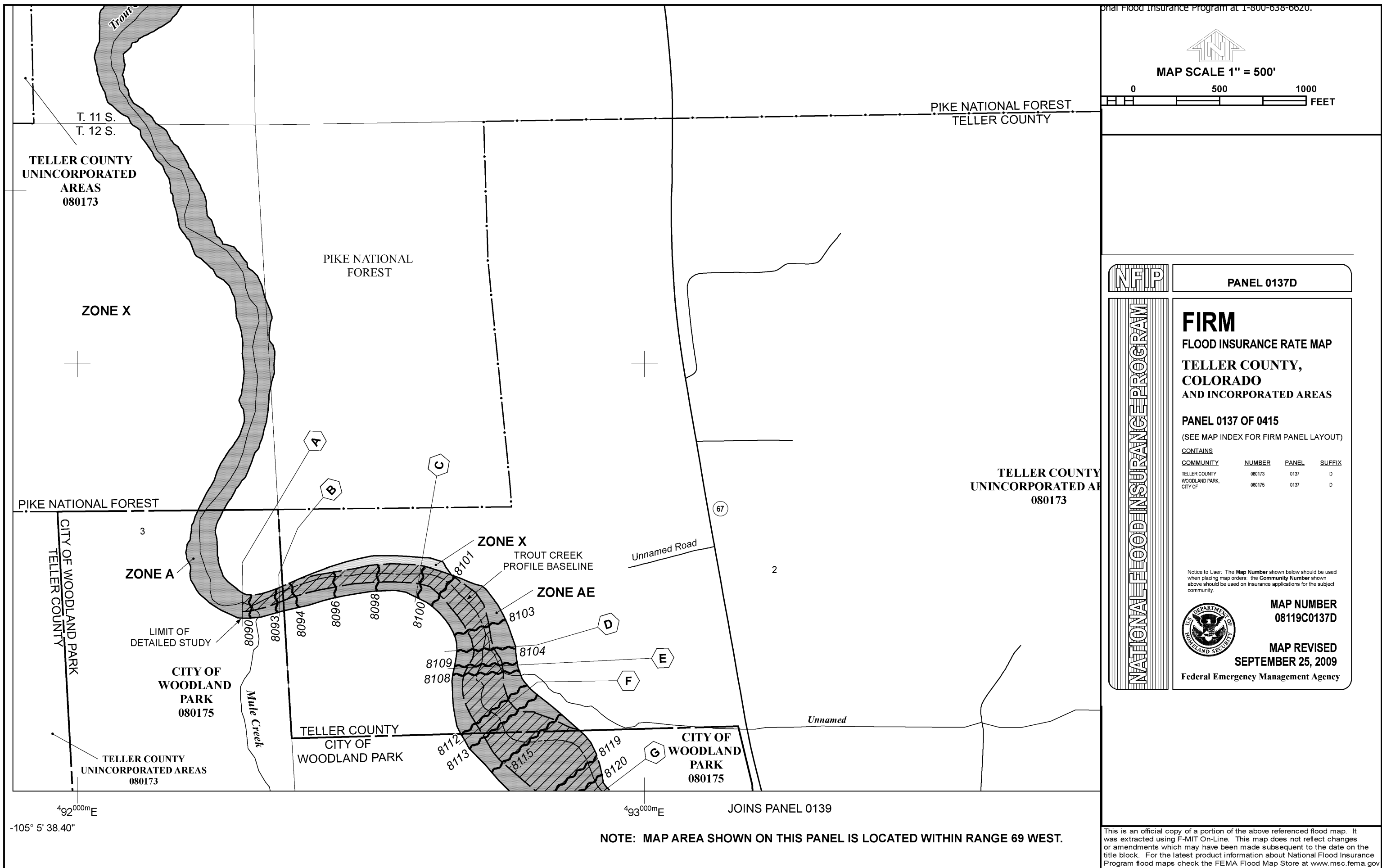


Figure 5.1 Trout Creek Floodplain Near Northern City Limits

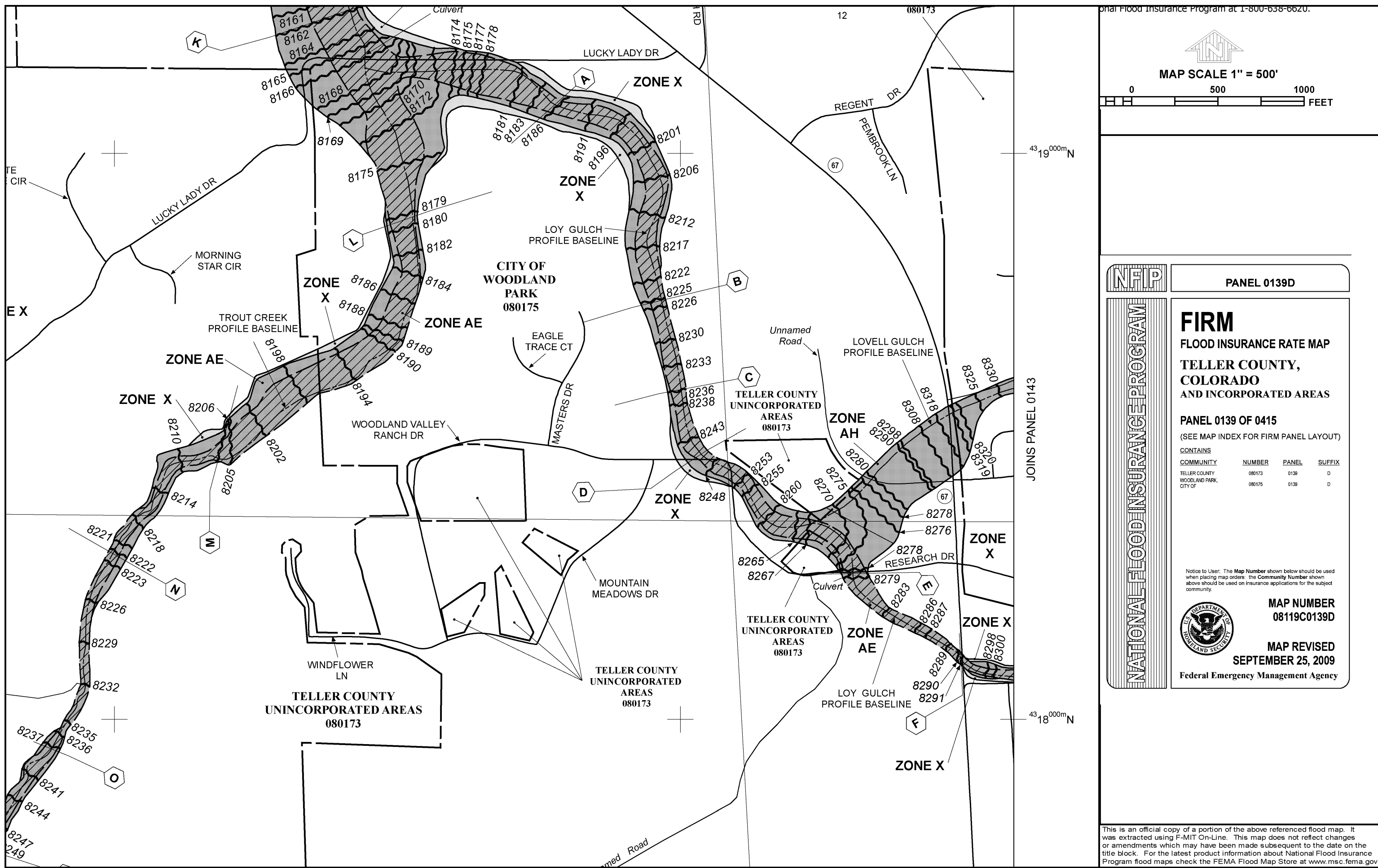
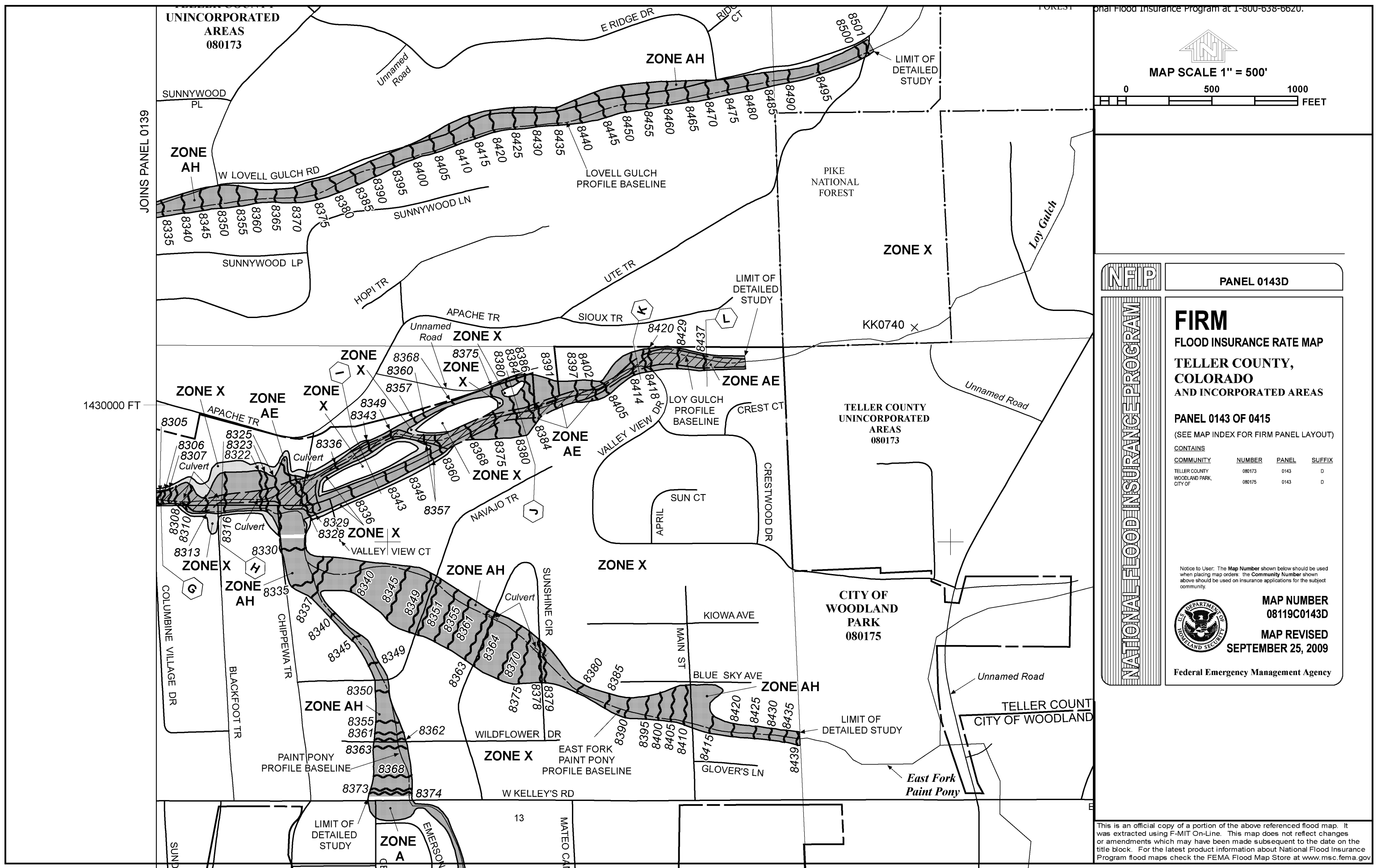


Figure 5.3 Loy Gulch Floodplain and Upper Trout Creek



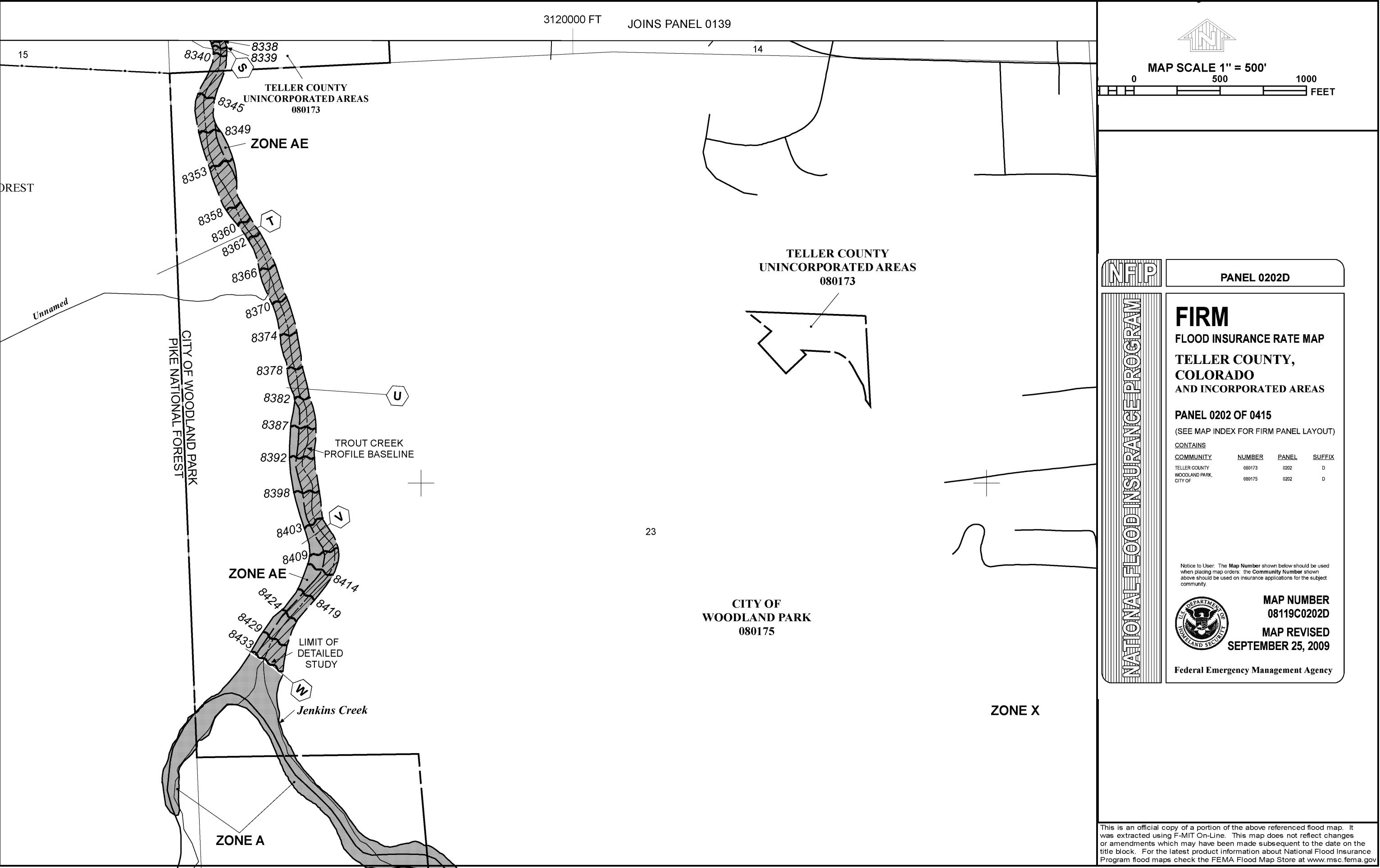


Figure 5.5 Upper Trout Creek, Including Detailed (Zone AE) Mapping

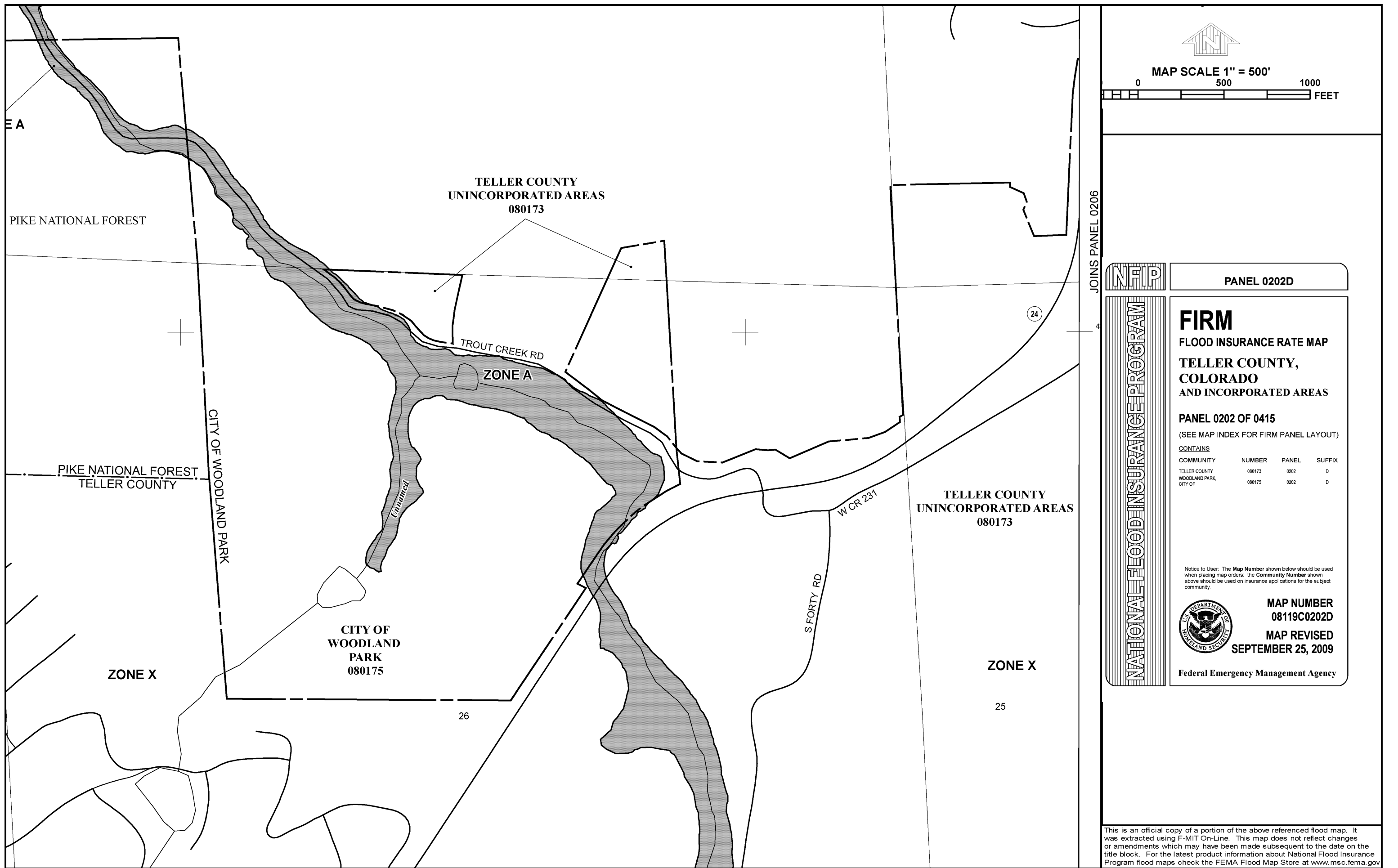


Figure 5.6 Upper Trout Creek Approximate (Zone A) Floodplain Mapping

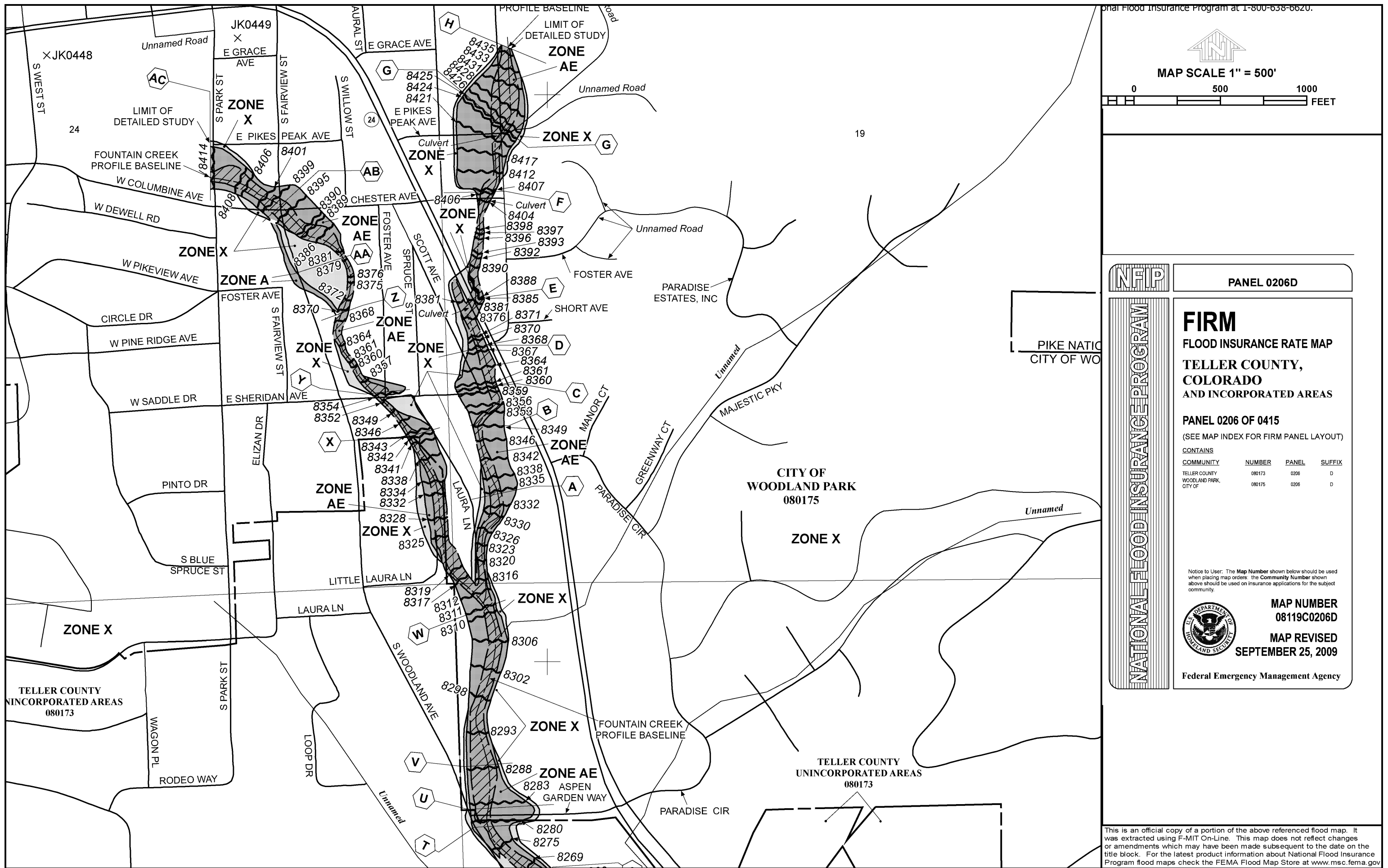


Figure 5.7 Upper Fountain Creek Floodplain Mapping

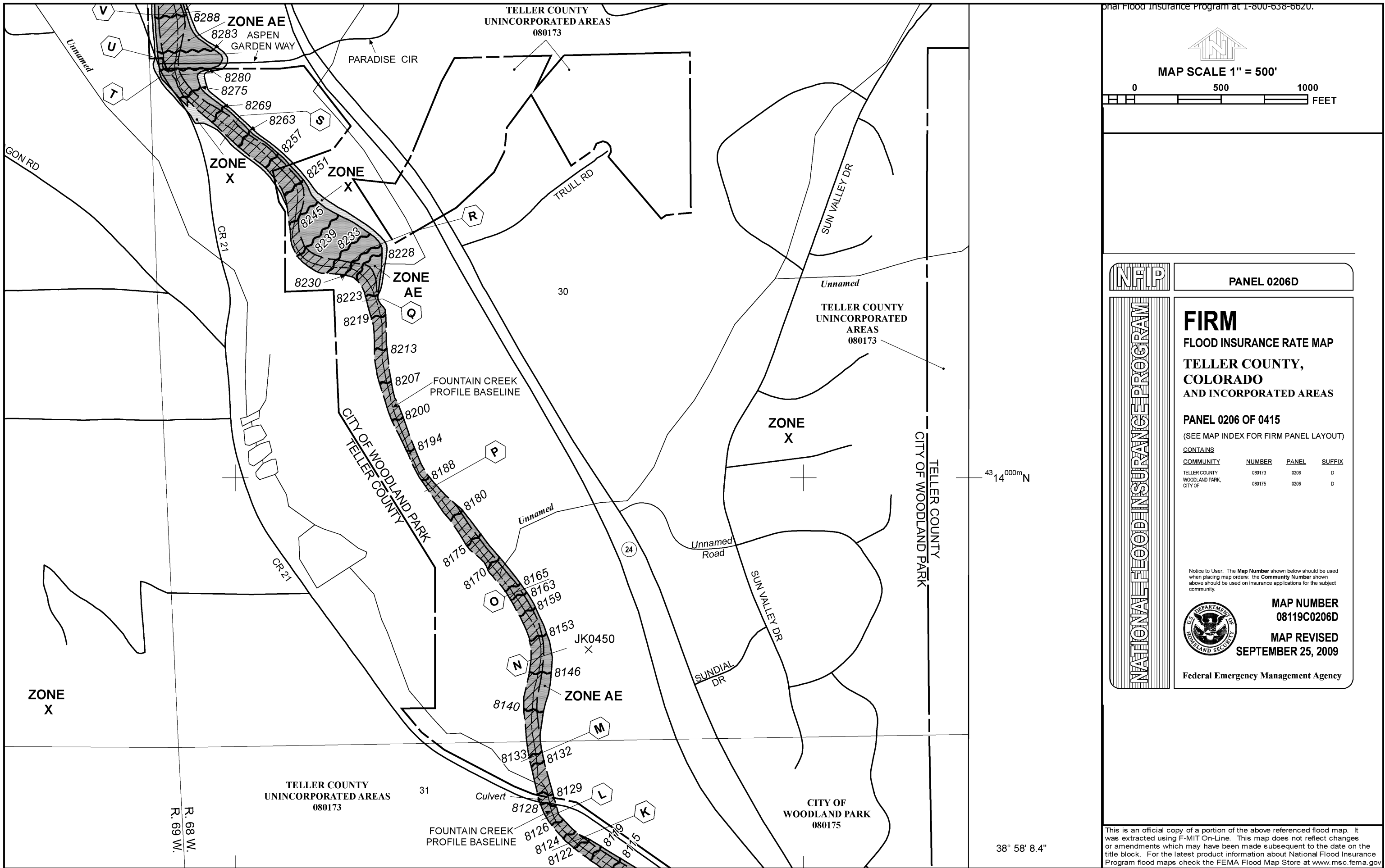


Figure 5.8 Upper Fountain Creek Floodplain Mapping (Continued)

Chapter 6

Hydrology

Contents

1.0	Introduction.....	1
1.1	Watersheds	2
1.2	Design Flows.....	2
1.3	Sources of Design Flows and Types of Hydrologic Analyses	4
1.3.1	Published Hydrologic Information	4
1.3.2	Statistical Methods.....	4
1.3.3	Rainfall/Runoff Methods	5
1.4	Data Requirements	5
1.5	Selecting Hydrologic Methods.....	5
2.0	Rainfall.....	6
2.1	Rainfall Depths and Intensities	6
2.2	Hydrologic Basis of Design for Water Quality—Water Quality Capture Volume (WQCV)	9
3.0	Snow	10
4.0	Rational Method.....	11
4.1	Rational Method Runoff Coefficient (C)	11
4.2	Time of Concentration	13
4.2.1	Overland (Initial) Flow Time.....	13
4.2.2	Travel Time	13
4.2.3	First Design Point Time of Concentration in Urban Catchments	15
4.2.4	Minimum Time of Concentration	15
4.2.5	Post-Development Time of Concentration	15
4.2.6	Common Error in Calculating Time of Concentration	15
4.3	Rainfall Intensity (I).....	16
4.4	Basin Area (A)	16
5.0	Runoff Reduction Methods	16
5.1	Four Step Process.....	16
5.2	Effective Imperviousness	17
6.0	Design Hydrology Based on Future Development Conditions.....	17
6.1	On-site Flow Analysis.....	17
6.2	Off-site Flow Analysis	17

Tables

Table 6-1. Depth-Duration-Frequency Relationships for Woodland Park, Colorado	7
Table 6-2. Intensity-Duration-Frequency Relationships for Woodland Park, Colorado.....	7
Table 6-3. Drain Time Coefficients for WQCV Calculations.....	9
Table 6-4. Cold Climate and Physiographic Design Challenges (adapted from Center for Watershed Protection 1997)	10
Table 6-5. Runoff Coefficients for Rational Method (UDFCD 2001)	12
Table 6-6. Conveyance Coefficient, C_v	14

Figures

Figure 6-1. Depth-Duration-Frequency Relationships for Woodland Park, Colorado (from NOAA Atlas 14)	8
Figure 6-2. Intensity-Duration-Frequency Relationships for Woodland Park, Colorado (from NOAA Atlas 14)	8
Figure 6-3. Estimate of Average Overland Flow Velocity for use with the Rational Formula.....	14
Figure 6-4. Standard Form SF-1, Time of Concentration	19
Figure 6-5. Standard Form SF-2, Rational Method Calculations.....	20

1.0 Introduction

This chapter describes hydrologic methods for determining design flows and volumes for the planning and design of stormwater management facilities in the City of Woodland Park. The development of appropriate hydrology for a project should be one of the first steps in the planning and design process. Accurately estimating design flows and volumes is critical to the proper functioning of facilities. Depending on the size of the drainage basin and the type of project, different hydrologic methods may be appropriate. In some cases, flow estimates may be available from previous studies, and these should be considered and evaluated, especially when new hydrologic analysis results in significant changes to previous estimates.

A general discussion of the overall process of developing plans and analyzing drainage systems can be found in the UDFCD Storm Drainage Criteria Manual (UDFCD Manual) Volume 1, Planning Chapter. The UDFCD Runoff Chapter and Volume 3 also provide valuable background on hydrologic methods for water quality and flood control that should be used when more complex analysis is required. The Colorado Springs Drainage Criteria Manual (Colorado Springs Manual) (2013) also provides useful information, and should be used for guidance when analyses using the Natural Resources Conservation Service (NRCS) Curve Number method are necessary.

Design flows for stormwater facilities are primarily based on rainfall events, and a range of possible storm events must be considered. In Woodland Park, snowmelt is a significant source of runoff and streamflow and must be accounted for in planning and design. Other sources of runoff such as nuisance flows can affect a project design and must also be identified. Anticipated changes to drainage area characteristics, especially due to development, must be fully considered for facilities to function as intended.

Average annual precipitation in Woodland Park is approximately 24 inches. The wettest months are March through August, with an average August precipitation depth of approximately 4.4 inches. The first frost typically occurs in September, and the last frost is typically in late May or early June. The City receives approximately 140 inches of snow in an average winter, and the ground remains frozen for extended periods. A summer monsoon often brings heavy rainfall in July and August, which typically are the two wettest months. Short-duration thunderstorms (cloud bursts) occur frequently during the monsoon and can produce intense rainfall/runoff and flash flooding. Rainstorms of greatest significance have historically occurred between the months of May and September.

Urbanization can have a significant impact on runoff by increasing peak flow rates, runoff volumes, and the frequency of runoff. This increase in runoff can lead to stream erosion, habitat degradation, and increased pollutant loading. However, with proper planning, increased runoff can be managed to create or supplement existing wetland areas or riparian habitats, which may provide significant benefits to the watershed. The increase in runoff from development is especially pronounced when drainage systems are designed to quickly and “efficiently” convey runoff from paved areas and roofs directly into inlets and storm sewers, discharging eventually into drainageways that are typically designed to convey flows at maximum acceptable velocities. Whether for one site or for a whole watershed, this increase in runoff and acceleration of flood peaks can be estimated by the hydrologic methods discussed herein.

Projects in the City of Woodland Park include both new development and redevelopment. Upcoming post-construction stormwater regulations from EPA that are currently in the rulemaking process are likely to include more stringent stormwater requirements for redevelopment and may include expansion of Municipal Separate Storm Sewer System (MS4) coverage to smaller communities such as Woodland Park. By implementing measures to shift hydrology back toward a more natural state, redevelopment

projects will help improve the drainageways in Woodland Park and downstream communities. Detention and water quality, in accordance with this Manual, are to be provided for all new development.

In addition to increased runoff, the reduction of available sediment due to urbanization has a destabilizing effect on downstream channels. When the natural sources of sediment are eliminated by paving, building structures or stabilized channels, runoff will tend to replace the natural sediment supply with new sources. Therefore, even an effective reduction in developed runoff to levels approximating historic rates will probably not eliminate the need for the stabilization of downstream systems.

In terms of stormwater quality management, hydrology is fundamental because increased flow rates and volumes of runoff, especially from frequently occurring storms, have the potential to affect receiving waters and aquatic resources. Effective stormwater management seeks to disconnect impervious surfaces, decrease flow velocities, and convey runoff over vegetated ground surfaces, leading to filtering, infiltration, and attenuation of flows. These principles can also be reflected in the hydrologic variables discussed in this chapter, yielding longer times of concentration and reduced runoff peaks and volumes.

1.1 Watersheds

The dividing line between the Fountain Creek Watershed and the Upper South Platte Watershed runs right through the center of Woodland Park. Fountain Creek, with its headwaters beginning in Woodland Park, drains south into the Arkansas River at Pueblo, Colorado. The Fountain Creek Watershed is approximately 927 square miles and is characterized by “extremes in temperature and precipitation, large elevation changes, steep gradients, diverse ecosystems, and a multitude of water uses” (Fountain Creek Watershed Flood Control and Greenway District). The Upper South Platte Watershed is expansive, covering roughly 2,600 square miles from the Continental Divide to Strontia Springs Reservoir. The Upper South Platte Watershed also varies greatly in elevation and gradient and encompasses five major municipal reservoirs as well as several smaller reservoirs. Streams within the Upper South Platte Watershed that traverse parts of the City of Woodland Park include Trout Creek and Loy Gulch.

1.2 Design Flows

A broad range of storm events pass through stormwater facilities and natural drainageways. These range from those producing little or no runoff prior to development to extensive and extreme storm events that produce life threatening and destructive floods. To effectively and efficiently analyze even a small percentage of all possible events is time and cost prohibitive. Therefore, to efficiently plan and design stormwater facilities, “design flows” have been established to represent events that are typical or representative of the range of runoff events that can occur. In most cases, projects can be adequately designed using estimates of these representative flows. Depending on the type of project, design flows may include “baseflows,” “low flows,” “minor flows,” “major flows” and “flood flows.” For site design, minor (5-year) and major (100-year) flows are of greatest interest and typically will be calculated using the Rational Method as described in this chapter. Baseflows, low flows and flood flows must also be considered for projects involving channel design. A description of each of these types of flows is provided below and methods for estimating these design flows are described later in this chapter.

1. **Baseflows.** Baseflow estimates (sometimes referred to as “trickle flows”) are used to account for flows that may not be directly related to storm events but may be created by groundwater recharge of streams, wastewater return flows, excess irrigation, water system losses, and other urban water uses. Baseflows are the flows that can be observed in streams and engineered drainageways during dry weather. Channel improvements must account for these flows to address erosion potential in the lower portion of channel sections. The presence of these flows in historically dry basins can also interfere with the growth of certain types of vegetation.

However, these same flows can provide water to sustain vegetation along low-flow channel banks or in channels with wetland bottoms where vegetation was not previously supported.

2. Low Flows. Low flows are used primarily for open channel design and are defined as those flows resulting from relatively frequent storm events that are contained within a well-defined or main channel portion of the floodplain (sometimes these are referred to as “bankfull flows” or “channel forming flows” for natural streams). Flows greater than the low-flow event begin to flow beyond the main channel into the overbank or floodplain portion of natural channels. It is generally accepted that the bankfull discharge has a return period that is in the 1-year to 2-year range, but this value can change significantly, especially when there is urbanization in a basin. “Low flows” should not be confused with “minor flows” which are associated with a specific recurrence interval, as described below, and are generally greater than “low flows” for natural channels.
3. Minor Flow. Minor flows are defined as those flows resulting from relatively frequent storm events that are contained within a portion of the conveyance system such as gutters and storm sewers and are typically defined by a specific return period. Flows greater than the minor flow event typically exceed storm drain capacity and begin to interfere with human activity, such as traffic and pedestrian access. For the purposes of this Manual, the minor flow is defined by the 5-year storm runoff event.
4. Major Flow. Major flows must be conveyed to avoid safety hazards, undue interference with human activity, damage to adjacent structures and damage to conveyance systems. The 100-year runoff event has been identified as the major flow that must be safely conveyed according to this Manual. This design flow is typically used to determine maximum street capacities and to size certain facilities such as culverts. While the 100-year flood is the basis for floodplain regulation for most areas in Woodland Park, larger flood events can and will occur.
5. Flood Flows. In this Manual the term “flood flows” is used to refer to any flows that exceed the low-flow channel, whether natural or engineered. Flood flows must be conveyed to avoid safety hazards, damage to adjacent structures and damage to conveyance systems. Flood flows are typically used to design open channels, size detention ponds and to delineate floodplains. Flooding is often associated with rather extreme events, but is actually defined by any event that causes flows to spill from the low-flow channel onto the overbank or floodplain area of a channel. The 100-year runoff event has been identified as the major flood event that defines the regulatory floodplain according to this Manual. However, flood studies typically include evaluation of other events such as the 10-, 25-, 50- and 500-year events. In some cases, it may be necessary to evaluate lesser flows, such as the 2-year or 5-year flow, to consider critical hydraulic conditions. In some situations, it may be appropriate to address more severe flows, such as the 500-year flow. For instance, drop structures may be largely submerged during the 100-year event, with critical hydraulic conditions occurring during lesser floods. Also, where critical infrastructure, including hospitals, emergency response facilities, etc. may be at risk, State and local floodplain regulations may require evaluation of less frequent (more extreme) events such as the 500-year flood.

Prudent management of upstream land uses and the implementation of runoff reducing practices such as Low Impact Development (LID) and/or Full-Spectrum Detention (FSD), described in detail in the UDFCD Manual, have the potential to reduce the volume and rate of runoff for design flows received by downstream systems. These effects are generally most significant for frequently occurring events. How design flows are affected by upstream basin conditions (under future “build out” conditions) must be fully considered.

1.3 Sources of Design Flows and Types of Hydrologic Analyses

Estimates of runoff are required for a variety of purposes in stormwater management analyses. In some cases, previously completed analyses may be available for the project area. When gauge data are available over an extended period of record, they typically are the most reliable source of flow estimates. However, in headwaters areas, stream gauges with extended periods of record are limited, and calculations are commonly used to define hydrology (with field checking for reasonableness based on observed events). Designers should consult with the City to determine applicability of master plans in the area. However, it is often necessary to complete new analyses that more accurately represent project conditions and provide estimates where they are needed to complete the project. Whenever new analyses are needed, they shall be completed based on the methodologies described in this Manual.

To provide plans and designs that are appropriate for current and future conditions, hydrologic analyses must include various scenarios. Scenarios will typically include multiple runoff events, changes in land uses and alternative system plans such as for transportation. Each scenario must be identified and properly described so that the drainage system plan and possible alternatives can be adequately evaluated.

1.3.1 Published Hydrologic Information

The 1996 *Woodland Park Stormwater Management Plan* was prepared for many of the Woodland Park drainage basins. This plan contains information regarding hydrology for a range of storm events at numerous design points within the study watersheds. This study contains information about watershed and sub-watershed boundaries, soil types, percent imperviousness, and rainfall. When published flow rates are available, these values shall be used for design unless they are considered to be inaccurate or unreliable due to physical changes in the drainage basin or in criteria. The need for additional evaluation and the use of other values shall be approved in writing in advance of any related planning or design work. Note: The City of Woodland Park is currently in the process of creating a city-wide drainage master plan that will supersede the 1996, so applicants are advised to consult with the City to be sure that hydrology is consistent with ongoing planning efforts.

Published hydrologic information for major drainageways can also be found in Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS). For all FEMA-related projects, the FEMA hydrologic data shall be consulted. Flow rates published in FEMA FIS studies typically represent existing conditions at the time the study was completed and generally do not incorporate any future development.

1.3.2 Statistical Methods

In some situations, statistical analysis of measured stream flow data provides an acceptable means of determining design flows. Statistical analyses for larger, less-frequent storm events are to be limited to drainageways with a long period of reliable flow data that had no significant changes occur in land uses within the tributary watershed during the flow record. A minimum period of record of 30 years is recommended for statistical analysis of events up to and including the 100-year event; however, when performing statistical analysis for frequently occurring events, such as a 2- or 5-year event, a shorter period of record may be acceptable.

Statistical analyses of gage data should be completed using the Log-Pearson Type III analysis as performed by programs such as the U.S. Geological Survey (USGS) PeakFQ analysis tool. The gage identification and location should be indicated on all calculation sheets and model output.

1.3.3 Rainfall/Runoff Methods

It is typically necessary to estimate runoff for a project when no previous estimates have been provided, especially for lot or multi-lot redevelopment projects and new development projects. The most common method for making these estimates is by converting rainfall (using intensity, depth and temporal and spatial characteristics) to runoff by representing basin characteristics that affect the volume and rate of runoff expected. There are numerous methods that can be applied; however, in most cases in Woodland Park, the Rational Method will prove sufficient for small to medium sized development and redevelopment projects. Generally, best results will be obtained using smaller catchment sizes in the Rational Method, and in no case should the Rational Method be applied for drainage areas larger than 130 acres or when routing is required.

For larger projects and projects involving major drainageways, more complex methods involving models to generate hydrographs are appropriate. These methods are documented in detail in the UDFCD and Colorado Springs Manuals. The method selected will depend on the purpose of the analysis and the scale of the project, but for most projects in Woodland Park, the Rational Method is appropriate. This manual intentionally provides flexibility for the engineer to choose the rainfall-runoff modeling method that is most appropriate for the goal of the project. The modeling upon which the FIS is based was conducted using the NRCS curve number method, with 24-hour SCS rainfall distributions for model input (SCS Type II for Trout Creek and SCS Type IIA for Fountain Creek). When the NRCS method is used for rainfall and runoff modeling, these same distributions are recommended for application for consistency with the FIS. In some cases, however, other models may be more suitable than an NRCS curve number-based model for evaluating hydrology. For example, in areas with significant storm sewer networks, where pressurized flow occurs in the major event, a model such as the EPA Stormwater Management Model (SWMM) may have better capabilities to analyze the system. While many of the hydrologic calculations in the City can be accomplished using the Rational Method, when hydrograph-based modeling is necessary, the applicant should consult with the City to determine the most applicable loss method and routing model to use for the situation being analyzed. The Colorado Springs Manual provides guidance on the NRCS method, and the UDFCD Manual provides guidance on EPA SWMM.

1.4 Data Requirements

Prior to commencing a hydrologic analysis the designer must research and collect the necessary data to provide inputs for the hydrologic method to be used. These data may be available from existing sources or may need to be created for the project at hand. These data will typically include: topographic mapping, existing and future land use conditions for each scenario to be evaluated, an inventory of existing and proposed structures (in waterways and other structures associated with development) within the study area, soil types, ground cover types, groundwater conditions, site location information (horizontally and vertically), previous studies, and any other documents that can provide needed background information. It is the responsibility of the designer to identify and collect the most appropriate and accurate data available to complete the analysis. Some useful sources of information include previous major drainage planning studies, NRCS Soil Surveys, USGS mapping (detailed survey data are needed for design), the USGS StreamStats program, nearby rain gages and stream gages, storm sewer mapping, historic and current aerial photography, and other sources.

1.5 Selecting Hydrologic Methods

The Rational Method shall be the default hydrologic method for drainage analysis for development and redevelopment projects in the City. It is most applicable to development and redevelopment projects in Woodland Park given the fact that the City is largely developed and sits at the headwaters of two major

watersheds. The Rational Method is a relatively simple approach where only peak flows are required and a hydrograph is not required also making it well suited for use in Woodland Park. The 1996 *Woodland Park Stormwater Management Plan* included watershed and sub-watershed level hydrology and routing and established reliable hydrology for major drainageways in Woodland Park. The plan should be consulted for work in drainageways as well as analysis of drainage areas and runoff characteristics for off site analysis. While this chapter provides guidance on the Rational Method, for larger development projects and projects involving work on major drainage ways, more complex modeling methods may be required, including the NRCS Curve Number Loss Method and unit hydrograph as implemented in USACE HEC-HMS model or the U.S. Environmental Protection Agency Stormwater Management Model (EPA SWMM) as conditions warrant. For documentation and guidance on application of these methods, consult with the Colorado Springs Manual for the NRCS Curve Number method and the UDFCD Manual for EPA SWMM.

For runoff volume estimates, the Water Quality Capture Volume (WQCV) is calculated using an empirical equation provided in this chapter. For detention sizing, the Rational Formula-Based Modified Federal Aviation Administration (FAA) Method (FAA 1966, sometimes referred to as the “FAA Procedure”), as modified by Guo (1999a), provides a reasonable estimate of storage volume requirements. This method, provided in the Storage Chapter, and/or empirical equations are appropriate for detention sizing for most applications in Woodland Park. For larger facilities, hydrograph-based design may be required using procedures from the UDFCD and/or Colorado Springs Manual, depending on the hydrologic method used.

2.0 Rainfall

This section describes rainfall characteristics for use with the above mentioned hydrologic methods in determining design flows and volumes. Rainfall data to be used are based on National Oceanic and Atmospheric Administration, *Precipitation-Frequency Atlas of the United States, Midwestern States, Volume 8, Version 2.0* (NOAA Atlas 14), updated in 2013. Precipitation depth maps in the NOAA Atlas can be used to determine 6-hour and 24-hour point rainfall values and to determine rainfall depths and intensities for other durations. NOAA Atlas 14 data are also available online. The online version of the data allows for determination of precipitation statistics at a specific point location, accounting for some spatial variability of rainfall. Applicants can use the tables and figures included in this manual, which represent typical conditions throughout the City, or they may use the online tool based on the specific project location. Any major differences between depths and intensities found online versus those provided in this manual should be carefully evaluated in conjunction with the City Engineer.

For modeling of large watersheds (generally greater than 10 square miles), depth area reduction factors (DARFs) are typically applied to account for an aerial reduction of point precipitation estimates. Since much of the hydrologic analysis in Woodland Park can be accomplished using the Rational Method and because there are few subwatersheds that begin to reach the size where a DARF would be applied, DARFs are not included in this manual. If an applicant is modeling a watershed with an area greater than 10 square miles and wishes to apply a DARF, the applicant shall consult with the City Engineer to determine the appropriate adjustment factor based on the DARF recommendations in the Colorado Springs Manual.

2.1 Rainfall Depths and Intensities

Rainfall depths must be determined based on the duration and return period of the design storm. Depths can be derived by the methods described in the NOAA Atlas. The depths reported in the NOAA Atlas represent probable total depths for each duration and return period at a point on the ground. The NOAA

Atlas has recently been updated and new rainfall mapping has been published. This chapter is based on the updated NOAA mapping, and the updated NOAA mapping shall be used as the basis for hydrologic design in Woodland Park. As discussed above, the primary hydrologic method that will apply to most development and redevelopment projects in Woodland Park is the Rational Method. Therefore this section presents depth-duration-frequency and intensity-duration-frequency tables and figures (Tables 6-1 and 6-2 and Figures 6-1 and 6-2). In cases where hydrograph analysis is needed, the reader should refer to the storm depths in Table 6-1 and Figure 6-1, along with the NOAA Atlas, to determine appropriate point precipitation depths that can be applied to the design storm distribution methods in the UDFCD (Colorado Urban Hydrograph Procedure) and Colorado Springs Manuals (SCS). The most up-to-date mapping from NOAA (NOAA Atlas 14) is available online (http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=co).

Table 6-1. Depth-Duration-Frequency Relationships for Woodland Park, Colorado

Duration (minutes)	Precipitation Depth in Inches for Range of Recurrence Intervals							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5	0.23	0.28	0.36	0.43	0.55	0.64	0.74	1.01
10	0.34	0.41	0.53	0.64	0.80	0.94	1.09	1.48
15	0.41	0.50	0.64	0.78	0.98	1.15	1.33	1.81
30	0.52	0.63	0.81	0.98	1.24	1.45	1.68	2.28
60	0.64	0.76	0.97	1.17	1.48	1.75	2.03	2.80

Table 6-2. Intensity-Duration-Frequency Relationships for Woodland Park, Colorado

Duration (minutes)	Precipitation Intensity in Inches Per Hour for Range of Recurrence Intervals							
	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5	2.77	3.32	4.31	5.21	6.56	7.70	8.93	12.10
10	2.03	2.44	3.16	3.82	4.81	5.64	6.54	8.89
15	1.65	1.98	2.57	3.10	3.91	4.59	5.32	7.22
30	1.05	1.25	1.63	1.96	2.47	2.90	3.36	4.57
60	0.64	0.76	0.97	1.17	1.48	1.75	2.03	2.80

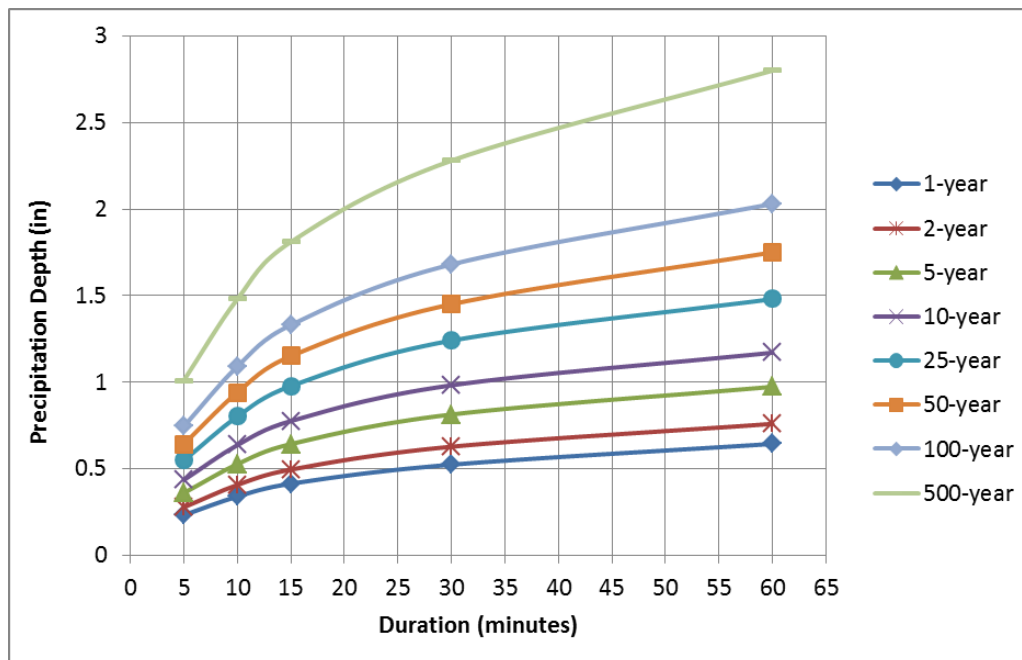


Figure 6-1. Depth-Duration-Frequency Relationships for Woodland Park, Colorado (from NOAA Atlas 14)

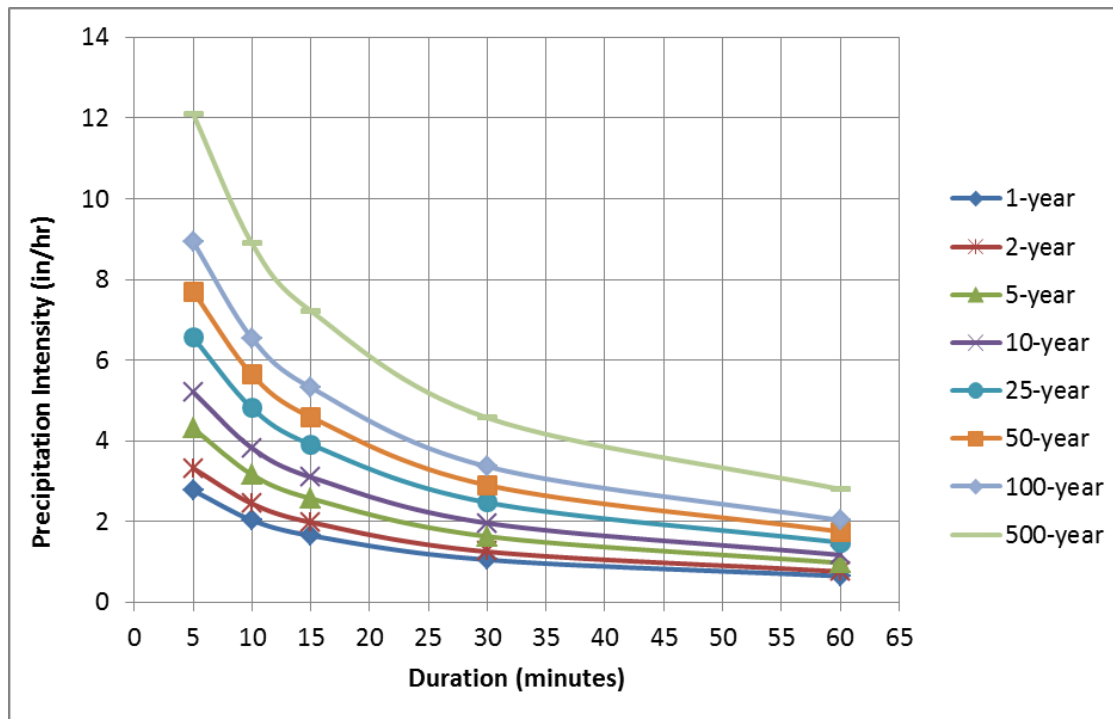


Figure 6-2. Intensity-Duration-Frequency Relationships for Woodland Park, Colorado (from NOAA Atlas 14)

2.2 Hydrologic Basis of Design for Water Quality—Water Quality Capture Volume (WQCV)

The hydrologic basis of design for water quality in Woodland Park is retention of 75% of the 2-year runoff volume, which is roughly equivalent to the WQCV defined by UDFCD. The primary difference between the Woodland Park criterion for 75% of the 2-year runoff volume and the WQCV used by UDFCD is that the Woodland Park criterion requires retention of the capture volume, while the UDFCD criterion allows for slow release. Retention of 75% of the 2-year runoff volume is the standard for the City of Woodland Park. In areas where soils are not suitable for infiltration or where infiltration of the retention volume could cause problems for adjacent structures, the WQCV, with a slow release in accordance with the UDFCD Manual may be used in place of the 75% of the 2-year runoff volume criterion. Applicants wishing to use the WQCV with slow release criterion as a substitute for the retention criterion should consult with the City Engineer to explain why retention/infiltration is infeasible for a given project site.

While guidance in the preceding sections focuses on the hydrologic events related to flood control and conveyance facilities, small frequently occurring events form the basis of design for water quality facilities. The WQCV, corresponding to roughly an 85th percentile event, defines storage volume requirements for stormwater best management practices (BMPs) and is roughly equivalent to 75% of the 2-year runoff volume. The basis for establishing the 85th percentile event and guidance for implementing water quality facilities is described in Volume 3 of the UDFCD Manual. Because of a limited period of record for hourly precipitation data suitable for analysis to determine the WQCV specific to Woodland Park, the WQCV procedure from the UDFCD Manual shall be used to determine the WQCV in Woodland Park, with an adjustment to account for orographic effects. The following equation shall be applied:

$$\text{WQCV} = 1.15 \cdot a \cdot (0.9 \cdot I^3 - 1.19 \cdot I^2 + 0.78 \cdot I) \quad \text{Equation 6-1}$$

Where:

WQCV = Water Quality Capture Volume (watershed inches)

a = Coefficient corresponding to WQCV drain time (Table 6-3)

I = Imperviousness (must be expressed as a decimal [%/100] and not a percent).

Table 6-3. Drain Time Coefficients for WQCV Calculations

Drain Time (hrs)	Coefficient, a
12 hours (sand filters, bioretention, retention ponds)	0.8
24 hours (constructed wetland basins)	0.9
40 hours (Extended dry detention)	1.0

3.0 Snow

Snow is significant in Woodland Park, with approximately 140 inches falling in a typical winter. However, due to the timing of intense rainfall later in the summer (typically during the monsoon in July and August) peak flow rates for stormwater design are typically the result of rainfall events rather than snowmelt or rain on snow events.

Although snowmelt may not drive the sizing for drainage and water quality infrastructure, snowmelt and freezing conditions must be factored into design to account for:

- Baseflows from melting in the spring;
- Frozen ground through most of the winter that limits infiltration potential;
- Snow storage areas near detention facilities;
- Water quality practices and other drainage infrastructure;
- Maintenance requirements due to sanding
- Other factors.

Table 6.4 identifies a number of challenges associated with Woodland Park's cold climate and setting.

**Table 6-4. Cold Climate and Physiographic Design Challenges
(adapted from Center for Watershed Protection 1997)**

Condition	Design Challenge
Cold Temperatures	• Pipe freezing, in some cases even at locations where there is flowing water that is slowed by a transition such as a bend • Ice-cover on permanent water surfaces • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities • Diurnal cycle of melting and freezing in winter and spring • Mid-winter warm ups and runoff
Deep Frost Line	• Frost heaving • Reduced soil infiltration
Short Growing Season	• Short time period to establish vegetation • Different plant species appropriate to cold climates than to moderate climates
Significant Snowfall	• High runoff volumes during snowmelt and rain-on-snow • High pollutant loads during spring melt • Sand applied to some roads and walks for improved traction • Snow management may affect BMP storage
Sanding Practices	• Heavy sediment load
Steep Slopes	• Rapid runoff • Potentially high "background" levels of erosion • Potential for mudflows and debris flows

4.0 Rational Method

The Rational Method is used to determine runoff peak discharges for drainage basins up to and including 130 acres in size and when hydrologic routing is relatively simple. However, the drainage area should be divided into sub-basins that represent homogeneous land uses, soil types or land cover. The Rational Method is most typically applied for site-level development projects and sizing of inlets and storm drains. The Rational Method is based on the relationship between rainfall intensity and runoff, and is expressed by the following equation:

$$Q = C \cdot I \cdot A \quad (\text{Eq. 6-2})$$

In which:

Q = the maximum rate of runoff (cubic feet per second [cfs])

C = the runoff coefficient that is the ratio between the runoff volume from an area and the average rainfall depth over a given duration for that area

I = the average intensity of rainfall for a duration equal to the time of concentration (in/hr)

A = basin area (acres).

The assumptions and limitations of the Rational Method are described in the UDFCD Manual, Volume 1, Runoff Chapter. Standard Form 1 (SF-1) and Standard Form 2 (SF-2) are provided at the end of this chapter as Figure 6-4 and Figure 6-5, respectively, to provide a standard format for Rational Method calculations. The SF-1 Form is used for calculating the time of concentration, and the SF-2 form is used to estimate accumulated peak discharges from multiple basins as storm runoff flows downstream in a channel or pipe. Results from the Rational Method calculations shall be included with the drainage report submittal. As an alternative to SF-1 and SF-2, the UD-Rational spreadsheet can be used to document basin parameters and calculations or other spreadsheets or programs can be used as long as the information and format is the similar to that shown in these standard forms.

4.1 Rational Method Runoff Coefficient (C)

The runoff coefficient represents the integrated effects of infiltration, detention storage, evaporation, retention, flow routing, and interception, all of which affect the time distribution and peak rate of runoff. Runoff coefficients are based on the imperviousness of a particular land use and the hydrologic soil type of the area and are to be selected in accordance with Table 6-5.

The procedure for determining the runoff coefficient includes these steps:

1. Categorize the site area into one or more similar land uses and drainage areas, each with a representative imperviousness.
2. Based on the dominant hydrologic soil type in the area, use Table 6-5 to estimate the runoff coefficient for the particular land use category for the design storms of interest.
3. Calculate an area-weighted average runoff coefficient for the site based on the runoff coefficients from individual land use areas of the site.

When analyzing an area for design purposes, urbanization of the full watershed, including both on-site and off-site areas, shall be assumed.

Gravel parking areas, storage areas, and access drives shall be analyzed based on an imperviousness of 80%. This is due to the potential for gravel areas being paved over time by property owners and the resulting adverse impacts on the stormwater management facilities and adjacent properties.

There are some circumstances where the selection of impervious percentage values may require additional investigation due to unique land characteristics (e.g., recent burn areas). When these circumstances arise, it is the designer's responsibility to verify that the correct land use assumptions are made.

When multiple sub-basins are delineated, a composite C value can be calculated:

$$C_c = (C_1A_1 + C_2A_2 + C_3A_3 + \dots C_iA_i) / A_t \quad (\text{Eq. 6-3})$$

Where:

C_c = composite runoff coefficient for total area

C_i = runoff coefficient for subarea corresponding to surface type or land use

A_i = area of surface type corresponding to C_i (units must be the same as those used for total area)

A_t = total area of all subareas for which composite runoff coefficient applies

i = number of surface types in the drainage area.

Table 6-5. Runoff Coefficients for Rational Method (UDFCD 2001)

Land Use or Surface Characteristics	Percent Impervious	Runoff Coefficients											
		2-year		5-year		10-year		25-year		50-year		100-year	
		HSG A&B	HSG C&D	HSG A&B	HSG C&D	HSG A&B	HSG C&D	HSG A&B	HSG C&D	HSG A&B	HSG C&D	HSG A&B	HSG C&D
Business													
Commercial Areas	95	0.79	0.80	0.81	0.82	0.83	0.84	0.85	0.87	0.87	0.88	0.88	0.89
Neighborhood Areas	70	0.45	0.49	0.49	0.53	0.53	0.57	0.58	0.62	0.60	0.65	0.62	0.68
Residential													
1/8 Acre or less	65	0.41	0.45	0.45	0.49	0.49	0.54	0.54	0.59	0.57	0.62	0.59	0.65
1/4 Acre	40	0.23	0.28	0.30	0.35	0.36	0.42	0.42	0.50	0.46	0.54	0.50	0.58
1/3 Acre	30	0.18	0.22	0.25	0.30	0.32	0.38	0.39	0.47	0.43	0.52	0.47	0.57
1/2 Acre	25	0.15	0.20	0.22	0.28	0.30	0.36	0.37	0.46	0.41	0.51	0.46	0.56
1 Acre	20	0.12	0.17	0.20	0.26	0.27	0.34	0.35	0.44	0.40	0.50	0.44	0.55
Industrial													
Light Areas	80	0.57	0.60	0.59	0.63	0.63	0.66	0.66	0.70	0.68	0.72	0.70	0.74
Heavy Areas	90	0.71	0.73	0.73	0.75	0.75	0.77	0.78	0.80	0.80	0.82	0.81	0.83
Parks and Cemeteries													
Parks and Cemeteries	7	0.05	0.09	0.12	0.19	0.20	0.29	0.30	0.40	0.34	0.46	0.39	0.52
Playgrounds	13	0.07	0.13	0.16	0.23	0.24	0.31	0.32	0.42	0.37	0.48	0.41	0.54
Railroad Yard Areas	40	0.23	0.28	0.30	0.35	0.36	0.42	0.42	0.50	0.46	0.54	0.50	0.58
Undeveloped Areas													
Historic Flow Analysis-- Greenbelts, Agriculture	2	0.03	0.05	0.09	0.16	0.17	0.26	0.26	0.38	0.31	0.45	0.36	0.51
Pasture/Meadow	0	0.02	0.04	0.08	0.15	0.15	0.25	0.25	0.37	0.30	0.44	0.35	0.50
Forest	0	0.02	0.04	0.08	0.15	0.15	0.25	0.25	0.37	0.30	0.44	0.35	0.50
Exposed Rock	100	0.89	0.89	0.90	0.90	0.92	0.92	0.94	0.94	0.95	0.95	0.96	0.96
Offsite Flow Analysis (when landuse is undefined)	45	0.26	0.31	0.32	0.37	0.38	0.44	0.44	0.51	0.48	0.55	0.51	0.59
Streets													
Paved	100	0.89	0.89	0.90	0.90	0.92	0.92	0.94	0.94	0.95	0.95	0.96	0.96
Gravel	80	0.57	0.60	0.59	0.63	0.63	0.66	0.66	0.70	0.68	0.72	0.70	0.74
Drive and Walks													
Drive and Walks	100	0.89	0.89	0.90	0.90	0.92	0.92	0.94	0.94	0.95	0.95	0.96	0.96
Roofs	90	0.71	0.73	0.73	0.75	0.75	0.77	0.78	0.80	0.80	0.82	0.81	0.83
Lawns	0	0.02	0.04	0.08	0.15	0.15	0.25	0.25	0.37	0.30	0.44	0.35	0.50

4.2 Time of Concentration

One of the basic assumptions underlying the Rational Method is that runoff is a function of the average rainfall rate during the time required for water to flow from the hydraulically most remote part of the drainage area under consideration to the design point. However, in practice, the time of concentration can be an empirical value that results in reasonable and acceptable peak flow calculations.

For urban areas, the time of concentration (t_c) consists of an initial time or overland flow time (t_i) plus the travel time (t_t) in the storm sewer, paved gutter, roadside drainage ditch, or drainage channel. For non-urban areas, the time of concentration consists of an overland flow time (t_i) plus the time of travel in a concentrated form, such as a swale or drainageway. The travel portion (t_t) of the time of concentration can be estimated from the hydraulic properties of the storm sewer, gutter, swale, ditch, or drainageway. Initial 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. The time of concentration is represented by Equation 6-4 for both urban and non-urban areas.

$$t_c = t_i + t_t \quad (\text{Eq. 6-4})$$

Where:

t_c = time of concentration (min)

t_i = overland (initial) flow time (min)

t_t = travel time in the ditch, channel, gutter, storm sewer, etc. (min).

4.2.1 Overland (Initial) Flow Time

The overland flow time, t_i , may be calculated using Equation 6-5.

$$t_i = \frac{0.395(1.1 - C_5)\sqrt{L}}{S^{0.33}} \quad (\text{Eq. 6-5})$$

Where:

t_i = overland (initial) flow time (min)

C_5 = runoff coefficient for 5-year frequency (see Table 6-4)

L = length of overland flow (300 ft maximum for non-urban land uses, 100 ft maximum for urban land uses)

S = average basin slope (ft/ft).

Note that in some urban watersheds, the overland flow time may be very small because flows quickly concentrate and channelize.

4.2.2 Travel Time

For catchments with overland and channelized flow, the time of concentration needs to be considered in combination with the travel time, t_t , which is calculated using the hydraulic properties of the swale, ditch, or channel. For preliminary work, the overland travel time, t_t , can be estimated with the help of Figure 6-3 or Equation 6-6 (Guo 1999).

$$V = C_v S_w^{0.5} \quad (\text{Eq. 6-6})$$

Where:

V = velocity (ft/s)

C_v = conveyance coefficient (from Table 6-6)

S_w = watercourse slope (ft/ft).

Table 6-6. Conveyance Coefficient, C_v

Type of Land Surface	C_v
Heavy meadow	2.5
Tillage/field	5
Riprap (not buried)*	6.5
Short pasture and lawns	7
Nearly bare ground	10
Grassed waterway	15
Paved areas and shallow paved swales	20

*For buried riprap, select C_v value based on type of vegetative cover.

The travel time is calculated by dividing the flow distance (in feet) by the velocity calculated using Equation 6-6 and converting units to minutes.

The time of concentration (t_c) is then the sum of the overland flow time (t_i) and the travel time (t_t) per Equation 6-4.

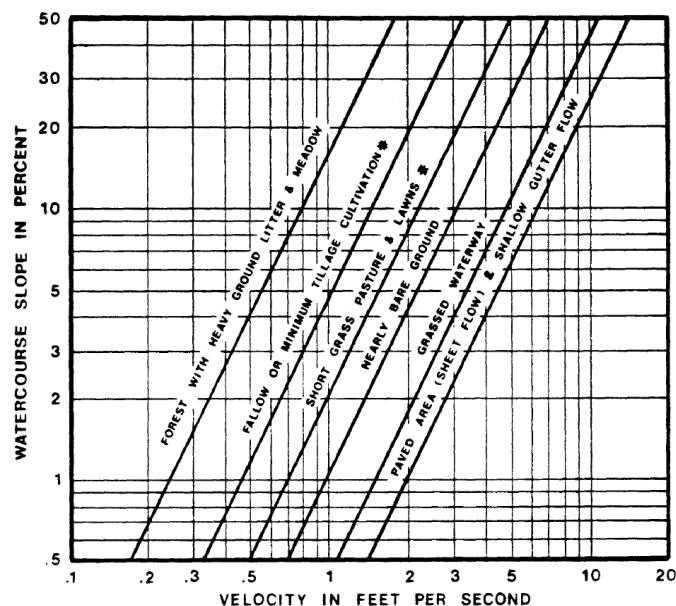


Figure 6-3. Estimate of Average Overland Flow Velocity for use with the Rational Formula

4.2.3 First Design Point Time of Concentration in Urban Catchments

Using this procedure, the time of concentration at the first design point (typically the first inlet in the system) in an urbanized catchment should not exceed the time of concentration calculated using Equation 6-7. The first design point is defined as the point where runoff first enters the storm sewer system.

$$t_c = \frac{L}{180} + 10 \quad (\text{Eq. 6-7})$$

Where:

t_c = maximum time of concentration at the first design point in an urban watershed (min)

L = waterway length (ft)

Equation 6-7 was developed using rainfall-runoff data collected in the Denver region and, in essence, represents regional “calibration” of the Rational Method. Normally, Equation 6-7 will result in a lesser time of concentration at the first design point and will govern in an urbanized watershed. For subsequent design points, the time of concentration is calculated by accumulating the travel times in downstream drainageway reaches.

4.2.4 Minimum Time of Concentration

If the calculations result in a t_c of less than 10 minutes for undeveloped conditions, it is recommended that a minimum value of 10 minutes be used. The minimum t_c for urbanized areas is 5 minutes.

4.2.5 Post-Development Time of Concentration

As Equation 6-5 indicates, the time of concentration is a function of the 5-year runoff coefficient for a drainage basin. Typically, higher levels of imperviousness (higher 5-year runoff coefficients) correspond to shorter times of concentration, and lower levels of imperviousness correspond to longer times of concentration, all other factors being equal. Although it is possible to calculate a longer time of concentration for a post-development condition versus a pre-development condition by increasing the length of the flow path, this is often a result of selecting unrealistic flow path lengths. As a matter of practice and for the sake of conservative design, it is required that the post-development time of concentration be less than or equal to the pre-development time of concentration. As a general rule and when sufficiently detailed development plans are not available, the post-development time of concentration can be estimated to be about 75% of the pre-development value.

4.2.6 Common Error in Calculating Time of Concentration

A common error in estimating the time of concentration occurs when a designer does not check the peak runoff generated from smaller portions of the catchment that may have a significantly shorter time of concentration (and, therefore, a higher rainfall intensity) than the drainage basin as a whole. Sometimes calculations using the Rational Method for a lower, urbanized portion of a watershed will produce a higher peak runoff than the calculations for the drainage basin as a whole, especially if the drainage basin is long or the upper portion has little or no impervious cover.

4.3 Rainfall Intensity (I)

The average rainfall intensity (I), in inches per hour, by recurrence interval, can be found from the Intensity-Duration-Frequency curves and data in Figure 6-2 and/or Table 6-2. The value for I is based on the assumption that the peak runoff will occur when the duration of the rainfall is equal to the time of concentration. For example, Figure 6-2 indicates a rainfall intensity of approximately 5.2 inches/hour for the 100-year event for a catchment with a time of concentration of 15 minutes. These curves are based on the rainfall depths from the 2013 update of NOAA Atlas 14 mapping for Woodland Park.

4.4 Basin Area (A)

The size of a drainage basin contributing runoff to a design point, in acres, is used to calculate peak runoff in the Rational Method. Accurately delineating the area contributing to each design point is one of the most important tasks for hydrologic analyses since the estimated runoff is directly proportional to the basin area. The area may be determined through the use of planimetric-topographic maps, supplemented by field surveys where topographic data has changed or where the contour interval is too great to distinguish the direction of flow. The drainage basin lines are determined by the natural topography, pavement slopes, locations of downspouts and inlets, paved and unpaved yards, grading of lawns, and many other features found on the urban landscape. In areas where there are storm drains, the entire contributing drainage area can sometimes be greater than the drainage area determined by topographic analysis of the ground surface, due to storm drains collecting runoff from areas that lie outside of the surface topographic extent of the basin.

5.0 Runoff Reduction Methods

Conventional methods for evaluating increased runoff volume and peak flows associated with urbanization make certain assumptions about the relationship between impervious surfaces and their effect on runoff. A primary assumption of many conventional methods is that the impervious surfaces are directly connected to the drainage features receiving the runoff. In reality, this connection is not always so direct, and adjusting land use planning and design practices to “disconnect” impervious areas (i.e. route flows from impervious areas to pervious areas rather than the gutter and street inlets), can reduce the rate and volume of runoff downstream. Many of the same practices that have been developed for improving water quality are also beneficial for reducing runoff volumes and peak flows. These practices can generally be referred to as Best Management Practices (BMPs), Low Impact Development (LID) and Green Infrastructure (GI) approaches. The effects of urbanization, the selection of BMPs, the implementation of LID approaches and their potential for reducing runoff are discussed in detail in Volume 3 of the UDFCD Manual. Key concepts associated with these practices are briefly summarized below with regard to their implications for estimating runoff.

5.1 Four Step Process

UDFCD has long recommended a “Four Step Process” for receiving water protection that focuses on reducing runoff volumes, treating the WQCV, stabilizing drainageways, 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. The Four Step Process is summarized as follows:

1. Step 1: Reduce runoff by disconnecting impervious area, eliminating “unnecessary” impervious area and encouraging infiltration into soils that are suitable.

2. Step 2: Retain 75% of 2-year runoff volume (when conditions are not suitable for retention and infiltration, the WQCV, with a slow, controlled release per the UDFCD Manual may be considered).
3. Step 3: Stabilize stream channels.
4. Step 4: Implement source controls.

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, increasing developable land and reducing the size of downstream facilities. A detailed description of the Four Step Process, which includes BMP selection tools and quantitative procedures for completing these steps, is provided in Volume 3 of the UDFCD Manual.

There are two primary approaches to reducing runoff volume and peak flows provided in this Manual. The first is to represent runoff reduction practices in the standard methods by converting the effects of these practices into a reduced value for imperviousness on a basin or sub-basin level. The second is to more directly represent the physical impacts of the BMPs and LID practices through modeling each of the elements at a sub-basin level. There is a significant difference in the level of detail and expertise required in the application of these two approaches. Most situations can be reasonably addressed through the application of an adjusted value for imperviousness, or “effective imperviousness.”

5.2 Effective Imperviousness

Volume 3 of the UDFCD Manual and the Colorado Springs Manual both provide methods that allow for adjustments to runoff calculations to account for disconnected impervious area and LID practices. The UDFCD Impervious Reduction Factor method, described in Volume 3, can be applied at a site development scale to determine adjustments in imperviousness for a range of storm return frequencies. The effective imperviousness determined using these methods (which will always be less than or equal to total imperviousness of the site) can be used in Rational Method calculations to account for the effects of runoff reduction practices, using Table 6-5 to determine runoff coefficients based on adjusted imperviousness values. The effects of volume reduction generally diminish with increasing storm frequency, and unless practices provide significant storage above and beyond the WQCV requirement, reductions in runoff coefficients for large storm events will be minimal.

6.0 Design Hydrology Based on Future Development Conditions

6.1 On-site Flow Analysis

Full site development shall be considered when the design engineer selects runoff coefficients or impervious percentage values and performs the hydrologic analyses for on-site areas. Changes in flow patterns and sub-basin boundaries due to site grading and proposed street and roadway locations must be considered. Time of concentration calculations must reflect increased surface flow velocities and velocities associated with proposed runoff conveyance facilities.

6.2 Off-site Flow Analysis

Fully developed conditions shall be considered when the design engineer selects runoff coefficients or impervious percentage values and performs the hydrologic analyses for off-site areas. Where the off-site area is undeveloped, fully developed conditions shall be projected using the best available land use

information, current zoning, or approved land use applications. The City shall be consulted to verify all assumptions regarding future development in off-site areas.

Where the off-site area is fully or partially developed, the hydrologic analysis shall be based on existing platted land uses, constructed conveyance facilities, and developed topographic characteristics. Consideration of potential benefits related to detention provided in off-site areas depends on the type of detention provided and whether or not the detention is publicly owned and/or maintained.

In general, the detention effects of on-site or multi-lot detention practices on private property will not be considered when determining off site flows and flood flows for downstream drainageways because they are not publicly owned and maintained. In some cases at the discretion of the City, detention effects of these types of facilities may be accounted for provided there is a drainage easement and agreement allowing the City to maintain the drainage facilities if the owner does not.

[illegible]

Figure 6-5. Standard Form SF-2, Rational Method Calculations

Chapter 7

Street Drainage

Contents

- 1.0 Introduction..... 1**
 - 1.1 Primary Function of Streets..... 1
 - 1.2 Design Criteria Based on Frequency and Magnitude 1
 - 1.3 Street Function in Storm Events..... 1

- 2.0 Standard Street Classification and Hydraulic Capacity..... 1**
 - 2.1 Allowable spread and depths..... 1
 - 2.2 Local streets with curb and gutter 2
 - 2.3 Calculation Spreadsheet 2
 - 2.4 Cross-Street Flow Conditions 3

- 3.0 Curbless Streets with Roadside Swales or ditches 3**
 - 3.1 Street cross-section..... 3
 - 3.2 Roadside Swale Design Considerations 3
 - 3.3 Roadside Ditch Design Considerations 4
 - 3.4 Driveways 4

Tables

Table 7-1. Allowable Street Encroachment and Depth of Flow 2

Figures

Figure 7-1. Street Capacity Chart Local Type I 5
Figure 7-2. Street Capacity Chart Local Type II.....6

1.0 Introduction

This chapter summarizes methods to evaluate runoff conveyance for standard street cross sections and curb types and identifies acceptable upper limits of street capacity for minor and major storm events. Street sections included in this chapter are the most common types used in Woodland Park. For non-standard sections, many of the principles and criteria will still apply; however, additional hydraulic analysis will be required. All non-standard street sections must be reviewed and approved by the City Engineer and applicants proposing a project involving a non-standard street section should consult with the City Engineer early in the planning process.

This chapter also provides guidance for reducing urban runoff and pollutant loading through the use of Low Impact Development (LID) techniques, such as curbless (or intermittent curb) streets with adjacent vegetated swales. Volume III of the UDFCD Manual and Volume 2 of the Colorado Springs Manual provide additional design guidelines and criteria applicable to LID.

1.1 Primary Function of Streets

Urban streets not only carry traffic, but stormwater runoff as well. The primary function of urban streets is for traffic movement; therefore, the drainage function is subservient and must not interfere with the traffic function of the street. When runoff in the street exceeds allowable limits, a storm sewer system or open channel/swale is required to convey the excess flows.

1.2 Design Criteria Based on Frequency and Magnitude

The design criteria for the collection and conveyance of stormwater runoff on public streets are based on an allowable frequency and magnitude of traffic interference. The primary design objective is to keep the depth and spread (encroachment) of stormwater on the street below an acceptable value for a given storm event and road classification.

1.3 Street Function in Storm Events

The use of streets for drainage conveyance during storm events is allowed with limitations on the depth of flow in the curb and gutter and the spread of flow onto the roadway, given traffic considerations. The maximum allowable street capacity is determined by these limits and may be affected by the type of curb and gutter, based on the geometry of the standard street sections. The primary function of streets in a minor storm event is to convey the frequently occurring flows quickly, efficiently, and economically to the next intended water quality treatment and/or drainage conveyance system with minimal disruption to street traffic. For the major storm event, the function of streets is to provide an emergency passageway for infrequent flood flows while maintaining public safety and minimizing flood damage. In the major event, the street becomes an open channel and must be analyzed to determine when flooding depths exceed acceptable levels.

2.0 Standard Street Classification and Hydraulic Capacity

2.1 Allowable spread and depths

Streets are typically given classifications such as local, collector, arterial and others. The standard local street configuration is addressed in this manual. Other street cross-sections shall be reviewed and approved by the City Engineer. Allowable spread and depth for street classifications are presented in Table 7-1.

Table 7-1. Allowable Street Encroachment and Depth of Flow

Street Classification	Allowable Encroachment	Allowable cross-street flow	Allowable Encroachment	Allowable cross-street flow
	Minor Storm		Major Storm	
Local	No curb overtopping. Flow may spread to crown of street.	6 inches depth in crossspan.	Depth of water in gutter shall not exceed 8.5 inches, unless ground slopes up behind walk in which case depth shall not exceed 12 inches, nor extend beyond the Right-of-Way.	12 inches depth above gutter flow line.
Collector	No curb overtopping. Flow spread shall leave the equivalent of one 10 foot driving lane clear of water.	6 inches depth in crossspan.	Depth of water in gutter shall not exceed 8.5 inches, unless ground slopes up behind walk in which case depth shall not exceed 12 inches, nor extend beyond the Right-of-Way.	12 inches depth above gutter flow line.
Arterial	No curb overtopping. Flow spread shall leave the equivalent of two 10 foot driving lanes clear of water - one lane in each direction. No more than two lanes in each direction shall be flooded.	None.	Depth of water in gutter shall not exceed 12 inches, nor extend beyond the Right-of-Way.	No cross-street flow. Maximum depth of upstream gutter of 12 inches.
Curbless Streets	Where no curb exists, depth of water shall not exceed 6" or past ROW, whichever is less.	6 inches depth in crossspan.	Where no curb exists, depth of water shall not exceed 12" or past ROW, whichever is less.	6 inches depth in crossspan.

2.2 Local streets with curb and gutter

The cross-section of the standard local street section is defined and detailed in Figure 5.3.2 of the City of Woodland Park Engineering Standards (Standards). There are two types of standard curb and gutter that are detailed in Figures 6.4.1 and 6.4.2 of the Standards. Figures 7-1 and 7-2 show the capacity limitations for each local street with both curb types for varying slopes. When alternate roadway sections are proposed, they shall be reviewed and approved by the City Engineer, and appropriate guidance for flow spreading and depth of flow must be established. Non-standard street cross-sections may be analyzed using the UDFCD spreadsheet UD-Inlet, which can be found on the UDFCD website, and is described below. Each roadway section has a different capacity, so it is important to use the section dimensions that apply to the particular street section of interest.

2.3 Calculation Spreadsheet

The Streets, Inlets and Storm Drains Chapter of the UDFCD Manual provides documentation of hydraulic street capacity and inlet calculations, and the UDFCD UD-Inlet spreadsheet can be used for determining

the minor and major storm street capacity and flow encroachments. The “Q-Allow” worksheet is contained within the UD-Inlet spreadsheet, which can be accessed via the internet at www.udfcd.org. This worksheet completes a hydraulic evaluation of theoretical street capacity for both the minor and major storms by calculating the street flow capacity based on both 1) the allowable spread and 2) the allowable gutter depth. A reduction factor is then applied to the theoretical gutter flow based on allowable depth, and the lesser of the allowable street capacities governs for the storm event. A Manning’s n-value of 0.016 is recommended on pavement.

2.4 Cross-Street Flow Conditions

Cross-street flow can occur in an urban drainage system under three conditions:

1. When the runoff in a gutter spreads across the street crown to the opposite gutter—This is prohibited for most streets for the minor event to allow for at least one lane to pass traffic, but for some street classifications, this type of cross street flow is allowable in the major event.
2. When cross-pans are used—Cross-pans shall be designed to convey the minor and major storm event within the criteria presented in this chapter. The design engineer shall evaluate the carrying capacity (with calculations provided) considering water on the roadway, as well as the side street. Refer to the Colorado Springs Manual and/or CDOT standard details for cross pan design information.
3. When the flow in a drainageway exceeds the capacity of a road culvert and/or bridge and subsequently overtops the crown of the street—This type of cross-street flow is prohibited in the minor event for all street classifications and in the major event for arterial streets. For local and collector streets the depth of overtopping must not exceed 12 inches at gutter flowline or 4 inches at crown. Chapter 11 provides additional information on culvert and bridge design criteria.

3.0 Curbless Streets with Roadside Swales or ditches

3.1 Street cross-section

For roadside swales and ditches, the City Engineer shall review and approve an alternate, non-standard street section. Roadside swales provide an opportunity to minimize directly connected impervious areas and thereby reduce the volume and peak rate of runoff and enhance stormwater quality. Roadside swales are used in conjunction with curbless (or intermittent curb) streets. This chapter distinguishes between roadside swales and ditches. For the purpose of this chapter, a ditch refers to an open channel that is designed primarily for conveyance with no or incidental infiltration. Some ditches in Woodland Park are paved; although, as these areas are redeveloped, soil riprap may be a more desirable way to achieve a stable, vegetated conveyance with additional infiltration benefits. A swale is similar to a ditch in that its primary function is conveyance; however, swales are generally sized for a broader cross section and shallower flow than ditches to maximize contact between runoff and vegetation to promote infiltration.

3.2 Roadside Swale Design Considerations

Maintenance shall be considered when designing and using roadside swales, including adequate area and side slopes to allow for maintenance access and vehicles. Roadside swales shall be designed based on site-specific conditions and hydraulic capacity. However, they will generally have a minimum depth of 9 inches below the edge of the street shoulder, a bottom width of at least 2 feet, and side slopes of 4:1 or flatter. Swales shall be stabilized with vegetation such as native grasses. The slope of the swale will generally be similar to the slope of the street. At the point where the maximum capacity of the swale is reached for the design event, runoff must be intercepted in an alternate system such as a vegetated drainageway or an area inlet and storm drain. Additional information on swales can be found in the

UDFCD Manual, and criteria and guidelines for maximizing water quality benefits of swales are provided in Volume 2 of the Colorado Springs Manual and Volume 3 of the UDFCD Manual.

3.3 Roadside Ditch Design Considerations

Maintenance shall be considered when designing and using roadside ditches, including adequate area and side slopes to allow for maintenance access and vehicles. Rural roadside ditches shall be designed in accordance with the criteria for minor drainageway grass-lined channels shown in Chapter 12, Open Channel Design. Grade control structures may be required to maintain velocities less than the maximum allowable.

There are cases when the roadside ditch criteria may need to be more stringent due to the function of the rural road. Even if a rural road has a low traffic volume, it may be important for emergency access to several properties and therefore require special design criteria. More stringent criteria for single point access roads may also be required.

At the point where the maximum capacity of the ditch is reached for the design event, runoff must be intercepted in an alternate system such as a vegetated drainageway or an area inlet and storm drain. Criteria for inlets are found in Chapter 8 of this Manual. When practical, the use of vegetated swales is preferred to the use of storm drains to provide contact of runoff with vegetation and soil and increase infiltration potential. In more urban portions of the City and along major roadways, storm drains will typically be the most practical solution. However, in residential areas of the City, there are many opportunities for roadside swales/ditches, and areas with existing hardened roadside conveyances (e.g. concrete or asphalt ditches) present retrofit opportunities as redevelopment occurs to provide enhanced water quality treatment as a part of the drainage conveyance system.

3.4 Driveways

In general, driveways or sidewalks that cross a roadside swale or ditch must provide conveyance under the driveway. Installation of a driveway culvert is recommended. Hydraulic capacity of the culvert must conform to the required street classification design considerations for depth and spread of flow. The ends of the culvert shall be protected either by installation of a flared-end section or concrete headwall, and other appropriate outlet protection as described in Chapter 10. Criteria for culvert design are presented in Chapter 11.

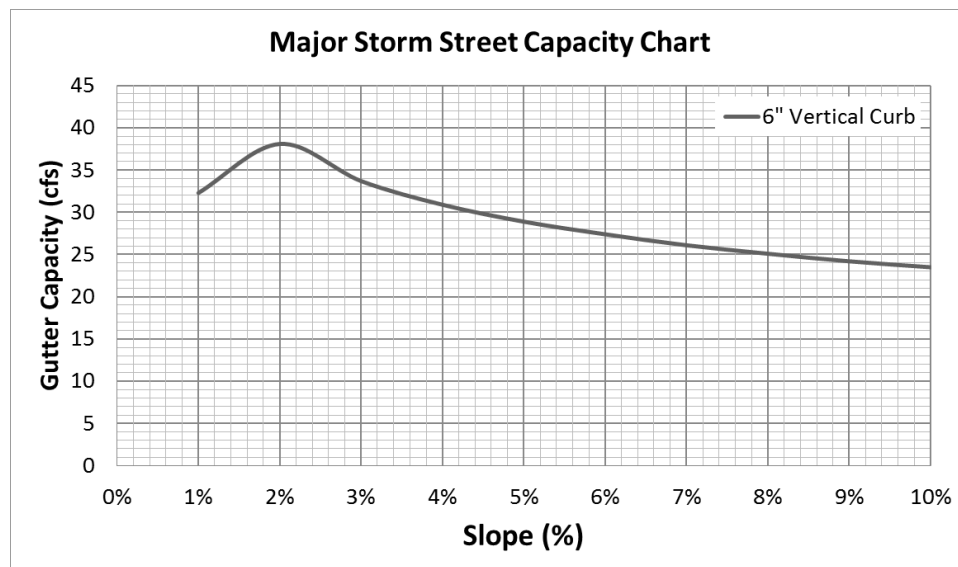
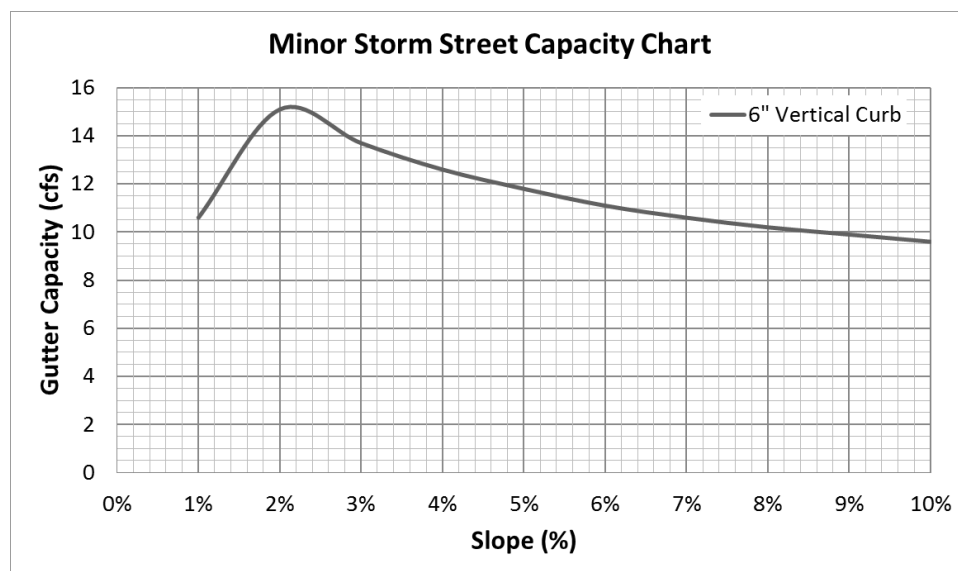
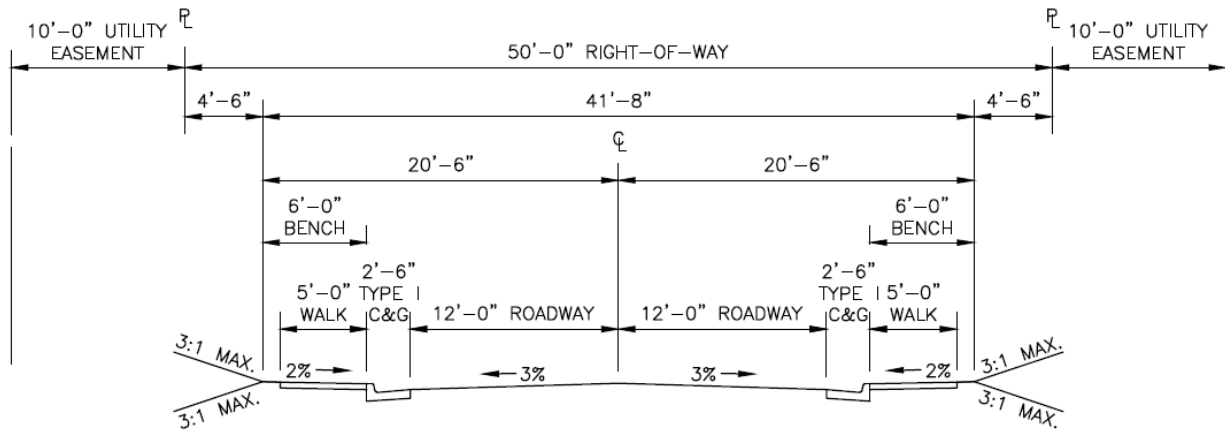
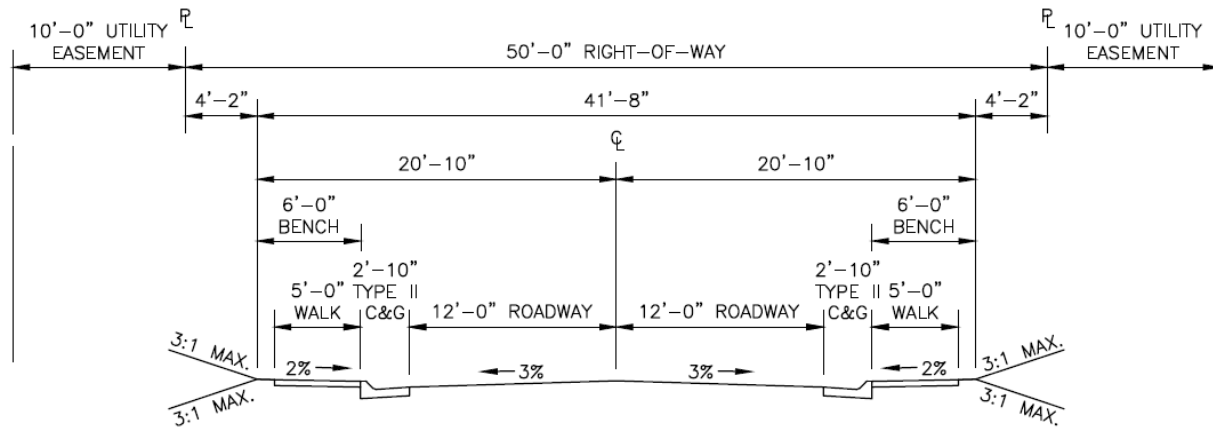
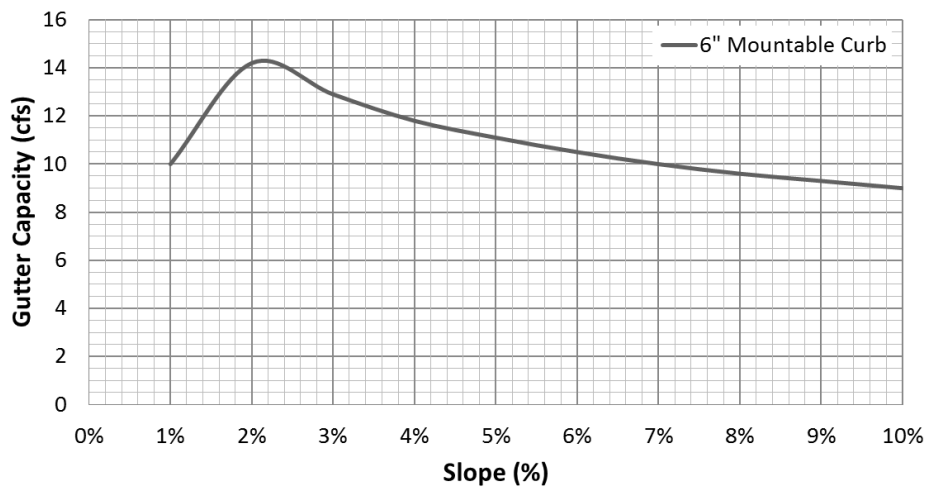


Figure 7-1. Street Capacity Chart Local Type I



Minor Storm Street Capacity Chart



Major Storm Street Capacity Chart

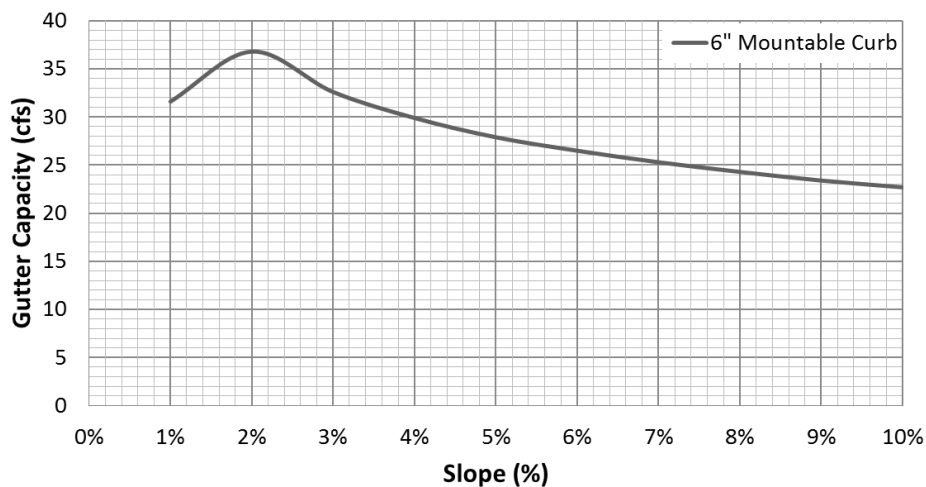


Figure 7-2. Street Capacity Chart Local Type II

Note for Figure 7-1 and Figure 7-2:

These charts shall only be used for the standard street sections as shown. The capacity shown is based on $\frac{1}{2}$ the street section as calculated by the UD-Inlet spreadsheets. Minor storm capacities are based on no crown overtopping, curb height or maximum allowable spread widths. Major storm capacities are based on flow being contained within the public right-of-way, including conveyance capacity behind the curb. The UDFCD Safety Reduction Factor was applied. An ' n_{STREET} ' of 0.016 and ' n_{BACK} ' of 0.020 was used.

Chapter 8

Inlets

Contents

1.0	Introduction.....	1
2.0	General.....	1
2.1	Function of Inlets	1
2.2	Types of Inlets.....	1
2.3	General Design Guidelines.....	2
3.0	Standard Inlets	5
3.1	Applicable Settings for Various Inlet Types	5
3.2	Standard Inlets Accepted for Use	6
4.0	Hydraulic Evaluation of Inlets	7
4.1	Inlet Location and Spacing.....	7
4.2	Inlet Capacity Factors	7
4.3	Design of Inlets on Continuous Grade	7
4.4	Inlets in Sump Conditions	8
4.5	Emergency Overflow Path with Drainage Tract	8
4.6	Roadside Inlets	8
5.0	Other Design Considerations	8
5.1	Median Inlets.....	8
5.2	Maximum Inlet Length	8

Tables

Table 8-1. Nuisance Flows: Sources, Problems and Avoidance Strategies	4
Table 8-2. Inlet Type Summary	5
Table 8-3. Standard City Inlets	6

Figures

Figure 8-1. Inlet Capacity Chart, Residential (Local) Streets Inlets on Grade Denver No. 14 Curb Opening	10
Figure 8-2. Inlet Capacity Chart, Minor Residential (Local) Streets Inlets on Grade CDOT Type R Curb Opening	11
Figure 8-3. Inlet Capacity Chart, Minor Residential (Local) Streets Inlets on Grade Denver No. 16 Combination	112
Figure 8-4. Inlet Capacity Chart Sump Conditions, Area (CDOT Type C) Inlet.....	13
Figure 8-5. Inlet Capacity Chart Sump Conditions, Curb Opening (CDOT Type R) Inlet.....	14

1.0 Introduction

Criteria and methodology for design and evaluation of storm sewer inlets are presented in this chapter. The review of all planning submittals will be based on the criteria presented herein.

2.0 General

2.1 Function of Inlets

The primary purpose of storm drain inlets is to intercept excess surface runoff and convey it into a storm drainage system, thereby reducing or eliminating surface flooding. Roadway geometry often dictates the location of street inlets along the curb and gutter. In general, inlets are placed at all low points (sumps), along continuous grade curb and gutter, at median breaks, intersections and crosswalks. The spacing of inlets along a continuous grade segment of roadway is governed by the allowable spread of flow. See further details of allowable spread of flow in Chapter 7, Street Drainage.

2.2 Types of Inlets

There are four major types of inlets approved for use within the right-of-way:

- Denver No.14 curb opening inlets,
- CDOT Type R curb opening inlets,
- Denver No. 16 combination inlets, and
- CDOT Type C area inlets.

Other types of inlets may be acceptable with review and approval of the City Engineer. Inlets are further classified as being on a “continuous grade” or in a “sump.” The term “continuous grade” refers to an inlet placed in a curb and gutter or roadside ditch or swale so that the grade of the street or ditch has a continuous slope past the inlet and, therefore, water ponding does not occur at the inlet. A sump condition exists whenever an inlet is located at a low point, resulting in ponding water.



Photograph 8-1. Inlet in sump



Photograph 8-2. Inlet on grade

2.3 General Design Guidelines

The following guidelines shall be used when designing inlets along a street section:

- Design and location of inlets shall take into consideration pedestrian and bicycle traffic. All inlet grates shall be pedestrian and bicycle-safe.
- Design and location of inlets shall be in accordance with the allowable spread and depth criteria established in Chapter 7, Street Drainage.
- Maintenance of inlets shall be considered when determining inlet locations. The slope of the street, the potential for debris and ice accumulation, the distance between inlets and/or manholes, and other factors shall be considered. Maintenance access shall be provided for all inlets.
- To avoid potential damage from large vehicles driving over the curb return and interference with pedestrian traffic, inlets shall not be placed in the curb return radii.
- Selection of the appropriate inlet grate shall be based on a number of factors, including, but not limited to, the adjacent land use and potential for pedestrian or bicycle traffic, the potential for debris and ice accumulation, visibility, expected loading from vehicles, and hydraulic capacity.
- In many cases, inlets are necessary at grade breaks, where street or ditch grades change from steep to relatively flat, because of the reduced conveyance capacities. Additionally, it is common for icing or sediment deposition to occur with nuisance flows in reaches where grades are relatively mild.

2.4 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 can pose problems such as algae growth and ice in both warm and cold weather months. 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.

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 8-3). 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 indicator 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 sloughing.

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, two-story houses, 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 area already developed), identifying problem areas and planning for maintenance is often the most effective practice for minimizing nuisance conditions.



Photograph 8-3. 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 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, the Colorado Department of Public Health and Environment (CDPHE) requirements must be followed.

Table 8-1 provides the various sources, problems and avoidance strategies associated with nuisance flows.

Table 8-1. 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.

Locating inlets in areas where water can be intercepted before it accumulates or slows down and has the opportunity to freeze in 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 tree canopy far greater than when initially planted. Tree canopy may vary seasonally, depending on the tree species (i.e., “solar shade 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 this is an ongoing part of the City’s 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 aide 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, Styrofoam, 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.

3.0 Standard Inlets

3.1 Applicable Settings for Various Inlet Types

Table 8-2 provides information on the appropriate application of the different types of inlets, along with advantages and disadvantages of each. The information provided in this table should be considered when selecting the inlet for a given site condition.

Table 8-2. Inlet Type Summary
(Source: UDFCD 2002)

Inlet Type	Applicable Setting	Advantages	Disadvantages
Grate	Sumps and continuous grades (should be made bicycle safe)	Perform well over wide range of grades	Susceptible to clogging, 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 Standard Inlets Accepted for Use

Table 8-3 summarizes the standard inlets permitted for use in Woodland Park.

Table 8-3. Standard City Inlets

Inlet Type	Standard Detail	Drawing No.	Permitted Use
Curb-Opening Inlet – CDOT	Type R	M-604-12	All street types with 6- vertical or mountable curb and gutter with appropriate transitions. Available inlet lengths 5', 10', 15'.
Curb-Opening Inlet – City & County of Denver	Type 14	S-620.1 S-620.2	All street types with 6-inch vertical curb and gutter, with appropriate transitions. Available inlet lengths 6', 9', 12', 15'.
Grate Inlet – CDOT	Type C	M-604-10	Roadside or median grass swales; Landscaped area drains; generally non-pedestrian accessible areas; Used in sump condition.
Combination Curb-Opening and Grate Inlet – City & County of Denver	Type 16	S-616.1 S-616.2 S-616.3	All street types with 6-inch vertical or mountable curb and gutter, with appropriate transitions. Available inlet lengths single (4'8"), double (8'5") and triple (12'3").

Photos of various inlet types can be found in the UDFCD spreadsheet UD-Inlet. Following are photos of the inlets described above. These are single inlets. Multiple inlet configurations such as double or triple inlets are also possible.



Photograph 8-4. Denver No. 14 Curb Opening Inlet (UDFCD Volume 1)



Photograph 8-5. CDOT Type R Curb Opening Inlet (UDFCD Volume 1)



Photograph 8-6. Denver No. 16 Combination Inlet in need of maintenance (UDFCD Volume 1)



Photograph 8-7. CDOT Type C Grate Inlet (UDFCD Volume 1)

Other inlets must be reviewed and approved by the City Engineer. UD-Inlet can be used for hydraulic analysis of 18 different typical inlet/grate combinations, as well as multiple inlets, which are often a good choice to provide additional interception without additional structures. Design of non-standard inlets will require detailed computations and justification for their use.

4.0 Hydraulic Evaluation of Inlets

4.1 Inlet Location and Spacing

The location and spacing of inlets is based upon street design considerations, topography (sumps), maintenance requirements, and the allowable spread of flow within the street. A significant amount of cost savings can be realized if inlets are placed in locations where their efficiency is maximized. The greater the efficiency of an inlet, the smaller the carryover flow, which may result in a smaller number of inlets downstream. Inlets are most efficient in a sump condition or along mild continuous street grades.

4.2 Inlet Capacity Factors

The capacity of an inlet located on a continuous grade is dependent upon a variety of factors including gutter slope, depth and velocity of flow in the gutter, height and length of the curb opening, street cross slope, and the amount of depression at the inlet. Inlets placed on continuous grades rarely intercept all of the flow in the gutter during the minor storm. This results in flow continuing downstream of the inlet and is typically referred to as “carryover.” The amount of carryover must be accounted for in the drainage system evaluation, as well as in the design of the downstream inlet. Inlets are most efficient in a sump condition or along mild continuous street grades. The capture efficiency of a curb-opening inlet depends on the length of the opening, the depth of flow at the curb, the street cross slope, and the longitudinal gutter slope. If the curb opening is long, the flow rate is low, and the longitudinal gutter slope is small, all of the flow may be captured by the inlet. However, a portion of the stormwater often bypasses the inlet as indicated by the inlet efficiency. See the Streets/Inlets/Storm Sewers Chapter in Volume 1 of the UDFCD Manual for additional information on the efficiency and design of curb opening inlets on continuous grades.

4.3 Design of Inlets on Continuous Grade

Figures 8-1 through 8-3 (located at the end of this chapter) provide capacity charts for the three recommended curb opening inlets (Denver No. 14, CDOT Type R and Denver No. 16 combination) on continuous grades along standard street sections for the minor and major storm events, based on the maximum allowable flow in the street section, incorporating appropriate clogging factors. Sump condition figures are also provided, including curves for an Area (CDOT Type C) Inlet. These charts may be used to evaluate the street if it is at the maximum allowable flow. The Colorado Springs and Denver Manuals includes charts for other types of inlets, which may be considered and approved on a case-by-case basis if standard inlets are not sufficient.

When flow in the gutter is less than the maximum flow, the UD-Inlet spreadsheets shall be used to determine the interception by the proposed inlet. See the Streets/Inlets/Storm Sewers Chapter of the UDFCD Manual for further discussion on the use of UD-Inlet for less than maximum allowable flow.

The Streets/Inlets/Storm Sewers Chapter of the UDFCD Manual provides detailed instruction on the appropriate analysis of inlet capacities including equations, coefficients, and examples. The worksheets are the most accurate means of determining inlet capture rates and capacity calculations. The spreadsheets analyze both street capacities and inlet interception rates for both the minor and major storm events simultaneously. The UD-Inlet Spreadsheets may be downloaded from the UDFCD web site at www.udfcd.org.

4.4 Inlets in Sump Conditions

Inlets located in sumps (low points) must be sized to intercept all of the design storm flows at an allowable depth of ponding. The capacity of an inlet in a sump is dependent upon the depth of ponding above the inlet and the amount of debris clogging the inlet. Ponded water is a nuisance and can be a hazard to the public; therefore curb opening and combination inlets (where approved for use) are highly recommended for sump conditions due to their reduced clogging potential versus grate inlets acting alone. Capacity charts for curb opening and combination inlets in a sump condition are provided in Figures 8-4 through 8-5. These charts are based upon the depth of ponding above the inlet. The depth of ponded water shall not exceed the maximum allowable water depth for the given street classification as summarized in Chapter 7, Street Drainage.

4.5 Emergency Overflow Path with Drainage Tract

A surface flow path shall be provided at all sump inlets to provide for emergency overflows if the inlet becomes clogged or if storm runoff exceeds design flows. The emergency overflow shall be designed to convey the major storm discharge assuming that no flow is carried in the storm sewer. The depth of ponding shall not exceed the maximum allowable water depth for the given street classification as summarized in Chapter 7, Street Drainage. Channels conveying overflows shall be designed based on criteria for open channels and shall be contained within public right-of-way or a tract, including the required freeboard.

4.6 Roadside Inlets

For roadside swales and ditches, the City Engineer shall review and approve alternate, non-standard street sections. Roadside swales are used in conjunction with curbless (or intermittent curb) streets. When the capacity of the roadside swale or ditch is reached, given the criteria for depth and spread of flow into the street, then roadside inlets may need to be placed. The standard roadside inlet is a CDOT Type C inlet. Alternate inlets shall be reviewed and approved by the City Engineer.

The capacity curves provided in Figure 8-4 for CDOT Type C inlets include a 50% reduction factor for a standard grate and a 75% reduction factor for a close mesh grate. If a CDOT Type C inlet is placed in an area with pedestrian traffic, a close mesh grate shall be used.

5.0 Other Design Considerations

5.1 Median Inlets

Median curbs are typically configured to direct flows away from the median or are normally “spill” curbs. In situations where the street configuration directs flows toward medians or where runoff from medians is concentrated, inlets must be placed to collect the flows. Inlets are required along or within the median to reduce ponding at curb and gutter low points and to eliminate concentrated flow crossing over the lanes of traffic. The final design and construction drawings must address inlet sizing, dimensions, and required curb and gutter transitions. In some cases, using a depressed, vegetated median with an inlet at the bottom of the depression can be an effective way to disconnect impervious area.

5.2 Maximum Inlet Length

Inlets shall be designed to blend in with the streetscape, and not present a dramatic structural departure from the general surroundings. The use of extremely long inlets is discouraged, as they are generally not

aesthetic, require increased maintenance, and are viewed as a hazard by the public. In addition, studies by the UDFCD show that excessively long inlets do not significantly increase interception rates. The maximum length of an inlet in a specific location shall not exceed 9 feet for Denver No. 16 inlets, and 15 feet for CDOT Type R inlets.

5.3 Matching Inlet to Street Slope

Inlets, whether precast or cast-in-place shall be constructed so that the cap or top of the inlet matches the slope of the street. This is particularly important on streets with steep slopes, as the elevation difference between the beginning and end of the inlet can be significant, particularly when double or triple inlets are used.

Street Section Data: Street Width Flowline to Flowline = 28'
 Type of Curb and Gutter: Type I 6" vertical and Type II 6" mountable

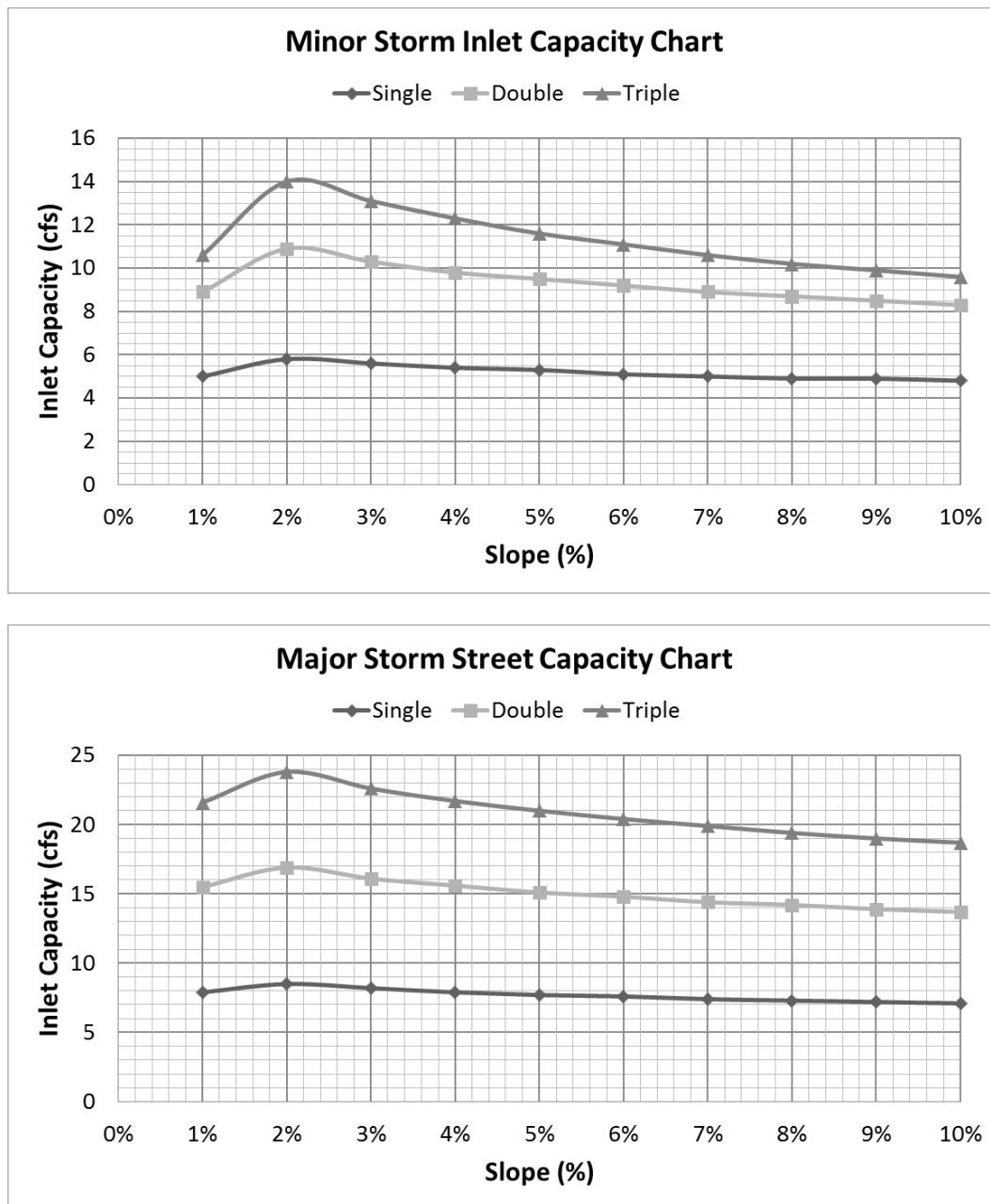


**Figure 8-1. Inlet Capacity Chart, Residential (Local) Streets Inlets on Grade
 Denver No. 14 Curb Opening**

The standard street section parameters as defined in Chapter 7 must apply to use these charts. For non-standard sections, the inlet capacity shall be calculated using the UDFCD spreadsheets. The maximum spread width is limited by the curb height based on no curb overtopping during a minor storm and flow being contained within the public right-of-way during the major storm.

Street Section Data: Street Width Flowline to Flowline = 28'
 Type of Curb and Gutter = Type I 6" vertical and Type II 6" mountable

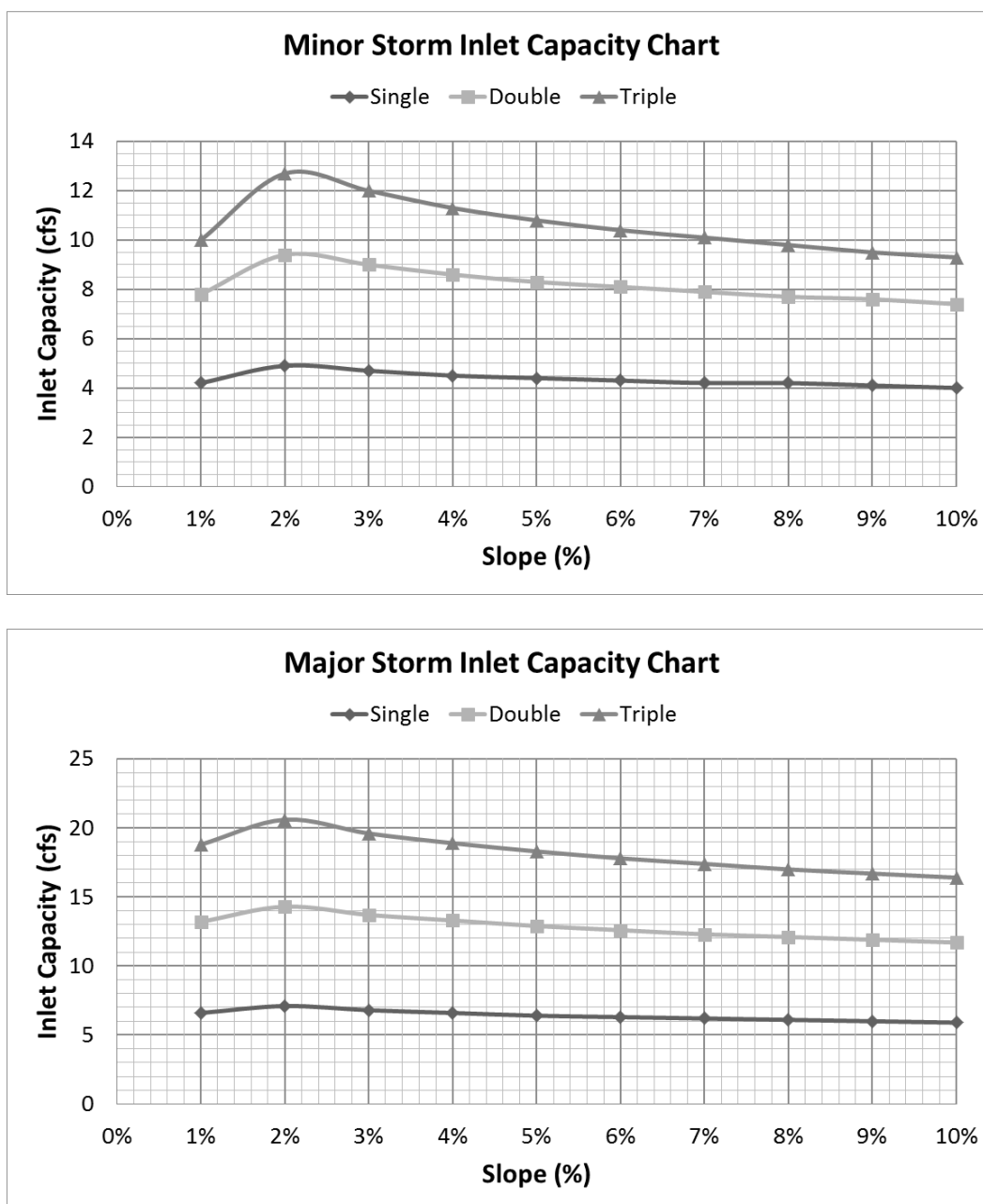


**Figure 8-2. Inlet Capacity Chart, Minor Residential (Local) Streets Inlets on Grade
 CDOT Type R Curb Opening**

The standard street section parameters as defined in Chapter 7 must apply to use these charts. For non-standard sections, the inlet capacity shall be calculated using the UDFCD spreadsheets. The maximum spread width is limited by the curb height based on no curb overtopping during a minor storm and flow being contained within the public right-of-way during the major storm.

Street Section Data: Street Width Flowline to Flowline = 28'
 Type of Curb and Gutter = Type I 6" vertical and Type II 6" mountable

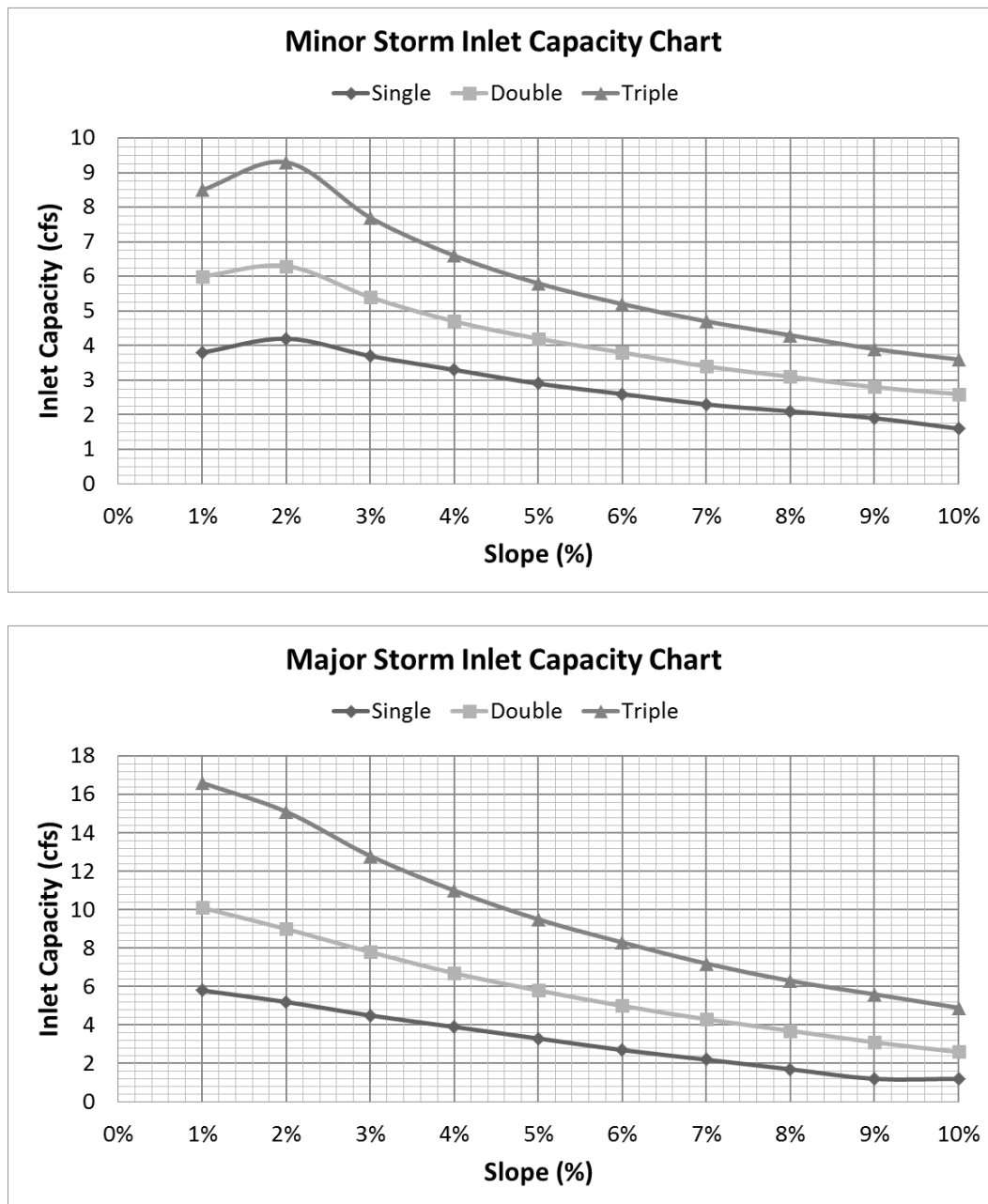


**Figure 8-3. Inlet Capacity Chart, Minor Residential (Local) Streets Inlets on Grade
 Denver No. 16 Combination**

The standard street section parameters as defined in Chapter 7 must apply to use these charts. For non-standard sections, the inlet capacity shall be calculated using the UDFCD spreadsheets. The maximum spread width is limited by the curb height based on no curb overtopping during a minor storm and flow being contained within the public right-of-way during the major storm.

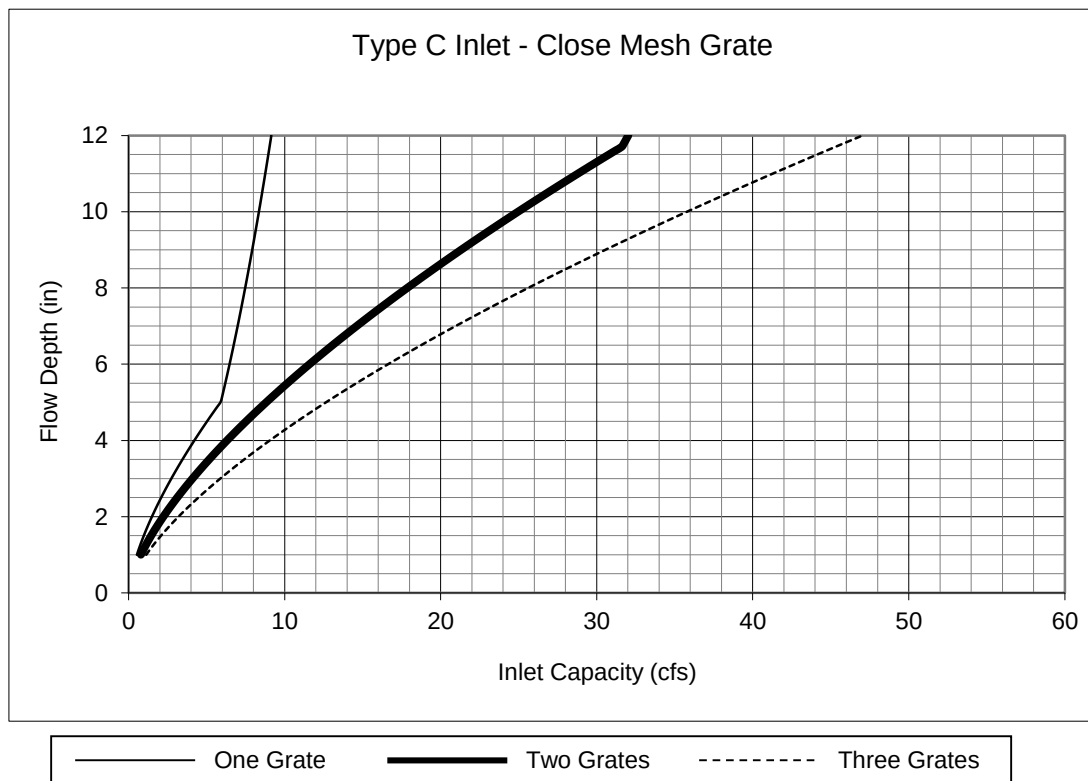
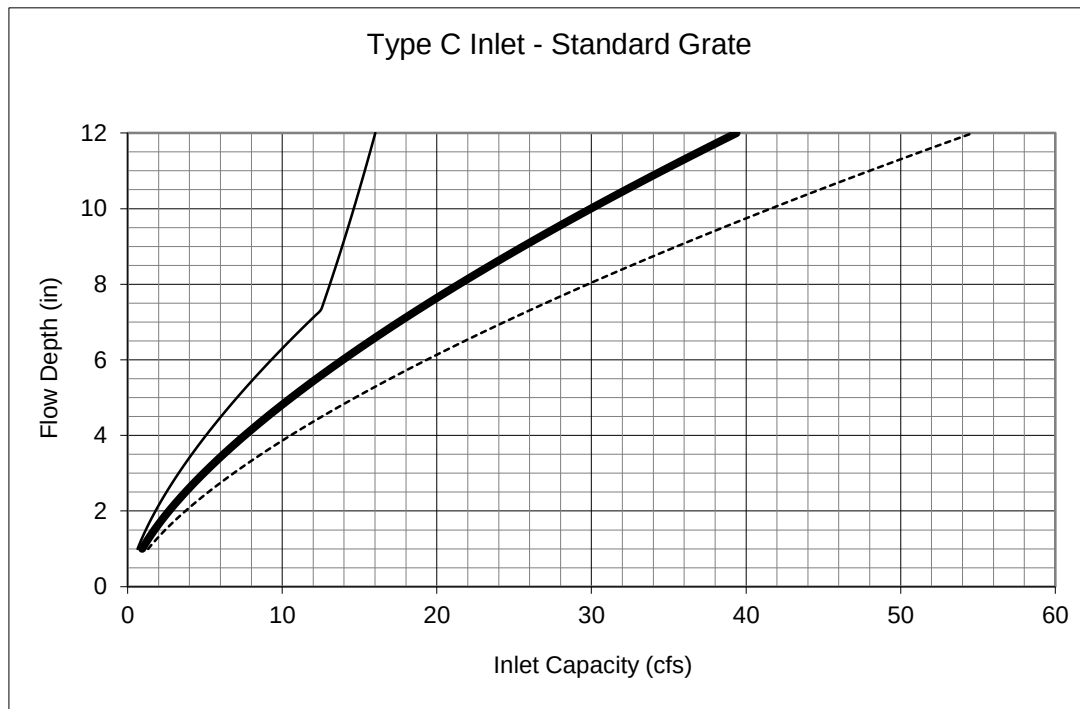


Figure 8-4. Inlet Capacity Chart Sump Conditions, Area (CDOT Type C) Inlet

Note: The City of Woodland Park standard inlet parameters must apply to use these charts.

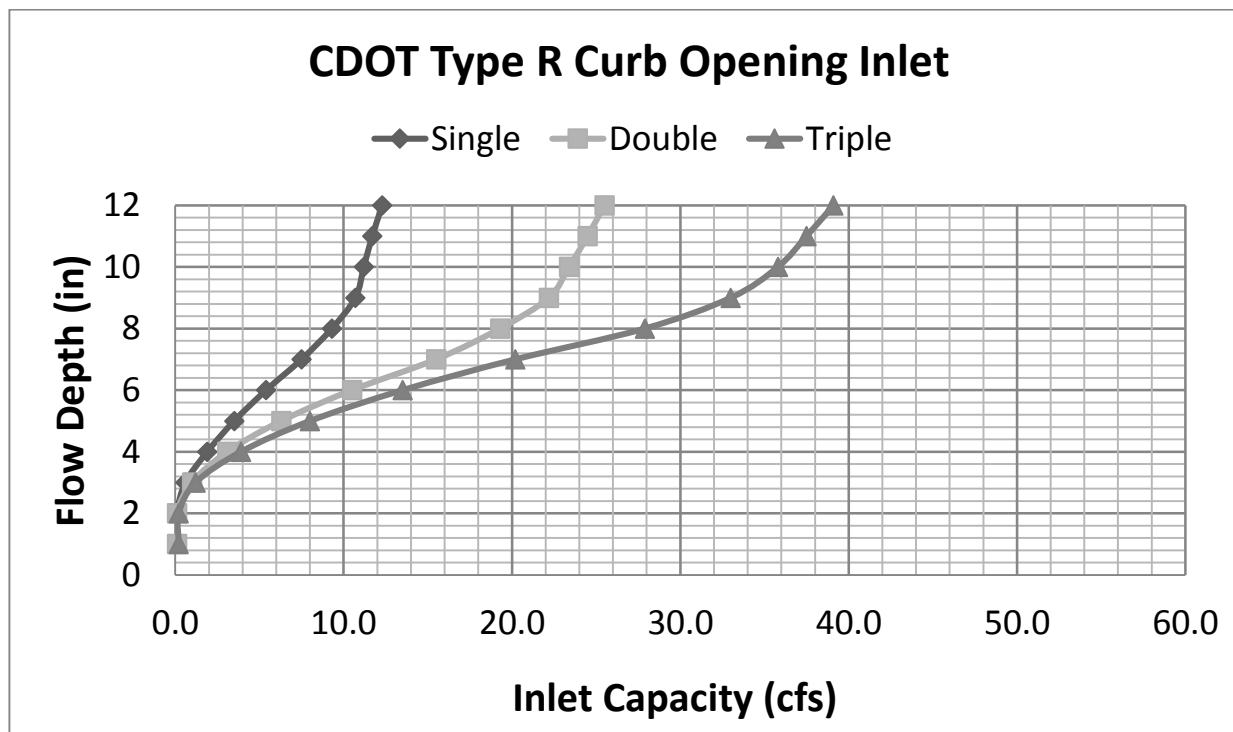
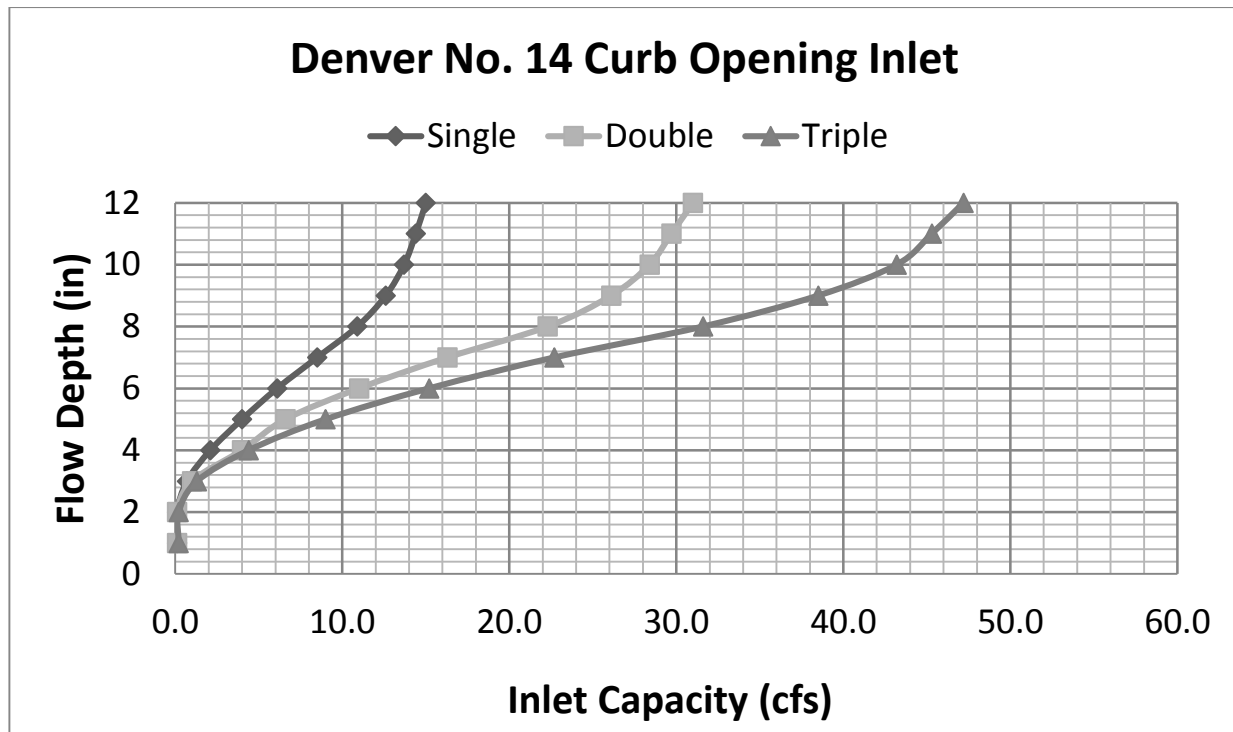
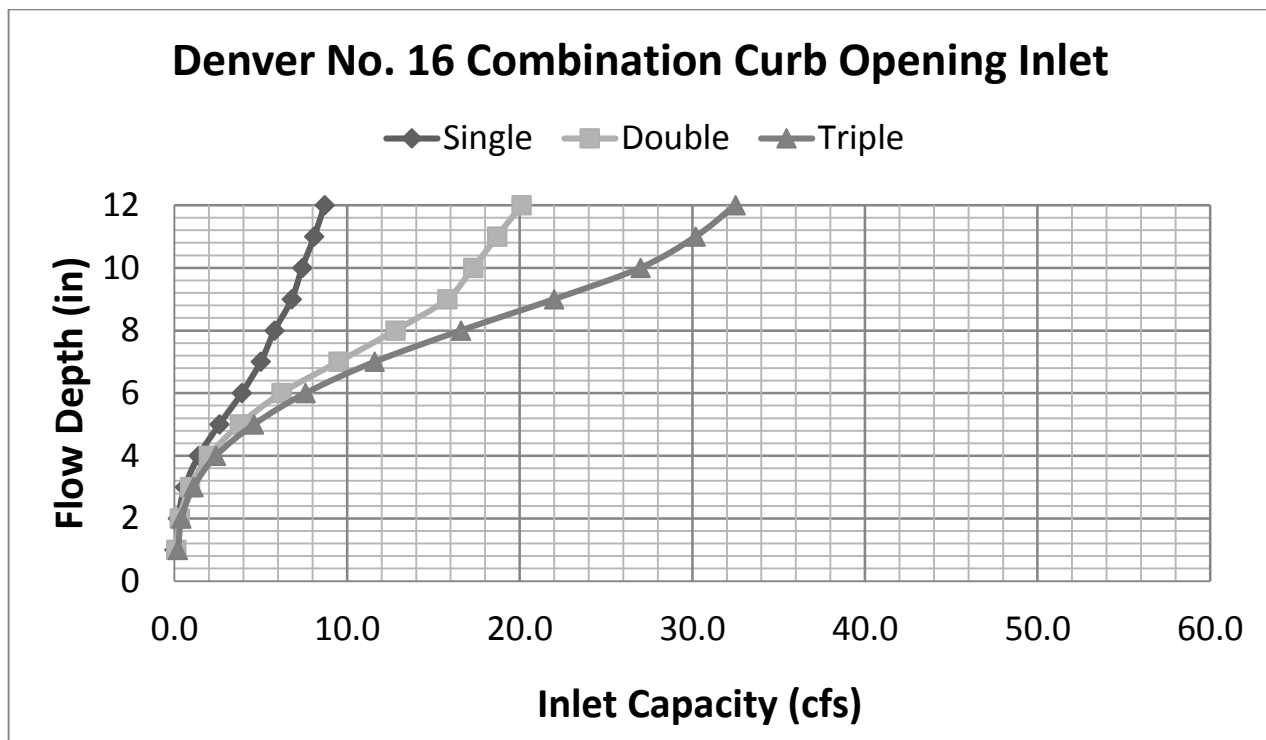


Figure 8-5. Inlet Capacity Chart Sump Conditions, Curb Opening Inlets

Note: The City of Woodland Park standard inlet parameters must apply to use this chart.



Note: The City of Woodland Park standard inlet parameters must apply to use this chart.

Figure 8-5 (cont.). Inlet Capacity Chart Sump Conditions, Curb Opening Inlet

Chapter 9

Storm Drains

Contents

1.0	Introduction.....	1
2.0	Runoff Reduction and Stormwater Quality Considerations.....	1
3.0	Design Storms.....	1
3.1	Minor Event	1
3.2	Major Event.....	1
4.0	Pipe Material and Size	2
4.1	Pipe Material	2
4.2	Minimum Pipe Size.....	2
4.3	Service Life	2
4.4	Other Design Considerations	3
4.4.1	RCP Pipe Class, Fill Height, and Installation Trench	3
4.4.2	Joints	3
4.4.3	Outfalls.....	3
4.4.4	Trash/Safety Racks	3
5.0	Easements.....	3
5.1	Easement Conveyance	3
5.2	Minimum Easement Widths.....	3
5.3	Allowable Landscaping and Surface Treatment in Easements.....	4
6.0	Vertical Alignment.....	4
6.1	Cover.....	4
6.2	Cover in Roadways	5
6.3	Utility Clearance	5
6.4	Concrete Cut-off Walls and Anchoring.....	5
7.0	Horizontal Alignment	5
7.1	Alignment.....	5
7.2	Stationing	5
8.0	Manholes	6
8.1	Required Locations	6
8.2	Manhole Types.....	6
8.3	Steps and Platforms.....	7
8.4	Drop Manholes.....	7
8.5	Other Design Considerations	8
9.0	Hydraulic Design.....	8
9.1	Allowable Velocity and Slope.....	8
9.2	Minor Storm Event Hydraulic Evaluation.....	8
9.3	Major Storm Event Hydraulic Evaluation.....	9
9.4	Hydraulic Calculations.....	9

Tables

Table 9-1. Maximum Manhole Spacing.....6

Table 9-2. Minimum Manhole Sizes.....7

1.0 Introduction

This chapter summarizes design criteria and evaluation methods for storm drain systems (also commonly referred to as storm sewers). The review of all submittals will be based on the criteria presented herein.

2.0 Runoff Reduction and Stormwater Quality Considerations

Traditionally, urban development has relied on storm drain systems in the upper portions of watersheds to prevent local flooding and to carry flows away quickly. As storm drains pick up more drainage area, they increase in size and convey urban runoff quickly downstream with little to no reduction in rate or volume or improvement in water quality.

Today, with the emphasis on runoff reduction and water quality enhancement, stormwater management practices are being revised to promote infiltration, attenuation and water quality enhancement. Properly designed sites with grass swales and other conveyances that provide opportunity for infiltration can serve in place of storm drains and/or allow smaller and less extensive storm drains to be constructed downstream. Disconnecting impervious area through the use of downspout routing to pervious areas, grass buffers and/or porous landscape detention (bioretention) can reduce demands on the downstream conveyance system. These types of practices, often termed “minimizing directly connected impervious areas” or “Low Impact Development” can also improve the quality of stormwater runoff and reduce the amount of dedicated water quality features required.

Although grass swales are compatible with many land uses, such as residential, parks, institutional, and others with relatively low densities, grass swales may not be practical in areas where there are many access points across the planned drainage path. Therefore, storm drains will continue to be an integral part of many drainage systems.

3.0 Design Storms

Both the “minor” and “major” storm events must be considered for properly designing storm drains. In each case, storm drains are to be designed to carry the portion of runoff that cannot be conveyed on the surface, as dictated by the available capacity in streets and swales.

3.1 Minor Event

At a minimum, storm drains are to be designed to convey storm runoff for the minor (5-year) event. Inlets shall be located per the recommendations in Chapter 8 to intercept runoff before street capacities are exceeded. Additional information on storm drain design is provided in the Streets, Inlets and Storm Drains Chapter of the UDFCD Manual.

3.2 Major Event

Under certain conditions, the storm drain system must be designed to convey flows greater than the minor storm runoff, in some cases up to the major (100-year) storm runoff. These conditions include:

- Where the street capacity for the major storm is exceeded.
- Where street crown overtopping would otherwise exceed criteria.
- Where major storm flows can split off in undesirable directions (i.e., flow splits at intersections).

- Where the storm drain system is accepting flow from an upstream storm drain system or branch that is designed for the major storm.
- Where regional storm drains are designed for the major storm.
- Where storm drains must convey undetained flows to a detention pond.
- Situations where surface flow of the major storm event would unduly interfere with use of the property or cause unwarranted damage.

If a storm drain is designed to carry major storm flows, the inlets to the storm drain shall be sized accordingly. The major storm event hydraulic grade line may be allowed to rise above the top of the storm drain pipe and surcharge the system. The ability of the storm drain to convey the major storm event shall be based on its capacity when the hydraulic grade line elevation is at least 1 foot below the flowline of gutter. In no case shall the surcharge create system velocities in excess of the maximum defined in Section 9.1. Additional information on storm drain design is provided in the Streets, Inlets and Storm Drains Chapter of the UDFCD Manual.

4.0 Pipe Material and Size

4.1 Pipe Material

All storm drains located within public rights-of-way, public easements or tracts shall be constructed with reinforced concrete pipe (RCP), Corrugated Metal Pipe (CMP), or High Density Polyethylene Pipe (HDPE, up to 30 inches in diameter). Circular pipe is the most cost-effective option for reinforced concrete, but elliptical pipe or box conduits may be a more appropriate option in areas where available cover is limited or to avoid utility conflicts. Residential driveway culverts may be CMP or HDPE in lieu of RCP.

Alternate pipe materials may be considered with approval prior to submittal of drainage reports for review. Trench details, bedding material, installation specifications, minimum cover or fill height limits, service life and construction testing requirements for alternate pipe materials shall be consistent with those recommended by the manufacturer/supplier or as determined appropriate.

4.2 Minimum Pipe Size

The minimum allowable pipe size for storm drains located within rights-of-way, public easements or tracts shall be 18 inches for laterals and 18 inches for trunk lines that collect flows from laterals or from upstream trunk lines.

4.3 Service Life

The service life for storm drain systems shall be 50 years. An extended service life of 100 years shall be required under these conditions:

- The depth of cover exceeds 15 feet.
- The system is located within the travel lanes of 4-lane or major and minor arterial roadways.
- The centerline of the storm drain pipe is located 15 feet or less horizontally from any building/permanent structure.

4.4 Other Design Considerations

4.4.1 RCP Pipe Class, Fill Height, and Installation Trench

The minimum class of reinforced concrete pipe shall be Class III, however, the depth of cover, live load, and field conditions may require structurally stronger pipe. Trench installation requirements, trench installation details, and allowable fill heights are shown in the City of Colorado Springs Standard Specifications, Sheets D-30, D-31 and D-32. It is the responsibility of the design engineer to develop and submit alternate trench and installation details when project specific conditions or loadings require modification to the standard installation. Alternate designs shall follow ASTM C1479.

4.4.2 Joints

Properly installed tongue-and-groove concrete pipe should have an interior joint gap of no more than 3/8-inch for pipe less than 36-inch diameter installed in a straight run. All storm drains shall have gasketed, water-tight joints. ASTM Standard C 443 covers flexible watertight joints for circular concrete sewer pipe and precast manhole sections, using rubber gaskets for sealing the joints.

4.4.3 Outfalls

Where storm drains discharge into open channels or detention ponds, outlet protection of the bank and overbank or pond bottom shall be provided to prevent erosion due to flows discharged from the storm drain. Erosion protection shall be designed to convey the storm drain design flow assuming that no flow is in the receiving channel or pond. The stability of the outfall protection must also be evaluated based on the flow conditions in the receiving channel. Design guidance for outfall conditions is provided in Chapter 10 of this Manual.

4.4.4 Trash/Safety Racks

Trash racks or grates should be used for safety purposes at any entrance to storm drains that are large enough that a child could become swept into or lodged in the entrance. Even relatively small diameter pipes can pose a risk due to the potential for hydrostatic forces to pin a person against the entrance to the storm drain. In Woodland Park, grates are also installed on many large culvert outfalls because of issues with some members of the public entering culverts. When trash racks are installed on culvert or storm drain outfalls, frequent inspection is recommended due to potential for accumulation of debris against the interior face of the downstream grate.

5.0 Easements

5.1 Easement Conveyance

Storm drains shall normally be installed within public right-of-way, easement or tracts, but when it is necessary to route a system through private property, drainage easements are required in order to ensure the proper construction, access and maintenance of storm drains and related facilities. All easements shall be conveyed by appropriate legal documents such as plats or grant of easements.

5.2 Minimum Easement Widths

Generally, easement widths shall be 2 times the depth to the pipe invert plus the conduit width, rounded up to the nearest 5 feet, but not less than 20 feet. The pipe shall be centered on the easement. When more

than one utility pipe is within the easement, the pipes shall have a minimum separation distance of 10 feet from centerline to centerline of pipe, and no pipe shall be less than 5 feet from the edge of the easement. These minimum widths assume a relatively shallow pipe depth. Deeper pipes are required to be constructed in accordance with OSHA requirements, and appropriate easements are required to allow for construction and potential future repair or replacement. When relatively large diameter pipes are proposed or when design depths are excessive, greater easement widths will be required, as determined by the City Engineer, his/her designated representative or City Utilities Director.

Easements for storm drains should be located to one side of property lines and not centered on the lines. Additional easements necessary to provide access to the storm drain, outlet, and other appurtenances are required if not accessible from a public right-of-way. A minimum easement width of 15 feet shall be provided for access and provisions must also be made for appropriate physical access to the easements, such as for grading and obstructions.

In general, storm drain easements shall be established exclusively for drainage facilities. If agreed to by all parties and where appropriate, such as for non-motorized public access, joint easements may be permitted. The width of joint easements will be determined on a case-by-case basis.

5.3 Allowable Landscaping and Surface Treatment in Easements

Although storm drain systems are designed to have a significant service life, there are circumstances which may require that the storm drain be accessed for inspection, maintenance, repair, and/or replacement. Storm drain easements should be designed to convey above ground flows in the event the storm drain or inlet becomes clogged or full flows exceed the design flow. It is, therefore, necessary to limit uses within the easement to ensure that surface conveyance redundancy and maintenance access is not impaired. Minor landscaping, including rock, shrubs, etc. may be appropriate where it can be demonstrated that the function of the easement is not compromised by the presence of the materials. Pavement over a storm drain easement may be allowable, providing that the property owner accepts responsibility for replacement in the event it is necessary to remove it to access the system. Improvements that are not allowed on storm drain easements include structures of any kind, retaining walls, permanent fencing, trees and others if determined to be a problem and/or costly to replace. Surface treatments on drainage easements shall be shown on the drainage report plan and final development plan.

6.0 Vertical Alignment

6.1 Cover

All storm drains shall be designed so that they will be structurally adequate for both minimum and maximum cover conditions. A minimum cover shall be maintained to withstand AASHTO HS-20 loading on the pipe in traffic areas. The minimum cover to withstand live loading depends upon the pipe size, type and class, and soil bedding condition, but shall be not less than 1 foot to the exterior pipe wall at any point along the pipe. There are numerous factors that ultimately affect the depth of cover over a pipe and in most cases it is likely that the cover will have to be greater than the minimum allowed due to other design factors. Some of the other factors that affect the depth of the pipe are hydraulic grade line elevations, inlet depths, adjacent utilities or utility crossings, including water and sewer services lines along residential streets, and connections to existing storm drain systems. When feasible, locating storm sewers below the frost depth (approximately 7 feet in Woodland Park) will aid with freezing and ice buildup; however, in practice, it is not always practical to have storm drains this deep due to conflicts with other utilities and elevations constraints. The maximum cover over storm drains shall also be considered and evaluated according to manufacturer's specifications. Should a design require a cover

depth of greater than 15 feet, an extended service life installation shall be provided.

6.2 Cover in Roadways

The roadway subgrade, which supports the pavement section is typically plowed (or scarified) to a certain depth, moisture treated and compacted prior to the placement of the sub-base, base course, and surfacing. There are also instances where the subgrade material must be excavated and replaced or treated to a certain depth to mitigate swelling soils. Subgrade treatment is typically required when doing overlays (full depth reclamation of pavement). These efforts can impact the storm drain system if it has not been designed with adequate depth. The design engineer shall use the best information available, including pavement design or soils reports to ensure that storm drain pipes have adequate depth during and after construction, but a minimum cover of 1 foot should be provided below the pavement subgrade.

6.3 Utility Clearance

For all storm drain crossings at utility lines, the appropriate agency shall be contacted to determine the requirements for the crossing. Generally, a minimum vertical clearance of 18 inches is required between a storm drain and a water main or a sanitary sewer, above or below (all clearances are defined as outside-of-pipe to outside-of-pipe). The design engineer shall give careful consideration to the potential impacts to existing utility construction trench and bedding.

6.4 Concrete Cut-off Walls and Anchoring

Where the storm drain pipe trench is susceptible to erosion, reinforced cast-in-place concrete cut-off walls shall be installed at no greater than 30 foot horizontal intervals. In addition, where storm drain pipe is installed in a slope of 3:1 or steeper, anchoring shall be provided at intervals no greater than 30 feet. The Applicant should consult with the City Engineer to determine the need for and spacing of cut-off walls based on the specific project characteristics including soil erodibility, slope and other factors.

7.0 Horizontal Alignment

7.1 Alignment

In general, storm drain alignments between drainage structures (inlets or manholes) shall be straight. The angle of confluence where pipe lines intersect shall be 90 degrees or less and where a lateral pipe of 36 inches or greater intersects a trunk line, the angle of confluence shall be 60 degrees or less. Manhole covers shall not be closer than one foot to the edge of the gutter pan.

7.2 Stationing

Storm drain system stationing shall increase from the downstream limit of the system to the upstream limit with the intersection of the alignment with the receiving system being the beginning point. Lateral pipes and inlets shall be stationed from the intersection with the alignment of the trunk line they are connected to. When a storm drain runs parallel to a roadway stationing, the roadway stationing may be used; however, pipe slope calculations must be based on the actual distances along the pipe line alignment. Vertical stationing and horizontal stationing must be the same for the same location in the system.

8.0 Manholes

8.1 Required Locations

Manholes or inlets are required whenever there is a change in size, direction, material type, or grade of a storm drain pipe to provide a hydraulic transition and maintenance and inspection access. A manhole shall also be constructed when there is a junction of two or more sewer pipes. The maximum spacing between manholes for various pipe sizes shall be as presented in Table 9-1.

Table 9-1. Maximum Manhole Spacing

Pipe Diameter	Maximum Distance Between Manholes
18 inch to 30 inch	400 feet
36 inch to 60 inch	500 feet
> 60	750 feet

8.2 Manhole Types

The required manhole type and size is dependent on the diameter of the largest pipe entering or exiting the manhole, and the horizontal and vertical alignments of all pipes entering or exiting the manhole. The appropriate manhole type shall be selected according to the guidance provided below.

There must be a minimum of 12-inches clearance from the outside of pipes adjacent to each other and pipes shall not enter or exit a manhole through the corner of a manhole structure. This 12-inch dimension must be measured on the inside wall of the manhole. It is the responsibility of the design engineer to determine the appropriate manhole type and required manhole size to achieve adequate space between the pipes entering or exiting the manhole structure. In those cases where modifications to standard manhole construction details are required, or where special junction structure designs are required, additional construction details must be developed and included in the construction drawing set.

Inlets may be used as junction structures in place of manholes to connect adjacent inlets if the interconnecting pipe can be fit within the standard inlet dimensions without modification to the inlet and if the additional flow can be passed through the structure in accordance with standard hydraulic criteria. Inlets may not be used as junctions along trunk lines.

1. **Type I Box Base Manhole.** This type of manhole is a cast-in-place concrete structure. It is appropriate to use this manhole for pipe diameters larger than 30-inch and with no change in the horizontal alignment. The typical dimensions shall be adjusted by the design engineer to accommodate specific project conditions. The Box Base Manhole shall be constructed per City of Colorado Springs Storm Sewer Manhole, Type I Standard Detail D-20A.
2. **Type II Circular Base Manhole.** This type of manhole is constructed from a cast-in-place base with precast riser sections. The Circular Base Manhole shall be constructed per City of Colorado Springs Storm Drain Manhole, Type II Standard Detail D-20B. Table 9-2 shows minimum manhole sizes, based on the diameter of the storm drain pipe.

Table 9-2. Minimum Manhole Sizes

Pipe Diameter (inches)	Manhole Diameter (feet)
18"	4'
21" - 42"	5'
48" - 54"	6'

The minimum manhole sizes shown for standard pipe sizes assume no change in alignment through the manholes, but in many cases the manhole diameter will need to be increased to account for changes in pipe alignment or multiple incoming pipes. Manhole bases shall be shaped to match the pipe section below the pipe springline. This shaping significantly reduces manhole losses. The appropriate loss coefficient can be determined using the UDFCD Manual for full shaping. The standard details in the UDFCD Manual provide guidance for shaping in the slab base.

3. **Type III Manhole.** This type of manhole is constructed using a modified pipe section as the base with precast riser sections. This manhole is appropriate for 48-inch pipe and larger, when there is no change in pipe size, material, alignment or slope. The Type III Manhole shall be constructed per City of Colorado Springs Storm Drain Manhole, Type III Standard Detail D-20C.
4. **Special Junction Structures.** Special junction structures may have to be designed when pipe sizes and alignment changes exceed those that can be accommodated by standard manhole types. Complete design and construction information must be provided to show conformance with all design standards and to provide sufficient detail for construction. Special junction structures must provide similar hydraulic benefits, structural characteristics and access features as the standard manhole types.
5. **Precast Structures.** Precast structures may be substituted for the standard manhole types and may serve as a special junction structure if they have prior approval and substantially conform to the standard dimensions and configuration of the approved types and conform to all design standards. Complete design and construction information must be provided to show conformance with all design standards and to provide sufficient detail for construction.

8.3 Steps and Platforms

Steps are required in all manholes exceeding 3.5 feet in height and shall be in accordance with AASHTO M 199. The Occupational Health and Safety Administration has specific standards for fixed ladders used to ascend heights exceeding 20 feet. Cages and/or landing platforms may be required to satisfy these requirements in excessively deep manhole structures. It is the design engineer's responsibility to ensure that the appropriate measures are designed and construction details are developed and included in the construction drawings, as needed to comply with the Occupational Health and Safety Administration standards. When landing platforms are proposed, consideration shall be given to the potential maintenance and inspection activities and the expected loadings on the platforms.

8.4 Drop Manholes

The drop within a manhole from the upstream to downstream pipe invert should normally not exceed 1 foot. There are cases when a drop larger than 1 foot may be necessary to avoid a utility conflict, reduce

the slope of the downstream pipe, or to account for the energy losses in the manhole. Drops that exceed 1 foot will be evaluated on a case-by-case basis, and additional analysis may be required.

8.5 Other Design Considerations

The following design criteria shall also be met:

- Pipes shall not decrease in diameter from upstream to downstream.
- The invert of a manhole shall be constructed with a drop between the upstream and downstream pipes. The drop shall be 0.2 feet on straight-through alignments, and 0.3 feet for lateral pipes of the same diameter. When different diameter pipes are used, crowns shall be matched.
- All manhole tops shall be eccentric to provide safe access by alignment with manhole steps and with benches in manhole bases.
- It is critical that gutter pans, curb heads, and any other problematic locations be avoided when determining the horizontal placement of manholes.

9.0 Hydraulic Design

Once the alignment of the storm drain system is determined, the peak flows in the system must be calculated followed by a hydraulic analysis to evaluate system characteristics and determine pipe capacity and size. The pipe size shall not decrease moving downstream (even if the capacity is available due to increased slope, etc.) in order to reduce clogging potential.

9.1 Allowable Velocity and Slope

The allowable storm drain velocity is dependent on many factors, including the type of pipe, the acceptable water level during the pipe design life, proposed flow conditions (open channel versus pressure flows), and the type and quality of construction of joints, manholes, and junctions.

1. **Maximum Velocity.** In consideration of the above factors, the maximum velocity in all storm drains shall be limited to 18 feet per second (feet/sec) for all design flows.
2. **Minimum Velocity.** The need to maintain a self-cleaning storm drain system is recognized as a goal to minimize the costs for maintenance of storm drain facilities. Sediment deposits, once established, are generally difficult to remove even with pressure cleaning equipment. Maintaining minimum velocities for frequently occurring flows will reduce the potential for sediment and debris accumulation. Storm drains should be designed with a minimum velocity of 2 feet/sec for a flow equal to 25 percent of the minor storm flow rate.
3. **Minimum Slope.** In general, the minimum allowable pipe slopes ensure that the minimum velocity is achieved, in those cases where the pipe is designed to flow near full. The minimum allowable longitudinal slope shall be 0.01 ft/ft (1.00 percent) for pipes smaller than 30 inches in diameter.

9.2 Minor Storm Event Hydraulic Evaluation

In the minor storm event, inlets are placed along the roadway where the flow in the roadway exceeds the minor event capacity of the street as defined in Chapter 7, Street Drainage. These inlets intercept flow, as

determined by the procedures in Chapter 8, Inlets, and convey it to a storm drain which must be sized to convey the intercepted flow.

The storm drain system shall be designed to convey the minor design storm without surcharging so that the design flow depth in the pipe is no greater than 80 percent of the pipe height. For the minor storm event, a storm drain is not flowing full, therefore the sewer acts like an open channel and the hydraulic properties can be calculated using Manning's Equation. Hydraulic grade line calculations must be performed to account for energy losses and to ensure that the system is not surcharged during the minor storm event. There may be some special cases where the proposed storm drain pipe is connected to an existing storm pipe (or a detention pond). If this existing pipe is surcharged, then the proposed system will receive backwater from the downstream pipe. In this situation, the minor event hydraulic grade line must be calculated to determine the impacts on the hydraulic grade line through the upstream portions of the system. Where the storm drain outfalls into a detention pond or channel, the tailwater condition will be determined based on the hydraulic grade elevation for the minor design storm event occurring in the receiving facility.

9.3 Major Storm Event Hydraulic Evaluation

The storm drain system layout determined for the minor event analysis must also be evaluated for the major storm event. If necessary, larger or additional inlets must be placed along the roadway when the flow in the roadway exceeds the major storm event capacity of the street as defined in Chapter 7, Street Drainage. The interception rates for all of the inlets shall then be calculated for the major storm event, based on the procedures in Chapter 8 Inlets, and the minor storm pipe sizes must be adjusted to convey the additional flows.

In the major storm event, it is acceptable to have a surcharge in the system. Manning's equation is not applicable for pipes under pressurized flow conditions. For pressurized flow conditions, use the Bernoulli equation (Darcy-Weisbach Friction Loss) or the Hazen-Williams equation. There may be cases where the major storm event does not result in a surcharge of the system. In these pipes, the capacity can be calculated using Manning's equation.

Hydraulic grade line (HGL) and energy grade line (EGL) calculations for the storm drain system shall be provided for the major storm event. For the major event, the hydraulic grade line should be at least 1 foot below the flowline of the gutter. Additional information on calculation of the HGL and EGL including loss coefficients through a storm drain system (at bends, junctions, transitions, entrances, and exits) can be found in the UDFCD Manual. The computed HGL shall be plotted on the construction drawings for each design flow, and the design flow and design frequency shall be noted on the drawing. In addition, the computed EGL for the major design flow shall be shown. Where the storm drain outfalls into a detention pond or channel, the tailwater condition will be determined based on the hydraulic grade elevation for the major design storm event occurring in the receiving facility.

9.4 Hydraulic Calculations

To show that a proposed design conforms to the design criteria described herein, appropriate hydraulic calculations must be completed and provided in an organized form. The methods and parameters described in the UDFCD Manual for analyzing storm drains are tools that may be applied. The City Engineer may approve alternative methods that produce similar, reasonable results to the UDFCD methods.

It is recommended that a computer program be used for the design or as a calculation "check" of a storm drain system. Computer programs such as StormCAD, EPA SWMM, HydroCAD, StormCAD, and

others may be used, if program documentation can be provided to show that the methodology and parameters applied in the program are similar to those recommended in the UDFCD Manual. See the UDFCD Manual for guidance on EPA SWMM and UDFCD methods for analyzing storm drains. In addition to description of the methods used to evaluate the hydraulic design of the storm drain system, adequate documentation of the system characteristics and configuration must be provided in both a detailed and summary format. The summary information for the entire system must show the parameters, coefficients and results for each system element in a tabular format. Documentation must include all input parameters including design flows by location, elevations, sizes, junction losses, coefficients, pipe roughness, alignment deflections, and other relevant information. Documentation must also show the results of the calculations including velocity by location, flow depth, Froude Number, HGL and EGL elevations (profiles), pipe capacities, and other information necessary to confirm that design criteria have been satisfied.

Chapter 10

Conduit Outlet Structures

Contents

1.0	Introduction	1
2.0	General Design.....	1
2.1	Inlet and Outlet Configuration	1
2.2	Safety Rails	1
2.3	Flared End Sections.....	1
2.4	Transition to Drainageways	1
3.0	Outlet Erosion Protection.....	2
3.1	Types of Erosion Protection	2
3.2	Selecting Type of Erosion Protection.....	2
4.0	Design of Outlet Erosion Protection	3
4.1	Riprap Lining	3
4.2	Low Tailwater Stilling Basins	4
4.3	Concrete Impact Stilling Basin	4
4.4	Concrete Baffle Chute	4

Tables

Table 10-1. Erosion Protection at Conduit Outlets	3
---	---

Figures

Figure 10-1. Conceptual Toewall Detail	5
--	---

1.0 Introduction

This chapter addresses the design of culvert outlets, which are typically oriented in-line with the flow in a drainageway, and storm drain outlets, which are typically oriented perpendicular to the flow in a drainage channel or detention facility. This chapter contains references to the UDFCD Manual for design procedures applying to both of these outlet types. Outlets into forebay sedimentation traps of water quality basins are discussed in Volume 3 of the UDFCD Manual.

Conduit outlet structures are necessary to dissipate energy at culvert and storm drain outlets and to provide a transition from the conduit to an open channel. A conduit outlet structure consists of an end section or headwall and wingwalls, safety rails (if required), and a riprap or concrete structure to dissipate flow energy at the exit of the conduit.

Occasionally, other hydraulic controls are located at culvert outlets. These hydraulic controls can include drop structures, which are discussed in Chapter 12, Open Channels.

2.0 General Design

2.1 Inlet and Outlet Configuration

All conduits 54 inches in diameter and larger shall be designed with headwalls and wingwalls. Conduits 48 inches in diameter and smaller may use headwalls and wingwalls or flared end sections at the inlet and outlet. Detailed grading plans showing proposed contours, spot elevations, and outlet erosion protection measures shall be included in the construction drawings at all conduit inlets and outlets.

2.2 Safety Rails

Conduit headwalls and wingwalls shall be provided with guardrails, handrails, or fencing in conformance with local building codes and roadway design safety requirements. Handrails shall be required in areas frequented by pedestrians or bicycles. The height of the handrail shall be 42 inches for pedestrian walkways or open areas and 54 inches for bicycle traffic. Acceptable materials include, but are not limited to, galvanized or painted steel, aluminum, and chain link fence.

2.3 Flared End Sections

Flared end sections shall not protrude from the embankment. Flared end sections require joint fasteners and toe walls at the outlet. Toe walls shall extend from the top of the vertical portion at the end of the flared end section to at least 3 feet below the invert. See Figure 10-1 for an acceptable toe wall configuration.

A minimum of three joints, including the joint connecting the last pipe segment to the flared end section, shall be mechanically locked with joint fasteners. Joint fasteners shall be constructed consistent with the details provided in CDOT Standard Plan No. M-603-10.

2.4 Transition to Drainageways

Storm sewer outlets shall be set with their inverts 1 to 2 feet (2 feet for wetland channels) above the natural channel bottom and provided with appropriate erosion protection measures. The drop is to reduce backwater effects in the storm sewer due to sedimentation. When a storm sewer outfalls into a channel with an overbank between the bank toe of the main channel and the low-flow channel, outlet protection

shall be extended to the invert of the low-flow channel using the design flow for the storm sewer. However, protection extended into the main channel of the receiving channel must be evaluated for stability during the major storm event in the main channel.

In general, in-line culvert inlet and outlet elevations should match drainageway invert elevations upstream and downstream. Outlets shall be provided with erosion protection measures as discussed later in this chapter.

If the existing drainageway has experienced degradation and the channel is incised, channel restoration improvements may raise the channel bottom back up to its former elevation. The design engineer shall determine the appropriate outlet elevations considering, at a minimum, the condition and stability of the existing channel and any potential stabilization or grade control improvements that would change the longitudinal grade or elevations along the channel. To ensure that outlets and energy dissipation improvements function properly, inlet and outlet elevations shall be set based on field survey information, rather than topographic mapping generated from aerial photography.

3.0 Outlet Erosion Protection

3.1 Types of Erosion Protection

Erosion protection in the form of riprap or concrete basins is required at the outlet of conduits to control scour. Erosion protection shall be designed for conduit outlets in accordance with Table 10-1. These are general guidelines only and are intended to supplement the UDFCD Manual. Other outlet erosion protection options, including many specialized types of concrete outlet structures, are available and may be used if approved on a case-by-case basis. These types of structures are listed in the Hydraulic Structures Chapter of the UDFCD Manual.

3.2 Selecting Type of Erosion Protection

Riprap protection downstream of culverts is considered for most situations where moderate outlet hydraulics govern (i.e., culvert exit velocities < 15 ft/sec). It is highly recommended that the designer use a low tailwater basin when a storm drain enters a drainageway at an approximate right angle, and drop structures or riprap lining should be used to guard against erosion for in-line culvert outlets on major drainageways.

In general, concrete structures are large, uncharacteristic of the natural environment, and require special safety and maintenance considerations. Concrete structures will not be approved in areas that are intended to complement the natural environment when other alternatives are feasible. Cases where a concrete stilling basin structure may be considered include situations where exit velocities are extremely high, turbulence at a conduit outlet is expected to be severe, and/or where space is particularly limited.

Table 10-1. Erosion Protection at Conduit Outlets

Erosion Protection Types	UDFCD Manual Chapter	Use For	Do Not Use For
1. Riprap Lining (Section 4.1)	Major Drainage	- Receiving channel on same line and grade - Storm sewer and culvert outlets - In-line culvert outlets - Velocities < 15 ft/sec - High tailwater - Fish passage	- Velocities > 15 ft/sec - Wetland channels
2. Low Tailwater Stilling Basin (Section 4.2)	Hydraulic Structures	- Storm sewer and culvert outlets - Velocities < 15 ft/sec - Low tailwater	- Velocities > 15 ft/sec - Confined receiving area - Major drainageways - Areas where standing water is unacceptable
3. Concrete Impact Stilling Basin (Section 4.3)	Hydraulic Structures	- Storm sewer outlets - Velocities > 15 ft/sec - Low tailwater	- In-line culvert outlets - High visibility areas
4. Concrete Baffle Chute (Section 4.4)	Hydraulic Structures	- Storm sewer outlets - Velocities > 15 ft/sec - Low tailwater - Degrading channel	- In-line culvert outlets - High debris potential - High visibility areas
5. Drop Structures	Hydraulic Structures	- Wetland channels - Low rise box culverts or small diameter pipes where plugging is possible - In-line culvert outlets	- Confined receiving area - Fish passage

4.0 Design of Outlet Erosion Protection

4.1 Riprap Lining

The procedure for designing riprap for culvert outlet erosion protection is provided in the Major Drainage Chapter of the UDFCD Manual. The riprap protection is suggested for outlet Froude numbers up to 2.5 where the outlet of the conduit slope is parallel with the channel gradient and the conduit outlet invert is flush with the riprap channel protection. An additional thickness of riprap just downstream from the outlet is required to assure protection from extreme flow conditions that might cause rock movement in this region. Protection is required under the conduit barrel and an end slope is necessary to accommodate degradation of the downstream channel.

4.2 Low Tailwater Stilling Basins

The majority of storm sewer pipes discharge into open drainageways, where the receiving channel may have little or no flow when the conduit is discharging. Uncontrolled pipe velocities have the potential to create erosion problems downstream of the outlet and in the channel. By providing a low tailwater basin at the end of a storm sewer conduit or culvert, the kinetic energy of the discharge is dissipated under controlled conditions, minimizing scour at the channel bottom.

Low tailwater is defined as being equal to or less than one-third of the storm sewer diameter/height and is based on the depth of flow in the receiving channel during the minor design storm event. Design criteria for low tailwater riprap basins for circular and rectangular pipe are provided in the Hydraulic Structures Chapter of the UDFCD Manual.

4.3 Concrete Impact Stilling Basin

The use of concrete impact stilling basins is discouraged where moderate outlet conditions exist, but there are situations when the design engineer may have to consider using an impact stilling basin. Those situations are generally discussed in the Hydraulic Structures Chapter of the UDFCD Manual. Impact stilling basins shall be designed in accordance with the Hydraulic Structures Chapter of the UDFCD Manual.

Design standards for an impact stilling basin are based on the United States Bureau of Reclamation (USBR) Type VI basin, a relatively small structure that produces highly efficient energy dissipation characteristics without tailwater control. Energy dissipation is accomplished through the turbulence created by loss of momentum as flow entering the basin impacts a large overhanging baffle. Additional dissipation is produced as water builds up behind the baffle to form a highly turbulent backwater zone. Flow is then redirected under the baffle to the open basin and out to the receiving channel. A check at the basin end reduces exit velocities by breaking up the flow across the basin floor and improves the stilling action at low to moderate flow rates.

Generally, the configuration consists of an open concrete box attached directly to the conduit outlet. The Hydraulic Structures Chapter of the UDFCD Manual provides a figure illustrating the general design for the impact stilling basin.

The standard USBR design above will retain a standing pool of water in the basin bottom that is generally undesirable from an environmental and maintenance standpoint. The Hydraulic Structures Chapter of Volume 2 of the UDFCD Manual modifies the standard USBR design to allow drainage of the basin bottom during dry periods. These modifications are shown in figures providing examples of the modified end wall design to allow basin drainage for urban applications and providing details of a “mini” impact basin that can be used for small pipe diameters from 18 inches to 36 inches.

4.4 Concrete Baffle Chute

The use of concrete baffle chutes is discouraged where moderate outlet conditions exist, but there are situations when the design engineer may have to consider using a concrete baffle chute. Those situations are generally discussed in the Hydraulic Structures Chapter of the UDFCD Manual.

A concrete baffle chute is normally used in situations where there is a very large conduit outfall, future channel degradation is expected, and there is a drop in grade between the culvert outlet and the channel invert. The original design (USBR Type IX baffled apron) has been modified slightly by UDFCD so it can be used with a conduit instead of an open channel. The Hydraulic Structures Chapter of the UDFCD

Manual provides some design and construction details for this type of basin, along with a figure providing an example of the general design for the baffle chute pipe outlet. Although this outlet dissipates energy along the slope, scour holes can form at the base of the structure. These scour holes can undermine adjacent banks, particularly where development encroaches close to the channel. The designer shall provide riprap erosion protection along the downstream channel where a scour hole is undesirable.

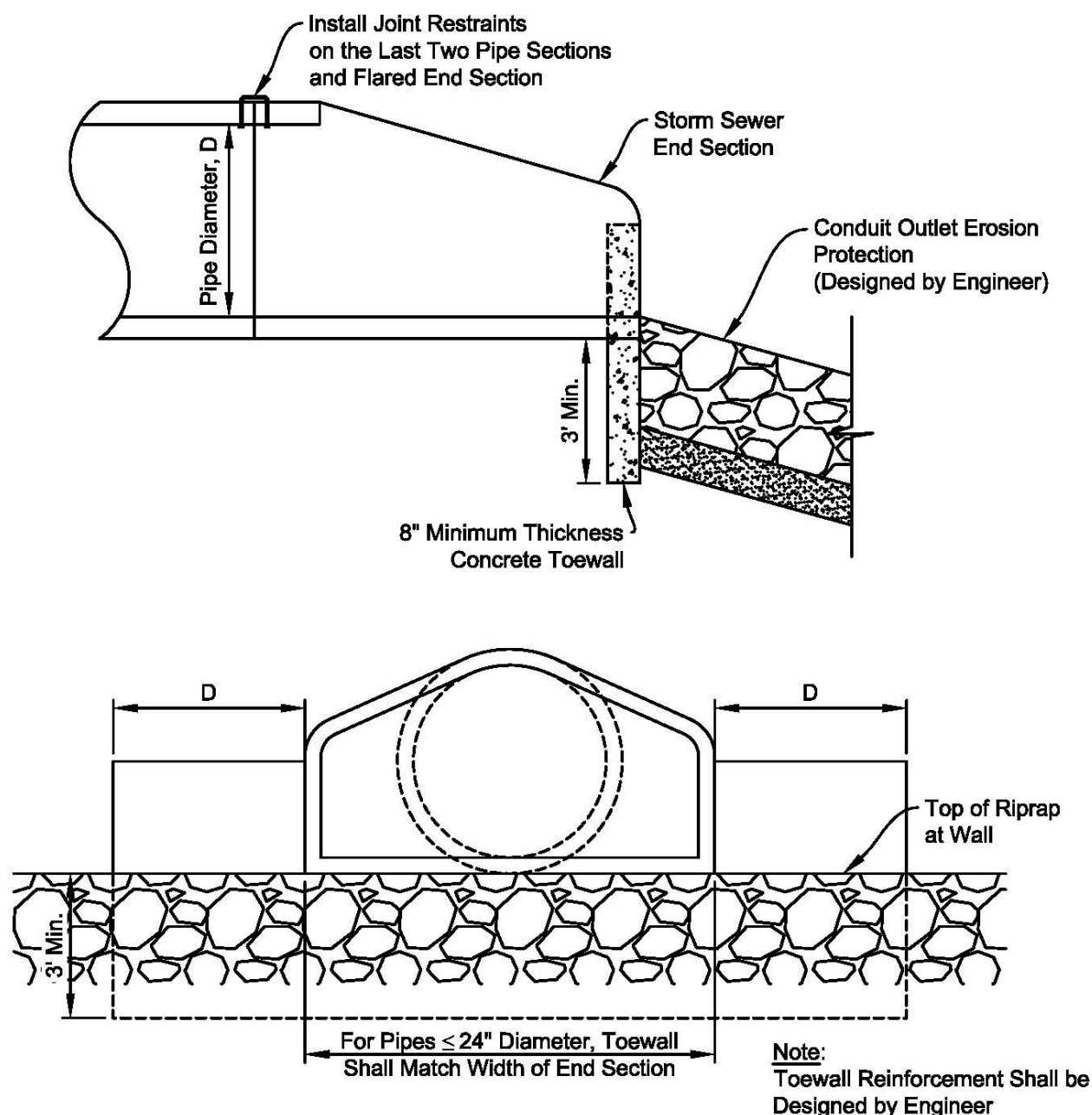


Figure 10-1. Conceptual Toewall Detail

Chapter 11

Culverts and Bridges

Contents

1.0	Introduction	1
2.0	General Design.....	1
2.1	Design Criteria	1
2.2	Design Flows.....	1
2.3	Permitting and Regulations	1
2.4	Aesthetics and Safety	2
2.5	Easement, Ownership and Maintenance Requirements	2
2.6	Trail Coordination.....	2
2.7	Utility Coordination	2
2.8	Channel Stability.....	2
3.0	Culvert and Bridge Sizing	3
3.1	Culvert and Bridge Sizing Factors	3
3.2	Sizing Procedure for Streets When Overtopping is Allowed	3
3.3	Allowable Headwater.....	4
3.4	Freeboard Requirements	4
4.0	Culvert Design	4
4.1	Construction Material.....	4
4.2	Minimum Size	4
4.3	Culvert Sizing and Design.....	4
4.4	Capacity Curves	5
4.5	Design Forms	5
4.6	Design Software	5
4.7	Velocity Considerations	5
4.8	Structural Design.....	5
4.9	Alignment.....	6
4.10	Stationing	6
4.11	Minimum Cover	6
4.12	Multiple-Barrel Culverts	6
4.13	Trash Racks.....	6
4.14	Inlets and Outlets.....	7
4.15	Debris.....	7
4.16	Service Life	7
5.0	Driveway Culverts.....	7
5.1	Applicable Criteria	7
5.2	Construction Material.....	7
5.3	Sizing	7
5.4	Minimum Cover	8
5.5	Culvert End Treatments	8
5.6	Design Velocity.....	8
5.7	Drainage Report and Construction Drawings.....	8
6.0	Bridge Hydraulic Design	8

7.0 Low-Water Crossings/Pedestrian Bridges.....9

Tables

Table 11-1. Allowable Culvert Overtopping for Minor Drainageways	3
--	---

Figures

Figure 11-1. Roadside Ditch Modification for Driveway Culverts.....	10
---	----

1.0 Introduction

This chapter addresses design criteria for culverts and bridges as they relate to drainageways. Generally, a culvert is a conduit for the passage of surface drainage water under a roadway, railroad, canal, or other embankment; a bridge is a structure carrying a pathway, roadway, or railway over a waterway.

2.0 General Design

2.1 Design Criteria

The procedures and basic data to be used for the design and hydraulic evaluation of culverts shall be consistent with the Culverts Chapter of the UDFCD Manual, except as modified herein. The designer is also referred to the many texts covering the subject for additional information, including *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5* (FHWA 2012).

Bridges are typically designed to cross the waterway with minimal disturbance to the flow. However, for practical and economic reasons, abutment encroachments and piers are often located within the waterway. Consequently, the bridge structure can cause adverse hydraulic effects and scour potential that must be evaluated and addressed as part of each design. The design of a bridge is very specific to site conditions and numerous factors must be considered.

There are many acceptable manuals that are available and should be used in bridge hydraulic studies and river stability analysis. The Major Drainage and Hydraulic Structures Chapters of the UDFCD Manual shall be consulted for basic criteria and information regarding other publications and resources. Additional references include the *CDOT Drainage Design Manual (CDOT 2004)* and FHWA publications including *Highways in the River Environment (FHWA 1990)*, *Evaluating Scour at Bridges (FHWA 2001)*, *Design of Encroachments on Flood Plains Using Risk Analysis (FHWA 1981)*, and *FHWA Stream Stability at Highway Structures (FHWA 2001)*.

2.2 Design Flows

Culverts and bridges shall be designed for future fully developed basin conditions consistent with approved drainage plans as outlined in the Hydrology Chapter. Specific requirements for culverts and bridges are contained in their respective sections and may vary depending on the classification of the roadway being crossed.

2.3 Permitting and Regulations

Designers of stream crossings must be cognizant of relevant local, state, and federal laws and permit requirements. Permits for construction activities in navigable waters are under the jurisdiction of the U.S. Army Corps of Engineers (USACE). For example, a USACE Section 404 permit is required for the discharge of dredged or fill material in waters of the U.S. Applications for federal permits may require environmental impact assessments under the National Environmental Policy Act of 1969. In Colorado, provisions of Senate Bill 40, which requires a Wildlife Certification, must be addressed on any stream crossing. Additionally, a Floodplain Development Permit is required for any stream crossing constructed in a regulatory floodplain, and FEMA CLOMR/LOMR requirements may apply, especially if work in the regulatory floodway is necessary. Refer to Chapter 5, Floodplain Management, for information regarding construction of improvements in floodplains.

2.4 Aesthetics and Safety

The appearance and safety of structures, including headwalls and wingwalls, are important considerations for acceptance of the design. The safety of the public, especially in areas of recreational use, shall also be considered when selecting the appropriate structure and handrail treatment for a given area. Structure geometry, materials, and the texture, patterning, and color of structure surfaces shall be selected to blend with the adjacent landscape and provide an attractive appearance.

2.5 Easement, Ownership and Maintenance Requirements

Culverts and bridges must be constructed within the public right-of-way for the roadway or within a combination of easements, tracts, and public right-of-way. Additional easement or right-of-way beyond the normal roadway right-of-way, tracts, or easement width may be required to facilitate the construction, operation and/or maintenance of the structure. Design plans for the structure shall include the proposed easement and/or right-of-way limits. Maintenance issues and access shall be considered in the structure design, and appropriate measures must be included to facilitate proper maintenance (e.g., access road if necessary).

2.6 Trail Coordination

Culverts and bridges often provide an opportunity for trails to cross roadways with a grade separation, avoiding conflicts between pedestrians and vehicles. Advance coordination with parks and trails personnel is necessary to determine if the proposed culvert or bridge location has been identified as a potential location for a separated grade trail crossing. If the location is determined to be compatible with a grade-separated trail from a planning standpoint and the crossing is physically possible, final design requirements for trail width, vertical clearance, surfacing, and lighting and safety improvements shall be coordinated with the parks and trails personnel. The low-flow channel adjacent to the trail bench shall pass the minor storm event or as much flow as practicable without inundating the trail, considering the duration of the flooding, inconvenience to the public, and available alternate routes. The low-flow channel adjacent to the trail shall convey flow at least equal to the capacity of the upstream low-flow channel when one is present. Connections of the trail to the roadway grade must be considered.

2.7 Utility Coordination

Utilities often run parallel to roadways and cross culverts or are located near culvert inlets and outlets. Advance coordination with the appropriate utility representatives is critical to avoid conflicts, provide adequate access, and protect them from damage.

2.8 Channel Stability

Drainage channels crossed by culverts and bridges must be stable for these structures to function as intended and remain structurally sound. The stability of the adjacent channel must be evaluated and addressed so that culverts and bridges are not threatened by channel degradation, sedimentation or migration. Guidance for stable channel design is provided in Chapter 12, Open Channels.

3.0 Culvert and Bridge Sizing

3.1 Culvert and Bridge Sizing Factors

The sizing of a culvert or bridge depends on several factors including whether the drainageway is major or minor, the street designation (i.e., residential, industrial, collector, arterial, or highway), the allowable street overtopping, and the allowable headwater depth. Overtopping is not allowed for any street designation at major drainageway crossings. Additionally, all new bridge structures must be designed to safely handle the major storm flows with the required freeboard.

For minor drainageways with culvert crossings, the allowable street overtopping for the various street designations is identified in Table 11-1.

Table 11-1. Allowable Culvert Overtopping for Minor Drainageways

Roadway Designation	Minor Storm	Major Storm
Residential, Industrial and Collector	No overtopping allowed	Must not exceed 12 inches at gutter flowline or 4 inches at crown ¹
Arterial	No overtopping allowed	No overtopping allowed
Freeway/Expressway	No overtopping allowed	No overtopping allowed

Note: No overtopping allowed for major drainageways.

¹ See Street Drainage Chapter, for further discussion regarding allowable flow depth in the street based on roadway designation.

When overtopping flows are allowed, adequate roadway embankment erosion protections measures should be provided to protect the roadway from erosion and potential embankment failure problems. Potential for overtopping and piping failures should be considered.

The criteria in this Manual are considered the minimum design standards and may need to be modified where other factors are considered more important. For example, the designer shall consider flooding of adjacent structures or private property, excessive channel velocities, availability of alternate routes, and other factors pertinent to a specific site. Lesser design criteria for rural areas or low-volume roadways may be approved on a case-by-case basis. Any variance from the design criteria outlined in this chapter will require prior approval.

3.2 Sizing Procedure for Streets When Overtopping is Allowed

When overtopping is allowed for residential, industrial, and collector streets, the following sizing procedure shall be followed:

1. Using the future developed condition major storm flow, the allowable flow over the street shall be determined based on the allowable overtopping depth and the roadway profile, treating the street crossing as a broad-crested weir.
2. The culvert is then sized for the difference between the major storm flow and the allowable flow over the street, using the allowable overtopping elevation as the maximum headwater elevation.

3. The culvert is then sized for the fully developed condition minor storm flow based on applicable design criteria.
4. The design culvert size shall be the larger of the two sizes.

3.3 Allowable Headwater

For all residential, industrial, and collector roadways, the maximum headwater to depth ratio for the major storm design flows will be 1.5 times the culvert opening height. For culverts through arterial roads and highways, the maximum headwater to depth ratio for the major storm design flows will be 1.2 times the culvert opening height. Headwater depth is typically measured from the centerline of the culvert rather than the invert.

3.4 Freeboard Requirements

No overtopping of roadways and bridges shall be allowed at major drainageway crossings for the major storm event. For culvert crossing structures, the minimum freeboard shall be 2 feet, measured from the major stormwater surface elevation to the lowest point of the roadway profile. The minimum required clearance for bridges shall be 2 feet, measured from the major stormwater surface elevation to the lowest elevation of the bridge low chord. However, the design engineer shall consider the profile grade of the bridge and roadway, potential for debris accumulation, predicted sedimentation, maintenance requirements, and other site-specific conditions to determine whether additional freeboard should be provided for the crossing structures.

4.0 Culvert Design

4.1 Construction Material

Culverts shall be made of reinforced concrete in round or elliptical cross-sections (minimum Class 3) or reinforced concrete box shapes that are either cast-in-place or supplied in precast sections. Other materials may be allowed if design criteria and service life requirements can be satisfied. Special design considerations, such as bedding requirements, shall also be considered if an alternate material is used. When the culvert is expected to carry a large, persistent load of abrasive material (e.g., gravel or cobble bedload), a special design is required to protect the full invert area (lower 90 degrees).

4.2 Minimum Size

The minimum pipe size for a cross culvert within a public right-of-way shall be 18 inches in diameter for round culverts, or shall have an equivalent cross-sectional area for arch or elliptical shapes. Box culverts shall be as tall as practical, but shall not have less than a 3-foot-high inside dimension.

4.3 Culvert Sizing and Design

Culvert design involves an iterative approach. Two references are particularly helpful in the design of culverts. The Culverts Chapter of the UDFCD Manual provides design aids and guidance taken from *Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts* (FHWA 2012). The FHWA circular explains inlet and outlet control and the procedure for designing culverts.

4.4 Capacity Curves

There are many charts, tables, and curves in the literature for the computation of culvert hydraulic capacity. To assist in the review of the culvert design computations and to obtain uniformity of analysis, the Capacity Charts and Nomographs provided in the Culverts Chapter of the UDFCD Manual shall be used for determining culvert capacity.

Selection of the appropriate entrance coefficients shall be based on the information presented in the Culverts Chapter of the UDFCD Manual or in *Hydraulic Design of Highway Culverts* (FHWA 2012). When non-standard design elements are utilized, the designer should refer to *Hydraulic Design of Highway Culverts* (FHWA 2012) for information on treating special cases.

4.5 Design Forms

Standard Form CU-8 in the Culverts Chapter of the UDFCD Manual or other versions of this form shall be used to present and document the culvert design process when spreadsheets or computer programs are not used for culvert sizing and design. Form CU-8 or the equivalent must be included in the drainage report when used to document the culvert design.

4.6 Design Software

UDFCD has prepared a spreadsheet to aid with the calculations for the more common culvert designs. The spreadsheet applications utilize the FHWA nomographs. FHWA's HY-8 Culvert Analysis program is another computer application used to design culverts (FHWA 2011). Other computer programs or software, which are based on the methodologies presented in *Hydraulic Design of Highway Culverts* (FHWA 2012) may also be used for culvert design. The UD-Culvert Spreadsheet and the FHWA's HY-8 Culvert Analysis programs are available on the UDFCD website www.udfcd.org.

4.7 Velocity Considerations

In the design of culverts, both the minimum and maximum velocities must be considered. A minimum flow velocity of 3 feet per second (ft/sec) is required when the culvert conveys runoff from frequently occurring storm events to reduce the potential for sediment accumulation and reduce maintenance requirements. A flow equal to 25 percent of the minor storm event flow shall be used to check the minimum velocity. The culvert slope must be equal to or greater than the slope required to achieve the minimum velocity. The slope should be checked for each design, and if the proper minimum velocity is not achieved, the pipe diameter may be decreased, the slope steepened, a smoother pipe used, or a combination of these may be used.

When a large culvert size is required to pass the major storm event, it may be necessary to route the minor storm event in a separate structure or in a portion of the larger culvert to maintain minimum velocities. Also, when the channel conveying flows to the culvert has a low-flow channel within its cross section, the design flow of the low-flow channel shall be passed through the culvert while maintaining the minimum velocity.

The velocity in a culvert during the major storm event shall not exceed 15 ft/sec.

4.8 Structural Design

As a minimum, all culverts shall be designed to withstand an HS-20 loading in accordance with the design procedures in *Standard Specifications for Highway Bridges, 17th Edition* (AASHTO 2002, updated

2005) and with the pipe manufacturer's recommendation and anticipated static and dynamic loadings. It is the engineer's responsibility to determine if a culvert installation needs to be designed to withstand a loading other than HS-20.

4.9 Alignment

The alignment of the culvert with respect to the natural channel is very important for proper hydraulic performance. Culverts may pass beneath the roadway normal to the centerline, or they may pass at an angle (skewed). Culverts shall be aligned with the natural channel to the extent practical. This reduces inlet and outlet transition problems.

Where the natural channel alignment would result in an exceptionally long culvert, modification of the natural channel alignment may be necessary. Modifications to the channel alignment or profile affect the natural stability of the channel, and proposed modifications shall be thoroughly investigated. In many cases where the channel alignment is modified, grade control or drop structures are needed to achieve stable channel slopes upstream or downstream of the culvert. Although economic factors are important, the hydraulic effectiveness of the culvert and channel stability must be given major consideration. Improper culvert alignment and poorly designed outlet protection may cause erosion of adjacent properties, increased instability of the natural channel and sedimentation in the culvert.

4.10 Stationing

Culvert stationing shall run from downstream to upstream and match channel stationing when designed as part of a channel improvement project. The location of the roadway centerline crossing with the culvert alignment shall be identified based on the culvert stationing.

4.11 Minimum Cover

The vertical alignment of roadways relative to the natural existing channel profile may define the maximum culvert diameter/height that can be used. Low vertical clearance may require the use of elliptical or arched culverts, or the use of a multiple-barrel culvert system. All culverts shall have a minimum of 1.5 feet of cover from the roadway subgrade elevation to the outside of the top of the pipe. A variance will be required for culverts with less than 1.5 feet of cover. When analyzing the minimum cover over a culvert, consideration should be given to potential treatment of the subgrade for mitigation of swelling soils, the placement of other utilities, live loading conditions, and other factors that may affect the pipe cover.

4.12 Multiple-Barrel Culverts

If the available fill height limits the size of the culvert necessary to convey the design flows, multiple culverts can be used. The number of separate culvert barrels shall be kept to a minimum to minimize clogging potential and maintenance costs. If each barrel of a multiple-barrel culvert is of the same type and size and constructed so that all hydraulic parameters are equal, the total flow shall be assumed to be equally divided among each of the barrels.

4.13 Trash Racks

Designs that include trash racks or grates on culvert inlets will be reviewed on a case-by-case basis when there is sufficient justification for considering the use of a trash rack or grate. Protecting public safety is of paramount importance when considering use of trash racks. Alternatives to limit access or catch debris upstream of the culvert inlet should be thoroughly investigated prior to considering improvements to the

culvert inlet. See the Culverts Chapter of the UDFCD Manual for additional discussion and requirements regarding these structures, including public safety precautions.

4.14 Inlets and Outlets

Culvert inlets will require erosion protection where stable channel velocities are exceeded. If needed, riprap erosion protection shall be designed according to the procedures outlined in the Major Drainage Chapter in the UDFCD Manual. Additionally, culvert outlets are discussed further in Chapter 10, Conduit Outlet Structures.

4.15 Debris

When flows are likely to carry floating debris or other materials sufficient to obstruct the culvert entrance, the potential effects of the debris shall be considered. To address the effect of the debris, the culvert design may be altered to pass a higher flow or debris blockage devices may need to be installed upstream of the culvert entrance.

4.16 Service Life

The service life for culverts shall be 50 years. An extended service life of 100 years shall be required when:

- The depth of cover exceeds 15 feet.
- The culvert is located within the travel lanes of 4-lane or major and minor arterial roadways.
- The centerline of the culvert is located 15 feet or less horizontally from any building structure.

The approval of alternative pipe materials shall be based on the determination that their service life is estimated to be at least equal to durations stated herein.

5.0 Driveway Culverts

5.1 Applicable Criteria

The requirements in this section apply to new rural residential subdivisions where the roadside ditch has some depth (typically greater than 18 inches). Urban roadside grass buffers/swales, which are usually shallow and primarily used to minimize directly connected impervious area for a development, will be treated in a different manner (see Volume 3 of the UDFCD Manual).

5.2 Construction Material

Driveway culverts shall be constructed from concrete (RCP), High Density Polyethylene (HDPE) or corrugated metal (CMP/CMPPA).

5.3 Sizing

Driveway culverts for new developments shall be sized to pass the minor storm ditch flow so that the allowable street encroachments and depths defined in Chapter 7, Street Drainage, are not exceeded. The minimum size for driveway culverts shall be 18 inches in diameter for round pipe or shall have a minimum cross-sectional area of 1.77 square feet for arch or elliptical shapes.

5.4 Minimum Cover

Driveway culverts shall be provided with the minimum cover recommended by the pipe structural design requirements or 1 foot, whichever is greater.

5.5 Culvert End Treatments

All driveway culverts shall be provided with end treatments on the upstream and downstream ends of the culvert to protect and help maintain the integrity of the culvert opening. Headwalls, wingwalls, and flared end sections are acceptable end treatments. Erosion protection shall be provided as necessary according to the criteria for culvert inlets and outlets. Toe walls are not typically required for driveway culverts.

5.6 Design Velocity

The driveway culvert design shall achieve the minimum velocities outlined in Section 4.7 of this chapter, and the maximum velocity shall not exceed 10 ft/sec.

5.7 Drainage Report and Construction Drawings

Additional information must be included in the drainage report and on the construction drawings for new subdivisions where the use of roadside ditches and driveway culverts is proposed. The effect of driveway culverts on the capacity of the roadway to convey storm flows must be evaluated. The allowable flow depths and lane encroachments defined by the Chapter 7, Street Drainage, must be maintained, and flows must be contained within available right-of-way.

Driveway culverts shall be sized for each lot in the subdivision drainage report, based on the tributary area at the downstream lot line. The construction drawings shall include information regarding sizes, materials, locations, lengths, grades, and end treatments for all driveway culverts. Typical driveway crossing/culvert details shall be included in the construction drawings. In general, typical roadside ditch sections do not have adequate depth to accommodate driveway culvert installations, which meet the criteria outlined in this section. Construction drawings must address the roadside ditch section in detail to ensure that adequate depth is provided to accommodate the driveway culverts, including the minimum cover and considering overtopping of the driveway when the culvert capacity is exceeded. See Figure 11-1 for additional information.

6.0 Bridge Hydraulic Design

As described in Section 2.1, the hydraulic design of a bridge is very specific to site conditions and numerous factors must be considered. A partial list of these factors includes location and skew, structural type selection, water surface profiles and required freeboard, floodplain management and permitting, scour considerations, deck drainage, and environmental permitting. The consideration of these factors requires that every bridge project have a unique design. All new bridges shall be designed to safely handle the major design storm event flows with the required freeboard. Replacement bridge structures should also be designed to the same standards; however, depending on the site conditions, adjustments to the criteria may be necessary.

Hydraulic analysis of the channel passing under the bridge must be of sufficient extent upstream and downstream to identify any conditions that might affect the hydraulic performance of the channel and structure. The channel cross section, including the low-flow channel, should be maintained through the bridge to the extent practical to minimize changes to the hydraulics of the channel. Generally, a rise of no

more than 1 foot in the water surface of the channel through the bridge structure should occur. Appropriate sediment transport and scour analyses shall also be completed to account for long-term changes in the channel bed or cross section. When debris flow is considered likely, the hydraulic capacity of the bridge crossing shall be appropriately adjusted to recognize the potential reduction due to accumulated debris or debris handling devices may need to be installed on the bridge or upstream.

7.0 Low-Water Crossings/Pedestrian Bridges

Crossings for pedestrian use can vary greatly from small, low-use crossings to regional trail crossings. The crossings can have impacts on the floodplain, wetlands, and wildlife habitat. For these reasons, pedestrian and low-water crossings will be treated on an individual basis, with criteria established following submittal of a request for the crossing. Consideration shall be given to floodplain impacts, debris accumulation and passage, sediment transport, structural design, tethering of the structure or potential blockage of other conveyance structures, clearances to water levels and structural members, maintenance responsibility and cost, and construction and replacement cost of the structure.

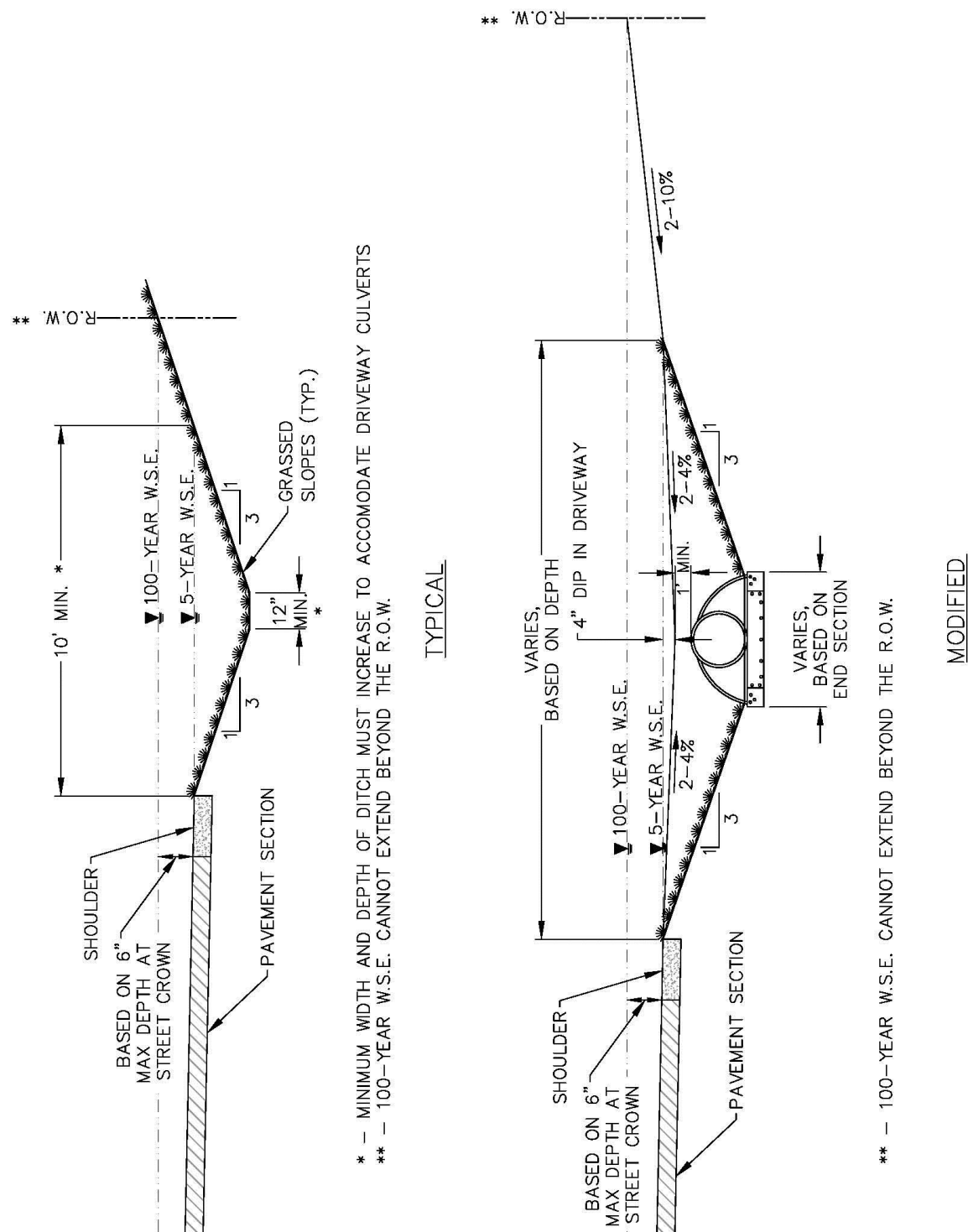


Figure 11-1. Roadside Ditch Modification for Driveway Culverts

Chapter 12

Open Channels

Contents

1.0	Introduction.....	1
1.1	Natural Drainageways	1
1.2	Impacts of Urbanization	2
1.3	Vision for Drainageways.....	3
1.4	Design Flows.....	4
1.5	Sediment Load	4
1.6	Channel Types.....	5
1.6.1	Major Drainageways	5
1.6.2	Minor Drainageways.....	9
1.7	Permitting and Regulations	10
1.7.1	Floodplain Hazard Development Permit.....	11
1.7.2	Section 404 Wetlands Permit.....	11
1.7.3	Endangered Species Act.....	11
1.7.4	Erosion Control/Stormwater Management Permitting	11
2.0	Hydraulic Analysis.....	12
2.1	HEC-RAS Analysis.....	12
2.2	Normal Depth Calculations.....	12
3.0	Design Guidelines.....	12
3.1	Major Drainageways	13
3.1.1	Create Low-Flow Channel	14
3.1.2	Establish a Low-Flow Design Longitudinal Slope.....	15
3.1.3	Utilize Vegetated Benches to Convey Overbank Flow	19
3.1.4	Stabilize Eroding Banks.....	19
3.1.5	Analyze Floodplain Hydraulics.....	20
3.1.6	Consider Aquatic Ecology	21
3.1.7	Undertake Major Drainageway Plan Improvements if Required	24
3.2	Minor Drainageways	24
3.2.1	Constructed Natural Channels.....	24
3.2.2	Grass-Lined Channels	25
3.2.3	Composite Channels	25
3.2.4	Wetland-Bottom Channels	25
3.2.5	Bioengineered Channels	26
3.2.6	Constructed Channels	26
4.0	Grade Control Structures	26
4.1	Low-Flow Drop Structures.....	27
4.2	Full-Channel-Width 100-Year Drop Structures	28
4.2.1	Constructed Natural Channel Drop Structures.....	28
4.2.2	Constructed Channel Drop Structures.....	28
4.3	Drop Structure Types	28
4.4	Drop Structure Placement	29
5.0	Revegetation	30

6.0	Easements, Ownership and Maintenance.....	30
6.1	Easements	30
6.2	Ownership	30
6.3	Maintenance.....	30
6.3.1	Design for Maintenance	30
6.3.2	Maintenance Responsibility.....	31

Tables

Table 12-1.	Channel Types	5
Table 12-2.	Hydraulic Design Criteria for Natural Unlined Channels	14
Table 12-3.	Fish Habitat Structures.....	23
Table 12-4.	Hydraulic Design Criteria for Grass-Lined Constructed Natural Channels	25
Table 12-5.	Grade Control Drop Height Limits	26
Table 12-6.	Roughness Coefficients	32

Figures

Figure 12-1.	Functions and Benefits of Natural Drainageways	1
Figure 12-2.	Impacts of Stream Degradation	2
Figure 12-3.	Incised Channel Evolution Model	8
Figure 12-4.	Design Elements Associated With Major Natural Drainageways	13
Figure 12-5.	Sediment Transport and Discharge Relationship	16

1.0 Introduction

This chapter summarizes the analysis and design methodology for projects that impact drainageways and describes methods for preserving natural drainageway features. Applicable criteria and design considerations are provided for stabilization of common channel types. Additional guidance required to complete channel design projects is provided in the Major Drainage and Hydraulic Structures Chapters of the UDFCD Manual.

1.1 Natural Drainageways

Natural drainageways are those that have developed from natural causes, as opposed to being human-made or having developed entirely as a result of urban runoff. A drainageway does not have to be entirely untouched by humans to function as a natural channel. Many natural drainageways in or near developed areas have been altered to some extent by human activity and exhibit varying degrees of impacts and stability. As shown in Figure 12-1, natural drainageways provide a number of important environmental and ecological functions and benefits, including:

1. Stable conveyance of baseflow and storm runoff.
2. Support of wetland and riparian vegetation.
3. Creation of habitat for wildlife and aquatic species.
4. Slowing and attenuating floodwater by spreading flows over vegetated overbanks.
5. Promotion of infiltration and groundwater recharge.
6. Enhancement of water quality.
7. Provision of corridors for trails and open space.
8. Enhancement of property values and quality of life.

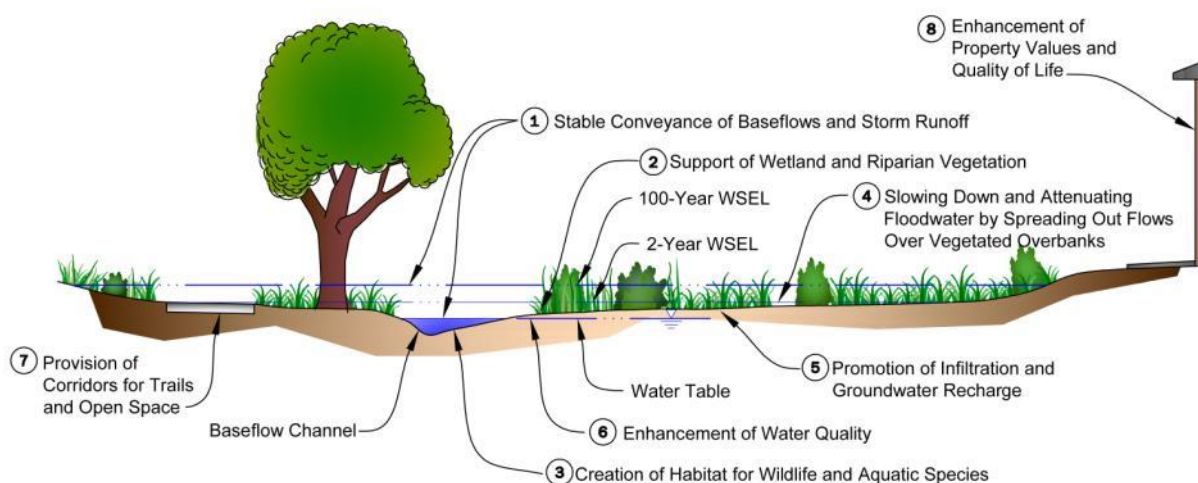


Figure 12-1. Functions and Benefits of Natural Drainageways

Natural drainageways are dynamic, responding to changes in flow, vegetation, geometry, and sediment supply that are imposed in developing urban environments. As a result, natural streams often face threats that can degrade their functions and benefits. Goals for the design of channels in an urbanizing environment include preserving the beneficial functions of natural channels, enhancing channels to improve functions, where practical, and mitigating the impacts of development. The designer's ability to accomplish these goals is affected by current and long-term conditions in the drainage basin upstream of the project reach.

1.2 Impacts of Urbanization

Urbanization typically increases the frequency, duration, volume, and peak flow of stormwater runoff and may also include filling and developing portions of the floodplain. Urbanization can introduce water sources unrelated to storm events (e.g., irrigation and treated sanitary wastewater discharges) that affect channel conditions. Additionally, the natural supply of watershed sediment is often reduced relative to undeveloped conditions when natural cover is replaced with paved areas and detention and stormwater quality ponds are installed. All of these factors contribute to the tendency of urban drainageways to degrade and incise as streams seek a new condition of equilibrium, producing negative impacts to instream habitats, riparian environments and adjacent properties, as illustrated in Figure 12-2 and described below.

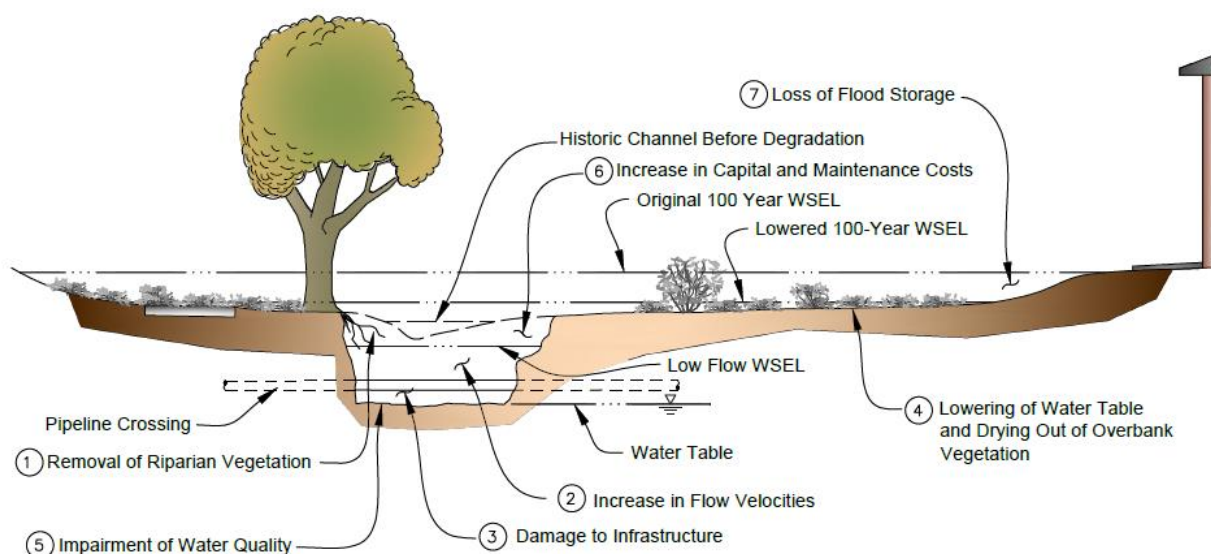


Figure 12-2. Impacts of Stream Degradation

1. **Removal of Riparian Vegetation.** Erosion typically strips natural vegetation from the bed and banks of drainageways. This disrupts habitat for aquatic and terrestrial species and leaves the channel exposed to further erosion damage. Subsequent bank erosion and undercutting increases the risk of excessive sediment and nutrient loading to downstream waterbodies.
2. **Increase in Velocity and Shear.** An incised channel concentrates runoff and increases flow velocities and shear stresses on the channel perimeter. It is not unusual for channel velocities to increase significantly in an incised condition. Stream flow conditions with erosive potential also occur more frequently. Additionally, a “feedback loop” may develop where incision leads to increased erosive capacity and then further incision. Once started, this process typically

continues until a new channel invert is established, potentially resulting in bare, near-vertical channel banks in place of the well vegetated, gently sloping banks of natural channels and a main channel disconnected from the natural floodplain. Knick points or “headcuts” generated by increases in velocity and shear can rapidly spread erosion impacts throughout drainage networks in the absence of effective grade controls.

3. **Damage to Infrastructure.** Channel erosion can threaten utility lines, bridges, and other infrastructure. Utility pipelines that were originally constructed several feet below the bed of a creek may become exposed as the channel bed lowers. 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 expose buried utility lines, undermine roadways and cause significant damage to adjacent properties and structures.
4. **Lowering of Water Table and Drying-out of Overbank Vegetation.** In many cases, lowering of the channel thalweg and baseflow elevation leads to a corresponding lowering of the local water table. Lowering the water table can have a negative effect on bank stability and aquatic and terrestrial ecology. Substantial lowering of the channel invert can make water inaccessible to wetland and mesic plant species, causing them to die out and be replaced by upland species which have poorer ground coverage, canopy and root structure. The result can be degradation or elimination of both aquatic and terrestrial habitat and destabilization of the channel banks.
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 1-foot deep across a width of 10 feet produces almost 2,000 cubic yards of sediment that could be deposited in downstream lakes and stream reaches. Along the Front Range of Colorado, these sediments contain phosphorus, a nutrient that can lead to accelerated eutrophication of lakes and reservoirs. Along some reaches of Fountain Creek, naturally occurring selenium can be mobilized into the stream system by urbanization and erosion into underlying geologic formations. Also, channel incision impairs the “cleansing” function that natural floodplain overbanks can provide through settling, vegetative filtering, wetland treatment processes, and infiltration.
6. **Increase in Capital and Maintenance Costs.** Typical stabilization projects to repair eroded drainageways require significant capital investment; the more erosion, generally the higher the cost of rehabilitation.
7. **Loss of Flood Storage.** Incision of the low-flow or main channel portion of the drainageway prevents flood flows from spilling into the overbank area where the natural storage helped to reduce downstream peak flows.

1.3 Vision for Drainageways

The vision for drainageways as described in this Manual is to go beyond simply stabilizing a channel against erosion and to implement enhanced stream stabilization. Stabilization can be accomplished by lining a channel with concrete; however, not only is this often the most expensive approach to stabilization, it also eliminates the ecological, aesthetic and recreational value of drainageways. Enhanced stream stabilization has the goal of maintaining or restoring natural streams and well-vegetated floodplains that are physically and biologically healthy, with the attributes shown in Figure 12-1. Plan form and cross-sectional geometry, riparian vegetation, grade-control features, and flood storage provisions should be integrated into channel designs to emulate the functions of natural features to the

extent practical. This vision is based on recognition that streams and drainageways are a valuable resource to the community and that capital and long-term maintenance costs to the community are typically lower when channel designs work with nature rather than against it. The implementation of these concepts is directly related to upstream basin conditions, including land uses, anticipated flows and flow control measures.

1.4 Design Flows

Flows conveyed by open channel are highly variable; therefore, it is not feasible to evaluate all of the possible flows a channel might convey. To simplify open channel design procedures, representative design flows have been identified. In most cases, open channel projects can be adequately designed using estimates of baseflows, low flows and flood flows. Full descriptions of these design flows and methods for estimating them are described in Chapter 6, Hydrology. General descriptions of these flow conditions include:

- Baseflows may not be directly related to storm events and are often not present in undeveloped drainage basins, but can become present after development. Their presence or absence can be a determining factor in the feasibility of implementing certain channel features, such as wetland bottoms.
- Low flows are normally contained within a well-defined channel that only overtops when a significant storm event occurs. Flows within this range are usually responsible for establishing the main channel section and the slope of the stream bed. The range of flows between baseflows and bank full capacity are generally those that are responsible for most of the geomorphic (channel shaping) activity and sediment transport. When a “natural” channel is planned or a natural channel is being preserved, special attention should be paid to this range of flows.
- Flood flows include any flows that exceed the low-flow or main channel capacity and have the potential to create unsafe or damaging conditions.

Open channel designs must account for each of these types of design flows and upstream drainage basin conditions, including practices implemented to reduce runoff volumes and other factors. By designing for these design flows, it is expected that adequate protection and conveyance will be provided for intermediate flows and that the proposed vision for drainageways can be achieved.

1.5 Sediment Load

The range of sediment loads carried by channels is affected by conditions and flows in the upstream drainage basin, impacts to the channel due to crossings or modifications, development activity and the extent of development-related improvements. Temporary sediment loads may differ from longer-term sediment loads. It is normally desirable to pass sediment through a design reach by designing the low-flow channel with sufficient hydraulic capacity to ensure that excessive sediment is not deposited in the reach over time. When evaluating a “design reach” the engineer should consider upstream and downstream potential for channel erosion and deposition, as hydraulic characteristics of the upstream and downstream reaches will affect the “design reach.” Estimates of the sediment load entering the project reach can be made by an analysis of the capacity and type of material conveyed in the upstream reaches. However, applying these methods can require extensive data collection and expertise that is often not available. Any project that requires these types of analyses must include a thorough description of the data sources and methodology to be used and submitted for approval. The City Engineer will determine if sediment load, deposition and/or scour analysis is required for a given project.

1.6 Channel Types

Open channels are influenced by changes in the upstream drainage basin contributing to the project reach as described above or by crossing structures, encroachments, debris and/or changes to vegetation within the project reach. The implementation of detention practices to attenuate peak flow rates and reduce cumulative erosion potential from urbanized areas is an important factor for assessing the feasibility of various channel types in terms of channel capacity and stability. The design of open channels must account for the effects of these factors over the design life of the project. Typical characteristics of the most common open channel types are described below, and in Table 12-1

Table 12-1. Channel Types

Channel Type	Typical Drainage Area ¹	Design Flows ²	Sediment Loads ³	Floodplain Preservation /ROW	Vegetation	Stabilization
Modified Natural Channel	>approx. 130 acres	$Q_f \approx Q_h$	$S_f \leq S_h$	Preservation of most of the floodplain and natural channel functions/ available ROW.	Limited disturbance/ native or compatible plant species and wetlands.	Generally limited to areas of instability and low-flow grade control, soil riprap, boulders, sculpted concrete, bioengineering, other compatible materials.
Constructed Natural Channel	<approx. 640 acres	$Q_f > Q_h$	$S_f < S_h$	Limited to full floodplain preservation/ provide natural channel functions when feasible/ROW availability varies.	Limited to significant revegetation, some preservation of natural vegetation, revegetation using native or compatible plant species and wetlands.	Low-flow stabilization and grade controls and possible full-channel-width grade controls.
Constructed Channel	<approx. 130 acres	$Q_f \gg Q_h$	$S_f \ll S_h$	Almost no floodplain preservation/ limited to no natural channel function.	Limited revegetation/ normally hard-lined.	Fully stabilized with linings (riprap, soil riprap, concrete, grouted boulders, etc.) and full-width drop structures.

¹Typical drainage areas may vary depending on approved master plans.

² Q_h =historic flows, Q_f =future flows

³ S_h =historic sediment loads, S_f =future sediment loads

1.6.1 Major Drainageways

In general, major drainageways are streams with contributing drainage basin areas greater than approximately 130 acres. This threshold generally corresponds to the threshold for regional detention

facilities as described in the Storage Chapter of this Manual. As a watershed urbanizes, providing detention storage (and volume reduction practices) upstream of or in the headwaters of major drainageways is advisable to minimize changes to hydrology that have the potential to affect stream stability and capacity needed in the drainageway. The amount of sediment transport in these drainageways can vary greatly depending on their location relative to upstream detention storage and the level of development; therefore, sediment transport estimates and stable slope considerations can also be important factors for designing major drainageways.

Projects affecting major drainageways must be completed so that natural drainageway features and benefits are preserved (and enhanced when feasible) or restored, unless otherwise designated in an approved master plan. Planning documents shall accurately identify all existing drainageways, floodplains, and other site features that may have beneficial natural features. Features proposed to be left in place and preserved or restored shall be clearly shown on the planning and/or design documents. A key consideration in the preservation of natural drainageways is obtaining an adequate easement of land that allows the drainageway to provide the natural function of flood storage and to allow the creation of open spaces that can provide habitat. This approach to channel design can also reduce the need to modify floodplain maps used in the administration of the National Flood Insurance Program (NFIP).

To the extent practical, major drainageway projects should protect and preserve these features, if present:

- General protection of aquatic and riparian habitat for threatened and non-threatened species that comprise a health ecosystem.
- Jurisdictional wetlands.
- Riparian vegetation such as cottonwood or willow trees, shrub willows, and wetland or transitional grasses.
- Baseflows.
- Overbank flood storage.
- Bedrock outcroppings or unique landforms.
- Historic, cultural, or archeological resources.

To complete the design of an open channel project, baseflows, low flows, and flood flows should be evaluated. At the discretion of the City Engineer, sediment transport evaluation may also be required. The evaluation of flood flows will normally include delineation of the floodplain for land planning purposes and for maintaining adequate freeboard at structures on adjacent developments and may also include scour calculations for utility crossings, bridge abutments and other structures. When the floodplain for the project reach is defined on a Flood Insurance Rate Map (FIRM), a revision to the regulatory floodplain may be necessary according to Chapter 5, Floodplain Management.

1.6.1.1 Modified Natural Channels

Most major drainageway projects can be described as modified natural channels. These projects require limited modifications to drainageways that allow most of the benefits of natural channels to be preserved or enhanced. Improvements will normally be limited to stabilization of the low-flow channel (unless a meandering low-flow channel is planned), crossing structures, grade control structures and limited stabilization of the banks to manage unstable areas or protect infrastructure. Loss of flood storage due to

encroachments should be mitigated by providing compensatory storage. Considerations for modified natural channels include:

1. **Preserving Streams Not Yet Significantly Impacted.** Drainageways that have not yet experienced degradation from increased urban runoff or other forms of erosion should be preserved by implementing the following improvements:
 - Grade control structures to limit degradation in the low-flow channel, stabilize existing headcutting and establish a flatter equilibrium slope than may have existed previously.
 - Utilization of vegetated overbank benches adjacent to the low-flow channel to allow flood flows to spread out and slow down and to dissipate energy.
 - Stabilized low-flow channel that can be vegetated, potentially with a bioengineered or wetland bottom.
 - Bank stabilization at select locations where existing instability or the potential for future instability is identified.
 - Planting supplemental vegetation to provide for the transition to species suited for “wetter” urban hydrology. Additional moisture can sustain wetland and riparian vegetation. These grasses, sedges and rushes, shrubs, and trees can help to stabilize the channel and provide diverse habitat for wildlife.
2. **Restoring Impacted Streams.** Drainageways that have already experienced significant erosion and down-cutting are to be addressed similarly to streams that are not yet degraded. However, eroded, incised channels should not be stabilized in a manner that retains the incised geometry with steep side banks. Instead, incised channels should be restored by raising the channel invert up to or near its historic elevation, allowing flood flows to spread out onto the natural floodplain, avoiding deep, concentrated flood flows within the main channel. The more a drainageway is allowed to degrade, the greater the disturbance will be required to provide restoration and the higher the cost will be. This is especially true if the channel is allowed to incise to a depth that exceeds the critical bank height for geotechnical stability and crosses the threshold for widening through slab failures of the banks.

Fountain Creek has experienced significant erosion, downcutting and widening through a long reach in Woodland Park stretching from below Sheridan Avenue to just upstream of Safeway/Aspen Garden Way. Much of this segment has progressed to the third stage of the incised channel evolution model (CEM; Stage III Figure 12-3). In this stage, bank heights and angles have exceeded the threshold of geotechnical stability. Slab failures and widening have commenced and channel rehabilitation becomes more challenging compared to the second stage in which bank heights have not exceeded critical levels. In streams with high energy relative to bank material size and little storage of failed material at bank the toe, the width-depth ratio of channel may continue to increase to a point where a return quasi-equilibrium conditions becomes unlikely (CEM Stage V; Figure 12-3). This appears to be the case with this segment of the Fountain Creek main stem.

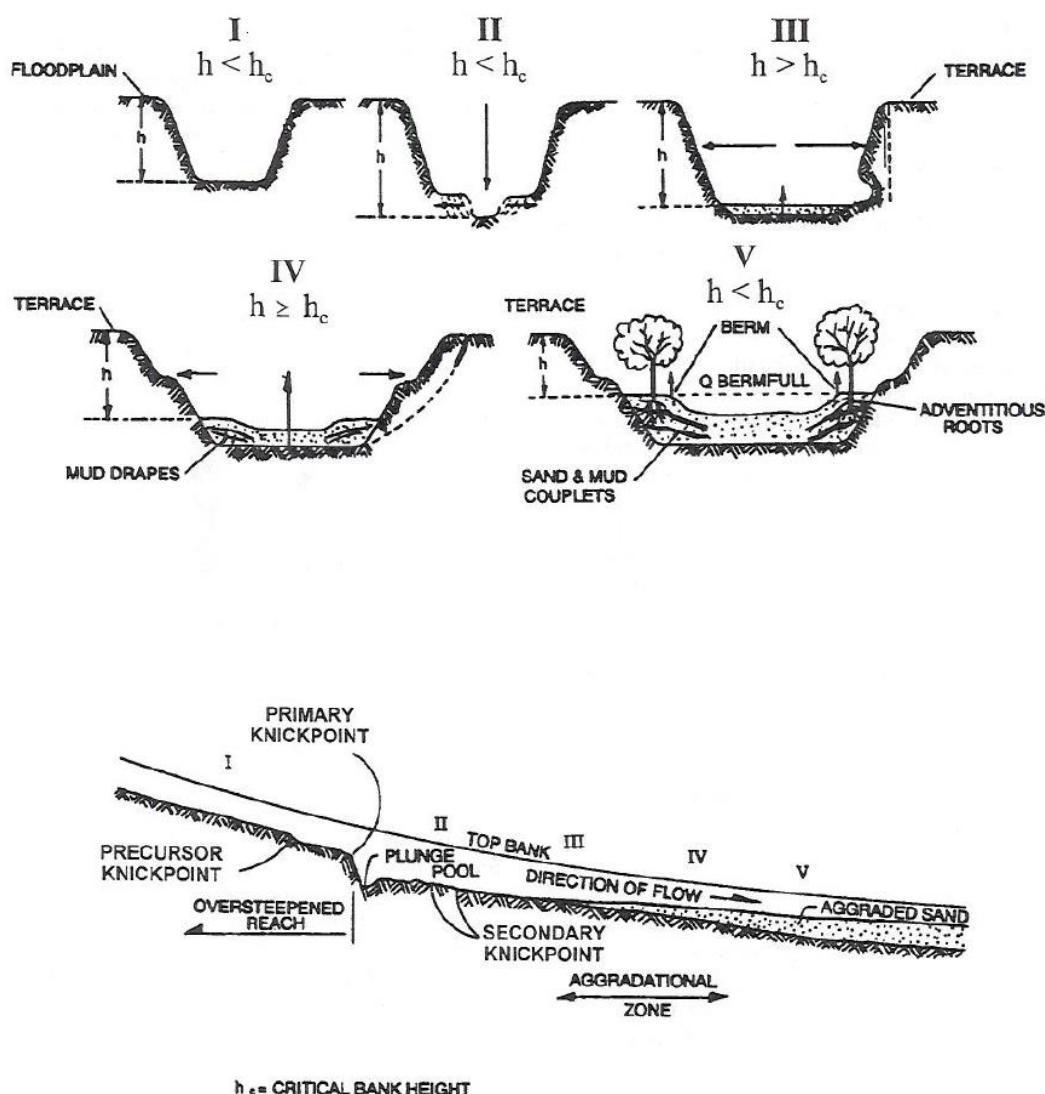


Figure 12-3. Incised Channel Evolution Model

(Schumm et al. 1984, Watson et al. 2002).

The City has developed plans to address these Stage III channel incision issues by constructing a long reinforced concrete box culvert. This is needed for this reach because of the extreme challenges and costs associated with re-creating a stable channel in an area with limited right-of-way, highly erodible soils, steep longitudinal channel slopes and significantly increased runoff (rate and volume) and decreased sediment supply from urbanized areas. While a box culvert is not an ideal solution to replace a reach of stream that once provided a number of the benefits depicted in Figure 12-1, the current condition of the stream exhibits most of the problems shown in Figure 12-2, and the box culvert will provide needed conveyance without the risk of infrastructure damage (exposed wastewater trunk line) and will dramatically reduce ongoing erosion along this reach.

The channel evolution model also indicates that the return to quasi-equilibrium conditions in downstream segments (e.g., aggradational reach behind Wal-Mart) is linked with the sediment supply provided by incising reaches upstream. As such, the management of incised channels is

most effective when undertaken with a system level perspective that accounts for the potential for upstream stabilization to create sediment deficits in downstream reaches. This also underscores the importance ongoing monitoring to identify incising stream segments before channels cross the bank stability threshold between CEM Stages II and III. Watson et al. (2002) provide a discussion of how the CEM can guide the evaluation of incised channel rehabilitation alternatives.

3. **Channel Crossings.** When influences to a natural channel are limited to a structural crossing such as a roadway and the upstream drainage basin is not expected to change significantly over time, the design process must fully consider historic basin conditions and the natural conditions of the drainageway. Construction of the crossing should seek to minimize the impacts to the natural functions of the drainageway and provide mitigation for unavoidable impacts. In this situation, the project should avoid encroachment into and the modification of the adjacent floodplain and interference with the natural tendencies of the drainageway such as meandering and sediment transport. This is best achieved by structures that span all or most of the floodplain (at least near crossings where there is typically contraction and expansion of the flow). When floodplain encroachment cannot be avoided, transitions upstream and downstream of the structure should be hydraulically efficient to minimize changes to the adjacent channel features and to the floodplain. The stabilization of eroded low-flow channels or banks to protect property or infrastructure may also be part of the project design. As part of these efforts, fill in the historic floodplain should be minimized to the extent practical so that the flood storage function of the channel is preserved.

By respecting natural historic drainage patterns and flood-prone areas in early planning and implementing water quality and detention practices, drainageways and floodplains can be preserved that provide adequate capacity during storm events, that are stable, cost-effective and of high environmental value, and that offer multiple use benefits to surrounding urban areas. In the absence of historic beneficial features, it may be desirable to design natural functions into projects.

1.6.2 Minor Drainageways

In general, minor drainageways or minor channels are streams with contributing drainage basin areas less than approximately 130 acres. Minor drainageways may be reconstructed, relocated, or replaced with a storm sewer in combination with flood conveyance in the street network. However, the creation of vegetated surface channels is encouraged wherever practical in the minor drainageway network. These drainageways will typically be located upstream of detention storage facilities, and design flows will be based on developed conditions that produce flows much greater than undeveloped conditions. Although natural channel features may not be present in these types of channels, it is desirable to create naturalistic features including base-flow channels, low-flow channels and vegetated overbank areas to provide some of the beneficial functions of natural channels.

The amount of sediment transport in minor drainageways is expected to be limited when the upstream watershed has been developed and is stable. Sediment loads may be high while the drainage basin is under development, but this is unlikely to continue as the drainage basin becomes more developed.

1.6.2.1 Constructed Natural Channels

When adequate land is available, it is desirable to construct a modified channel that provides the benefits of natural channels such as flood storage, aesthetic benefits and habitat. Such “constructed natural channels” should be designed to emulate the functions of natural drainageways shown in Figure 12-1. Where practical, existing natural features should be incorporated into the design. For these types of

projects, the primary design considerations are to emulate natural channels, avoid flooding of adjacent structures, provide stable channel conditions during flood flows, and pass sediment to reduce maintenance.

Stabilization improvements for the banks and overbank will depend on the design velocities and proposed ground cover. Grade control structures will normally be required for the low-flow channel. Grade control structures will also be required across the full channel section if overbank velocities exceed non-erosive levels.

This channel type includes grass-lined and composite channels, as defined by the UDFCD Manual, and may include bioengineered and wetland bottom channels, as well.

To complete the design of a constructed natural channel, low flows and flood flows must be analyzed to determine channel cross sections and slopes that will promote a stable channel. The evaluation of flood flows provides a delineation of the floodplain for land-planning purposes and provides the basis to maintain adequate freeboard for structures and adjacent developments. Flood flows also provide the basis for many types of scour analyses. If a baseflow channel is included in the design, baseflows must also be estimated. The presence of baseflows will also need to be considered if wetland bottoms are part of the design.

1.6.2.2 Constructed Channel

A channel that primarily provides flood flow conveyance may be necessary when upstream drainage basin conditions have already been significantly altered or are expected to be in the future, where the floodplain has already been significantly reduced, or where existing flooding is occurring. These channels may also be necessary where right-of-way is limited. Constructed channels will typically be fully lined with riprap, soil riprap, concrete, or manufactured linings. Some types of channel linings such as concrete, riprap and manufactured liners provide few benefits of a natural channel. The design of these channel types primarily depends on flood flows, but low flows and baseflows may be needed if sediment load passage is desired. The evaluation of flood flows provides the delineation of the floodplain for land planning purposes and provides the basis to maintain adequate freeboard at structures and for adjacent developments but will not normally be shown on the NFIP FIRMs for minor drainageways.

Most channel projects will be either a modified natural channel or a constructed natural channel. The conditions necessary to maintain a channel in fully natural conditions rarely occur in an urbanizing drainage basin and constructed channels are primarily intended to be used in retrofit situations where the upstream drainage basin is fully developed and there is limited right-of-way available. Table 12-1 summarizes the project conditions that generally determine the type of channel that is most appropriate.

1.7 Permitting and Regulations

Major drainage planning and design along existing natural channels can be a multi-jurisdictional process, and must comply with regulations and requirements ranging from local criteria and regulations to federal laws. Discussions with the relevant permitting authorities should be held early in the design development process and throughout construction to ensure that permitting and regulatory requirements are being met. Some of the more significant permitting processes required for typical channel projects are listed below. The list is not all-inclusive and additional permits may be required.

1.7.1 Floodplain Hazard Development Permit

A Flood Hazard Development Permit issued by the Floodplain Administrator is required for all activities proposed within Federal Emergency Management Agency (FEMA) mapped floodplains. Refer to Chapter 5, Floodplain Management for additional information on floodplain permitting and regulations.

1.7.2 Section 404 Wetlands Permit

Streams designated by the U.S. Army Corps of Engineers (USACE) as “jurisdictional” under Section 404 of the Clean Water Act are subject to specific protections established during the 404 permit process. The 404 permit may impose limits on the amount of disturbance of existing wetland and riparian vegetation, may require disturbed areas to be mitigated, and may influence the character of proposed stream improvements.

Additionally, sites located upstream of water quality facilities may require protection in the form of temporary (construction) and permanent on-site water quality measures, including reducing directly connected impervious area before discharging to the waterway. Volume 3 of the UDFCD Manual describes on-site measures for water quality.

The USACE should be contacted early in the design process to determine if the activities will require a 404 permit.

1.7.3 Endangered Species Act

Construction of improvements along drainageways may also be subject to regulation under the federal Endangered Species Act. The USACE, as part of the 404 permit process, will typically coordinate with the U.S. Fish and Wildlife Service (USFWS) to assess potential impacts to threatened and endangered (T&E) species. The USFW may require a Biological Assessment to determine impacts and significant mitigation measures may be required if impacts are expected. In some areas, Block Clearances may be in place so that some environmental assessments are not necessary. The designer should determine whether a Block Clearance is effective for the project.

Additionally, T&E species must be addressed as part of the FEMA Conditional Letter of Map Revision (CLOMR) process. If T&E species will not be affected by work associated with a CLOMR, the applicant typically submits a letter with a finding of “no likely impact” that has received concurrence from the USFWS. If T&E species will be affected by work associated with a CLOMR, FEMA requires documentation that the appropriate permits have been obtained before they will issue a Letter of Map Revision (LOMR).

1.7.4 Erosion Control/Stormwater Management Permitting

Projects that will disturb one or more acres of land require the development of a Stormwater Management Plan (SWMP) and submittal of a Notice of Intent (i.e., application) to obtain certification of coverage under the Colorado Department of Public Health and Environment (CDPHE) General Permit for Stormwater Discharges Associated with Construction Activity.

2.0 Hydraulic Analysis

Hydraulic analyses and reporting must be adequate to confirm that applicable criteria are being satisfied by the proposed design. Roughness coefficients provided in Table 12-6 at the end of this chapter shall be used for hydraulic calculations. Additional guidance for roughness coefficients and parameters necessary to complete proper hydraulic analyses is provided in the Major Drainage Chapter of the UDFCD Manual.

2.1 HEC-RAS Analysis

Hydraulic analyses necessary to confirm that design criteria are satisfied can be complicated and often involve variable boundary conditions, various flow rates, a varying water surface profile, irregular channel geometry and crossing structures. Most project conditions require using the USACE's HEC-RAS computer software, which is available free from their website, to adequately assess project conditions. The application of the HEC-RAS computer software shall use model parameters described in this Manual or in the program documentation or justification shall be provided for values used that are not consistent with these documents.

2.2 Normal Depth Calculations

Generally, normal depth calculations may be used when these conditions are met:

- Channel geometry is uniform.
- Channel parameters are uniform.
- Design flows are steady.
- Backwater effects are not present.
- Water surface profile is uniform.
- Hydraulic boundary conditions are well known for all design flows.
- No structures are creating variable water surface elevations affecting flow in the channel.

UDFCD has created several spreadsheet programs that provide assistance in the evaluation of typical channel designs and crossing structures when project conditions are appropriate for normal depth calculations. These design aids may be used to complete project designs when appropriate.

3.0 Design Guidelines

Each reach or each segment of the project reach must be evaluated to determine the basin conditions that will influence its function within the drainage basin or watershed and the applicable design standards. Channel design requirements are determined by whether they are categorized as major or minor channels and by the particular characteristics of the project reach. The Major Drainage Chapter of the UDFCD Manual provides a thorough discussion of drainageway planning considerations, which should be referenced for guidance on urban effects, route considerations, and drainageway layout within a site.

3.1 Major Drainageways

The natural channel design criteria described herein and in the Major Drainage Chapter of the UDFCD Manual shall be used for all major drainageways unless otherwise approved by the City Engineer. Typical design elements included in a major natural channel design project are shown in Figure 12-4 and summarized as follows:

1. Create low-flow channel.
2. Establish a low-flow design longitudinal slope.
3. Utilize vegetated benches to convey overbank flow.
4. Slope-back and stabilize eroding banks.
5. Analyze floodplain hydraulics.
6. Evaluate potential impacts to aquatic ecology and incorporate measures to enhance biologic functions, where practical.
7. Undertake major drainageway plan improvements if required.

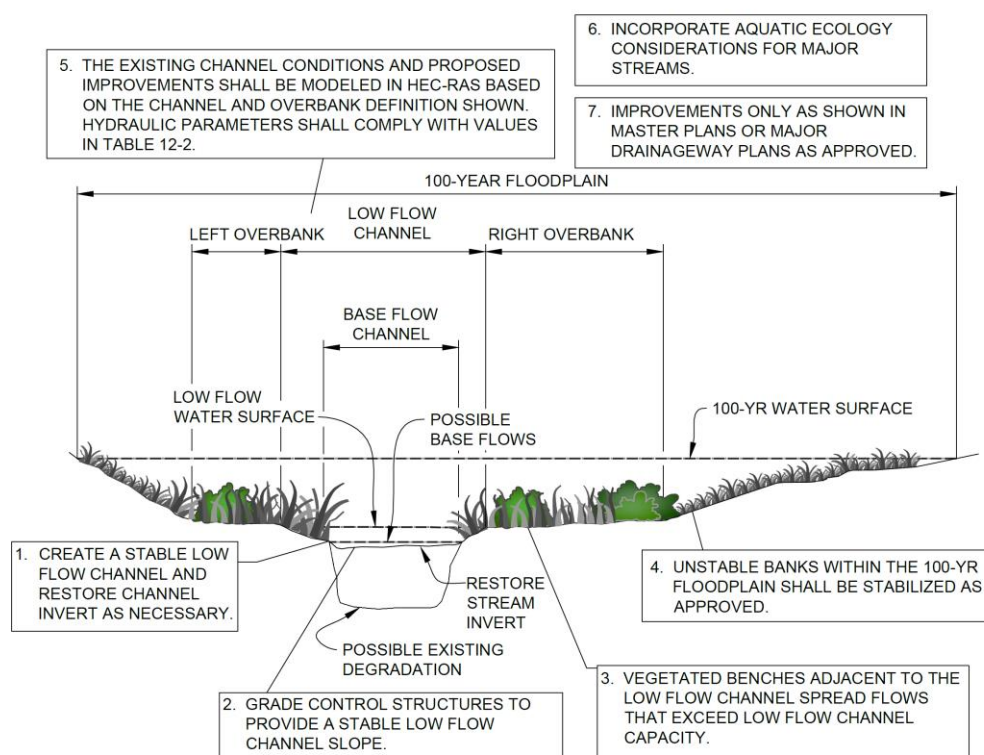


Figure 12-4. Design Elements Associated With Major Natural Drainageways

These seven steps are discussed in the following sections and comprise the recommended design approach for preserving, restoring, or modifying natural healthy drainageways. Designers shall address

these seven elements and submit their proposed approach for drainageway stabilization for review and approval by the City.

3.1.1 Create Low-Flow Channel

One of the primary design tasks is to preserve or establish a low-flow channel that is appropriately sized in relation to the adjacent overbank geometry and the design low-flow rate. In general, shallow low-flow channels with adjacent well-vegetated overbank benches are best suited to spread-out and attenuate flood flows. The top of low-flow channel banks shall normally be established along the edge of the historic overbank. This may require filling degraded incised channels, excavating overbank benches adjacent to the low-flow 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 and restores the relationship between the low-flow channel and the floodplain, although filling generally will impact biota that are able to inhabit the degraded channel. Sometimes, it may be difficult to raise the invert of a degraded channel. Existing storm sewer outfalls may have been installed near the bottom of the incised channel and constrain how much the channel bed can be raised. It may be necessary to remove the downstream end of low storm sewer outfalls and reconstruct them at a higher elevation. Also, raising the invert may cause a rise in a critical floodplain elevation if the regulatory floodplain was based on the degraded channel condition (it is recommended that floodplains be determined for restored, not degraded channel conditions). There may be a need for compensatory excavation in other portions of the floodplain to offset rises in the floodplain caused by filling in the eroded low-flow channel.

The width of the low-flow channel shall approximate the width of the historic low-flow channel within the design reach or in stable reference reaches upstream or downstream. Normally, a low-flow channel exhibits some meandering and sinuosity in natural channels. Modified channels should feature a meander pattern typical of natural channels. Side slopes for low-flow channel banks shall be no steeper than 4H:1V for unlined banks. Lesser slopes are encouraged and may provide improved vegetative cover, bank stability and access. Allowable velocities for unlined low-flow channels are shown in Table 12-2. Criteria for lined channels are provided in the Major Drainage Chapter of the UDFCD Manual.

Table 12-2. Hydraulic Design Criteria for Natural Unlined Channels

Design Parameter	Erosive Soils or Poor Vegetation	Erosion Resistant Soils and Vegetation
Maximum Low-flow Velocity (ft/sec)	3.5 ft/sec	5.0 ft/sec
Maximum 100-year Velocity (ft/sec)	5.0 ft/sec	7.0 ft/sec
Froude No., Low-flow	0.5	0.7
Froude No., 100-year	0.6	0.8
Maximum Tractive Force, 100-year	0.60 lb/sf	1.0 lb/sf

¹ Velocities, Froude numbers and tractive force values listed are average values for the cross section.

² “Erosion resistant” soils are those with 30% or greater clay content. Soils with less than 30% clay content shall be considered “erosive soils.”

3.1.1.1 Baseflow Channel

If baseflows are present within the low-flow channel or are anticipated to be present in the future, it must be determined how the baseflows will be accommodated. Two common approaches include: 1) the

invert of the low-flow channel can be shaped to accommodate a defined baseflow channel and a lower secondary overbank area or 2) the baseflows can be allowed to meander in the bottom of the low-flow channel without modifying the low-flow channel section. The baseflow rate may be based on available records from gage data, when available, but can be estimated based on field observations, seasonal hydrology and channel characteristics. The invert of the baseflow channel is typically unvegetated if a constant baseflow or frequent ephemeral flow is present, or vegetated with riparian or wetland species if baseflows are less frequent.

3.1.1.2 Wetland Bottom Channels

As described in the Major Drainage Chapter of the UDFCD Manual, there are circumstances where the use of a wetland bottom may be appropriate within the low-flow channel of a natural channel reach. Low-flow channels shall be designed with reference to the Major Drainage Chapter of the UDFCD Manual and the Treatment BMPs Chapter in Volume 3 of the UDFCD Manual. Riprap bank protection will generally not be required in wetland bottom channels. Freeboard requirements for wetland bottom channels shall be the same as those given for grass-lined channels.

3.1.1.3 Bioengineered Channels

Elements of bioengineered channels as described in the Major Drainage Chapter of the UDFCD Manual may be used in the design or stabilization of natural channels. Freeboard requirements for bioengineered channels shall be the same as those given for grass-lined channels.

3.1.2 Establish a Low-Flow Design Longitudinal Slope

Watershed development tends to cause channel degradation and a reduction in channel slopes. Therefore, the long-term stable slope of the low-flow channel is expected to be less than for undeveloped conditions and less than the longitudinal slope of the adjacent overbanks. To accommodate this anticipated change, grade control structures are required in the low-flow channel to create a “stairstep” profile to stabilize the low-flow channel and maintain the natural relationship between the low-flow channel and the floodplain. The estimated design slope determines how many grade control structures are required. A flatter design requires more grade control structures and increases costs. The spacing of drop structures depends on the original natural channel slope and the design slope necessary to stabilize the channel. The design and placement of grade control structures is described in Section 4.2, Grade Control Structures.

3.1.2.1 Ultimate Design Slope

Several methods have been developed to estimate channel slopes for ultimate (full) build-out upstream drainage basin conditions. When sediment loads are expected to decrease significantly and flows are expected to increase significantly, estimates of the ultimate stable slope tend to be flat. Even when flows are properly regulated through detention storage ponds upstream, the reduction in sediment load will still result in very flat estimates of the ultimate channel slope.

3.1.2.2 Interim Design Slope

When a long-term sediment supply may be present or when the time required for channels to reach their ultimate design slope can be long, methods that estimate an ultimate design slope based on no or a very limited sediment supply may be too conservative and increase the cost of channel stabilization. Therefore, intermediate design slopes may be used to construct fewer grade control structures initially if the need to ultimately construct additional structures is recognized and funded. Estimating design slopes

in developing watersheds is complicated by difficulties in estimating interim sediment supplies, flows, channel dimensions and floodplain encroachment. Understanding these development impacts on channel slope can be important for financing long-term stabilization needs and designing effective structures.

Various methods for estimating interim channel slope changes as a result of development can be applied; however, due to the lack of availability of historic data, the uncertainty of changes in key input parameters (such as sediment load and flow), the experience required to apply them correctly and the uncertainty of the results, a geomorphologist or civil/water engineer with expertise in sediment transport should be consulted. There are a variety of methods that can be used for estimating a stable channel slope included historical data analysis, reference reach analysis, HEC-20 Incipient Motion Method, HEC-2 Equilibrium Slope Analysis, Lane's Form Relationship (Julien 2002), and detailed sediment transport analysis. A useful analysis by Henderson (1966) combined the Einstein-Brown bedload transport formula, Chezy flow resistance formula, and mass conservation for steady uniform flow, into a single proportionality where q_s and q are sediment transport rate and water discharge per unit width.

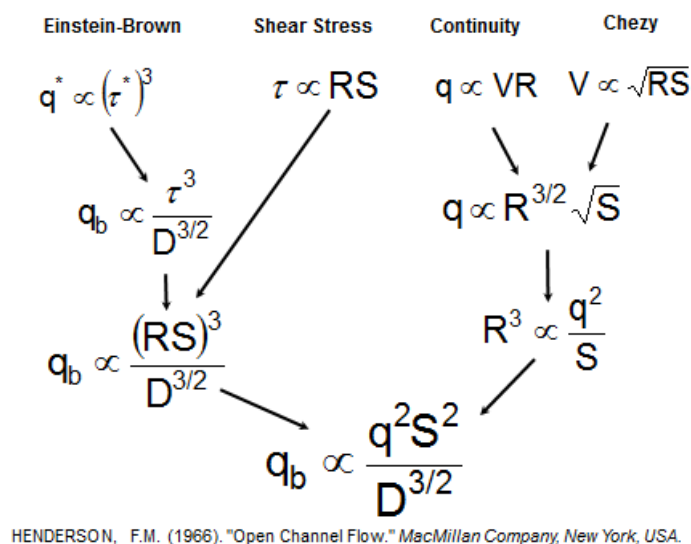


Figure 12-5. Sediment Transport and Discharge Relationship

For the purpose of interpreting past or future channel change, this relation can be solved for slope (S) and written twice as a ratio for the same reach at two different time periods.

$$\frac{S_2}{S_1} = \sqrt[3]{\frac{q_{b2}}{q_{b1}} \left(\frac{D_2}{D_1} \right)^{3/4} \left(\frac{q_1}{q_2} \right)} \quad \text{Equation 12-1}$$

This relationship can be applied to the evaluation of channel change if D and q_b are the grain size and rate of sediment supply to the reach and q is the water supply to the reach. In this case, slope can be interpreted as the slope necessary to transport the sediment supplied (at rate q_b) with the available flow q . An increase in S ($S_2/S_1 > 1$) is not likely to be associated with a large increase in bed slope (which would generally take a very long time), but rather indicates a tendency for the channel to accumulate sediment and aggrade under a future watershed condition. A decrease in S represents degradation, or a tendency

for the channel to incise. In most cases, little reliable information sediment supply is available. Nonetheless, this relation provides a useful relative estimate of the tendency of the channel to aggrade or degrade. Such an estimate may be at least as reliable (and perhaps more reliable) as that provided by more detailed calculations based on highly uncertain boundary conditions. Of particular interest is the delivery of coarse sediment that would be transported as bedload. Relatively coarse sediment (approximately the upper 35% of the bed material grain size distribution) has a disproportionately greater influence on stable channel slope compared to fine material. Therefore, the effect of reduced sediment delivery on channel stability depends primarily on the extent of imperviousness, channel erosion, and sediment trapping in areas of the watershed that yield coarse sediment, as opposed to the overall degree of development and impervious surfaces.

One of the challenges in applying equilibrium relationships based on sediment transport theory is the selection of appropriate dominant discharges to use in comparisons of pre- vs. post development conditions. Estimates of dominant discharge based on frequency analysis of peak flows do not directly account for the effects of urbanization on the frequency and duration of sediment transporting events.

Effective discharge analysis provides a more physically rigorous approach to quantifying the range of flows that are most responsible for transporting sediment and performing geomorphic work over engineering time scales. Such an approach allows designers to consider the full range of sediment transporting flows across the flow duration curve if continuous hydrologic data are available or can be generated through modeling for at least one, and preferably two to three decades of baseline and future conditions. Because it typically requires continuous hydrologic modeling (as opposed to single event), the effective discharge or “erosion potential” approach is more technically demanding and resource intensive. Nonetheless, for sand bed and labile channels the additional information this approach provides on cumulative sediment transport capacity across the full spectrum of sediment transporting flows is often essential for identifying a rational equilibrium slope.

If an applicant is considering sediment transport analysis to determine an interim channel slope, a meeting with the City Engineer should be held to review and agree on the methods of sediment transport/channel stability analysis before any formal submittal.

3.1.2.3 Estimating Historical Slopes

If field investigations or analyses of historical data indicate that channel conditions are currently in equilibrium, then measurements of the existing bed slope in the field or from topographic mapping can be used to provide a starting point for evaluating changes that may occur due to increased volume, flow rates and changes to sediment supply in the future. Channel slopes can vary along a stream reach so care must be exercised to utilize a slope value representative of the entire reach under design. Potential indicators of historical or on-going degradation include exposed infrastructure (pipe crossings or bridge foundations), extensive bank erosion and steep channel banks where the channel invert is below the roots of adjacent bank vegetation or has begun to expose them. Historical topographic mapping, FEMA studies, bridge or other structure design drawings can also provide insight on changing conditions. If field investigations or historical data indicate that channel conditions may not currently be in equilibrium, then data from a historical time when equilibrium conditions existed (aerial photos, maps, photos, etc.) should be used to estimate the historical slope. Potential sources of historical slope data include historical topographic mapping, previous studies and historical design drawings for structures. Stable reference streams or reference reaches can be used to estimate a stable slope. Geomorphic analysis of channel bank and valley slopes can be used to estimate channel slope for pre-development (undisturbed) conditions. The selection of reference reaches and geomorphic analysis of bank and valley slopes may be highly subjective and should be carried out only by qualified professionals with experience in geomorphology. The key is to

select reference reaches that have approximately the same sediment supply, valley setting and boundary conditions. In many instances these criteria are only met just upstream if they are met at all. Downstream reference reaches are sometimes adjusted to the increased sediment delivery provided by unstable design reaches that are upstream. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique* (USDA 1994) provides guidance on field measurement techniques.

3.1.2.4 Detailed Sediment Transport Analysis

A detailed sediment transport analysis may be appropriate when potential cost savings and available data are sufficient to justify the level of expertise and technical analyses required to produce reasonable results. These approaches to sediment transport analysis generally require using computer-based modeling. The most commonly used one-dimensional sediment transport model is HEC-6; however, most of its functions have now been incorporated into HEC-RAS. Other models that represent two-dimensional or even three-dimensional conditions are available, but are very computationally intensive and are not generally applicable for most routine channel design projects. The greater level of detail possible with a computer-based modeling approach includes:

- **Geometry:** Variations in channel geometry along reach can be modeled (mobile bed options only).
- **Sediment Data:** Sediment gradation data is utilized in the model and can be varied along the length of the channel reach depending on the number of samples taken. Most sediment transport models route sediment by size fraction and can simulate armoring (mobile bed option only).
- **Sediment Inflow Data:** A critical input into sediment transport models is the amount of sediment that is expected to enter the upstream end of the study reach or that might enter through tributaries along the study reach. This can be very difficult data to obtain or estimate.
- **Hydrology:** Measured or synthetic long-term hydrology (years) or hydrographs for single events can be discretized and modeled.

In spite of the greater level of detail, sediment transport modeling results can still have a wide margin of error and must usually be evaluated for reasonableness by comparisons with more conventional methods. Even with the greater level of detail, both data and modeling will have significant limitations and results should generally be interpreted only as indicating trends or ranges of potential change rather than exact future stream grades. The HEC-RAS Version 4.1 Hydraulic Reference Manual opens the discussion on sediment transport modeling by noting: “Sediment transport modeling is notoriously difficult. The data utilized to predict bed change is fundamentally uncertain and the theory employed is empirical and highly sensitive to a wide array of physical variables.” In keeping with this cautionary statement, uncertainty associated with modeling results should be considered when interpreting results. One of the most significant limitations of HEC-6/HEC-RAS modeling is that lateral bank erosion processes are not effectively modeled.

Detailed sediment transport modeling has some significant practical challenges, including:

- Considerable cost is typically required to develop model input data (hydrology, sediment, geometry) and to carry out the modeling itself.
- The method does not lend itself to standardized or “cookbook” approaches that can be concisely presented in a criteria manual. Considerable expertise and experience related to sediment transport modeling, hydrology and geomorphology are required.

In general, the importance of conducting a sediment transport analysis increases with higher sediment supply, the extent to which sand dominates the channel bed material, and the overall liability of the channel, i.e. flow energy relative to the erodibility of the channel boundary and floodplain materials. Estimates of sediment transport capacity based empirical relationships are often highly uncertain when the results are used as absolute magnitudes of sediment transport. However, application of a consistent and appropriate sediment transport relation can be very useful and quite accurate in estimating *relative* transport capacities among stream segments. This is especially true if a comparable supply reach in equilibrium and without intervening tributaries exists upstream of the reach of management interest. In this case, the relative sediment transport capacity of the supply reach versus the design reach can provide a robust estimate of a target design slope for re-establishing quasi-equilibrium.

3.1.3 Utilize Vegetated Benches to Convey Overbank Flow

For existing natural channels, vegetated benches often exist just above the tops of the eroded baseflow channel. When the historic natural floodplain is preserved and flows from upstream of the project reach are not expected to increase, it is likely that the undisturbed overbank areas of natural channels will be stable and require little or no stabilization. Raising the invert of degraded channels usually establishes a favorable overbank geometry. If necessary, benches can be excavated adjacent to the low-flow channel, especially if impacts to existing vegetation are minimal. It may be necessary to re-establish or supplement vegetation on the overbanks to build up a sturdy, durable cover to help retard flood flows and resist erosion. Except for the delineation of the floodplain limits, the hydraulic characteristics of this portion of the natural channel should not be a design consideration when the natural floodplain is stable and preserved.

3.1.4 Stabilize Eroding Banks

Steep unstable banks existing within the 100-year floodplain should be sloped back and stabilized. On a plan-view topographic map, designers shall indicate the location, height and existing slope of any unvegetated, steep, or otherwise unstable banks within the 100-year floodplain, along with the proposed approach for stabilizing the banks. This may occur where the low-flow portion of the channel has meanders that impinge on the outer channel banks.

The designer shall consider the existing bank conditions and angle of attack, the estimated potential for future erosion, and the proximity of infrastructure that could be impacted by the bank erosion as a basis for determining the appropriate method for bank stabilization. Other channel characteristics such as channel geometry, longitudinal slope, existing vegetation, underlying soils, available right-of-way and expected flow conditions shall be considered and analyzed with respect to the various potential improvements.

Unstable banks shall be protected using one of the following approaches.

1. **Sloping Back Banks:** Steep, unstable banks shall be cut back to a flatter slope and revegetated. The maximum permissible slope shall generally be 4H:1V (horizontal:vertical). Reducing bank slopes to 6H:1V or flatter will assist in the establishment and viability of vegetation, the stability of channel banks and accessibility of the waterway for recreation. Designers are encouraged to utilize flatter slopes whenever possible. In some locations, right-of-way constraints may dictate steeper slopes. In such areas, slopes up to 3H:1V may be permitted with appropriate slope protection and approval.
2. **Riprap Bank Protection:** Riprap bank protection is widely used to stabilize channel banks along the outside of existing channel bends and along steep banks that cannot be graded back

sufficiently due to right-of-way constraints, where flow velocities are too high, or where overbank grades are too steep. Riprap bank protection shall be designed in accordance with the Major Drainage Chapter of the UDFCD Manual. All riprap bank protection shall consist of soil riprap that is buried with topsoil and revegetated.

The riprap need only extend up the slope to where shear stresses do not exceed those for natural unlined channels as defined in Table 12-2. By applying those allowable shear stress limits to the equation for shear stress, the vertical distance from the 100-year water surface to the upper limit of the riprap layer can be calculated as follows:

If $\tau = \gamma dS$, then

$$d = \tau / \gamma S \quad \text{Equation 12-2}$$

For Erosive Soils, $\tau = 0.6 \text{ lb/sf}$ and if $\gamma = 62.4 \text{ lb/cf}$, then

$$d = 0.0096 / S \quad \text{Equation 12-3}$$

For Erosion Resistant Soils, $\tau = 1.0 \text{ lb/sf}$ and if $\gamma = 62.4 \text{ lb/cf}$, then

$$d = 0.0160 / S \quad \text{Equation 12-4}$$

Where:

d = vertical distance below 100-year water surface

S = channel overbank slope in ft/ft

3. **Bioengineered Bank Protection:** Experience with the application of bioengineering techniques to protect channel banks is growing along the Colorado Front Range. Bioengineering techniques are discussed in the Major Drainage Chapter of the UDFCD Manual.

3.1.5 Analyze Floodplain Hydraulics

The floodplain associated with existing or modified natural channels shall be analyzed using HEC-RAS to delineate the 100-year floodplain and evaluate flow velocities to assess drainageway stability based on flow rates for the range of design flows. It is important to analyze floodplain hydraulics based on conditions that are likely to cause the greatest resistance to flow and the highest water surface elevations in the short term and over time. Some of these conditions may include the following:

- Increased baseflows and runoff from development that promote increased growth of wetland and riparian vegetation, making drainageways hydraulically rougher.
- Stream restoration work that raises the bed of incised channels to levels that existed prior to degradation or flattens channel slopes.
- Upstream bank erosion or watershed erosion, flatter slopes, and increased channel vegetation that lead to sediment deposition and channel aggradation, raising streambed and floodplain elevations.

An accurate delineation of the floodplain is also necessary for laying out development projects and setting lot and building elevations adjacent to the floodplain according to the freeboard requirements defined in Chapter 5, Floodplain Management. For facilities that are not structures (typically not requiring a

building permit) such as roadways, utility cabinets, parks and trails improvements, etc., a minimum of 1 foot of freeboard is desirable. Assessments of freeboard at bends shall take into account super elevation calculated in accordance with the Major Drainage Chapter of the UDFCD Manual. The required freeboard should be contained within a floodplain tract and/or easement.

Incised or eroded channels shall not be analyzed based on their existing geometry, but on the geometry representative of a restored natural channel, as illustrated in Figure 12-1. Otherwise, the floodplain may be inappropriately low, constraining future restoration efforts such as installing grade control structures that raise the channel bed back to earlier conditions.

3.1.5.1 Floodplain Encroachments

Floodplain encroachments that reduce natural channel storage and increase downstream flows or velocities are discouraged. However, when encroachments are approved and proper documentation is submitted and approved as described in Chapter 5, Floodplain Management, channel hydraulics must be fully analyzed to ensure that the remaining natural channel features or designed low-flow channel are stable during flood flows. To ensure that encroachments into natural floodplains are stable, the criteria in Table 12-2 shall be confirmed through a hydraulic analysis of the low-flow channel and the residual floodplain during the 100-year flood event.

3.1.6 Consider Aquatic Ecology

When streams or major drainageways, such as Fountain Creek, have conditions that are favorable for supporting fish, additional consideration should be given to the baseflow and low-flow channel designs to provide conditions that are consistent with good aquatic ecological conditions, fish habitat and fish passage.

The Colorado Division of Wildlife currently lists 14 species of fish as endangered or threatened at the state or federal level. An additional 9 species are listed as state species of concern (CDOW 2011). The majority of these species are small plains fish, whose natural habitat includes the plains and transition zone stream systems throughout the Front Range where urbanization impacts have been greatest. Several species of cutthroat trout are also included on the list. Trout are most prevalent in the foothills and higher elevations where colder water temperatures and coarser substrates are found.

Aquatic habitat is degraded in a variety of ways by watershed urbanization and stream modification. Potential impacts include water quality, water quantity, loss of bank vegetation, bank erosion and channel invert degradation. Implementation of the natural stream design principles presented in this Manual can significantly help preserve or improve aquatic habitat. Important aquatic habitat design considerations include:

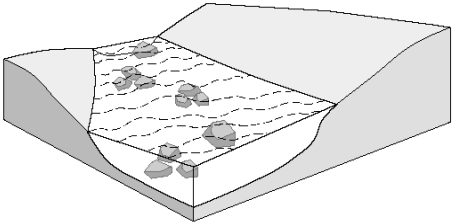
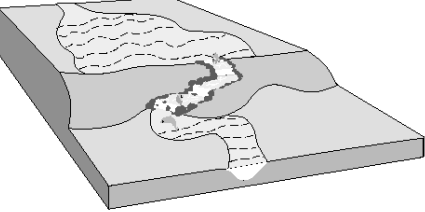
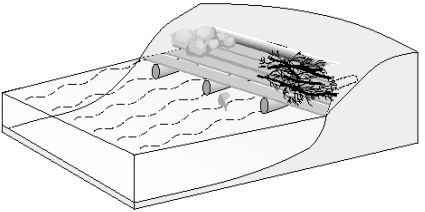
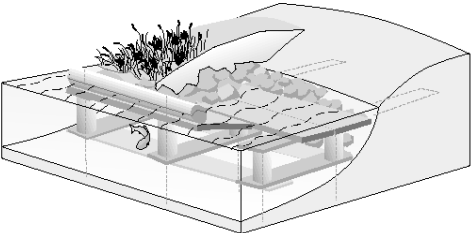
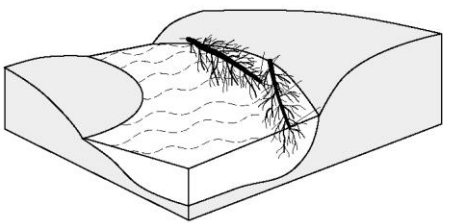
1. **Water Temperature.** Water temperature is one of the most important factors in determining the distribution of fish in freshwater streams (FISRWG 2001). Feeding and spawning activities are often keyed to water temperatures, and high water temperatures can be lethal to some species. Often in degrading stream systems, bank erosion results in a loss of perimeter vegetation and a widened channel bottom that produces shallow-flow depths. Limiting baseflow channel widths to increase typical flow depths and providing bank vegetation for shading can reduce solar heating of the water.
2. **Cover and Refuge.** Providing cover in the form of overhead vegetation, boulders, large woody debris, pools and other irregular features provides fish with spawning areas, protection from predation, and habitat for species that are critical to the food chain. Channel design elements

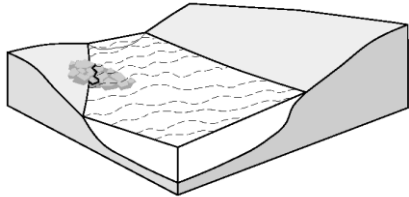
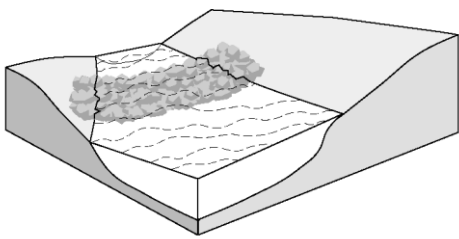
that can contribute to enhanced cover include pool and riffle sequences, a variety of vegetation types along the channel edge, variations in baseflow channel geometry, scour holes, groupings of boulders, and woody debris such as root wads and logs in various configurations. Several resources for the design of fish habitat enhancement structures are included in the references for this chapter.

3. **Habitat Diversity.** Diversity of habitat and hydraulic conditions allows for a greater diversity of species and a richer ecosystem. Channel designs can incorporate riffles, pools, small drops, boulders, large woody material, changes in channel geometry and a variety of riparian plant types to create diversity.
4. **Water Quality.** High organic matter and chemical content is common in urban stream systems. Channel designers typically have limited ability to change or rectify these conditions; however, identifying and understanding the characteristics of these sources should be incorporated into the project design. Sources typically include wastewater treatment plant discharges and urban runoff carrying various chemicals, fertilizers, yard cuttings and other organic matter. High organic content can lead to low dissolved oxygen levels and the death of aquatic organisms. Shading of channels with vegetation to reduce water temperatures and riffle and drop structures to induce aeration can help with this problem.
5. **Substrate.** Sand and silt substrates are generally the least favorable alluvial materials for supporting aquatic organisms and support the fewest species and individuals (FISRWG 2001). Smooth bedrock surfaces devoid of alluvium, which exist in many degraded stream systems along the Front Range, are even less favorable. Raising degraded channel invert with grade controls can naturally restore alluvial channel bottoms. Riffles and other rock structures can also add diversity to the substrate.
6. **Hydrology.** Both increases and decreases in natural channel flows can have adverse impacts on aquatic habitat. Withdrawals of water for agricultural, industrial and municipal uses can reduce stream flows to essentially dry conditions at some times of the year. Increases in flows from lawn watering return flows, runoff associated with increased imperviousness, and wastewater treatment plant discharges increase velocity and shear and can erode channel banks and bottoms removing habitat features and cover. Higher velocities can impede migration and reduce the portion of a stream that is habitable by native plains fish species, which are generally weak swimmers.
7. **Stream Crossing Structures.** Most plains fish species, unlike salmon and trout species, are relatively weak swimmers and have limited or no jumping capability. Because of this, stream crossing structures, such as grade controls, culverts or bridges, which create high velocity flows or small discontinuities in the water surface, can be an impediment to migration. Most plains fish species have ranging and migration for spawning behaviors that make stream connectivity critical to their survival (Ficke and Myrick 2010). Disconnecting stream segments with impassible hydraulic structures results in genetic isolation, which also degrades species viability. Two recent studies at Colorado State University on plains fish swimming performance and fish passage design recommendations are provided in the list of references for this chapter.

Maintaining natural stream systems and corridors is the best way to provide adequate and sustainable habitat for fish. Where restoration is taking place or where natural stream functions are limited by urbanization impacts, structures specifically constructed to enhance fish habitat may make sense. Table 12-3 provides a summary of the basic techniques most commonly employed, when they may be appropriate and cautions in their use. The References Chapter of this manual contains additional information on these types of structures.

Table 12-3. Fish Habitat Structures

Technique	Application/Description
	Boulder Clusters • Groups of boulders placed in the baseflow channel to create cover, scour holes and velocity refuges. • Not appropriate in sand-bed streams (boulders tend to sink into the scour holes they create). • Use caution with placement - can cause bank erosion. • Not appropriate in aggrading or degrading streams. • Can promote bar formation in high bed-load streams.
	Fish Passages • Variety of structure types intended to provide passage for fish over man-made obstructions such as dams or grade controls. • Typically expensive. • Can be rendered ineffective by stream invert degradation.
	Log/Brush/Rock Shelters • Log, stone and/or brush shelters constructed at the bank toe to provide overhead cover. • Inappropriate in streams where invert is aggrading or degrading. Stable invert and water levels are required. • Inappropriate where heavy bed-load movement exists. • Not recommended in areas of highly unstable banks.
	Lunker Structures • Submerged cells constructed of heavy wood and stone at the bank toe to provide cover for fish. • Typically expensive. • Inappropriate in streams where invert is aggrading or degrading. Stable invert and water levels are required. • Inappropriate where heavy bed-load movement exists. • Not recommended in areas of highly unstable banks.
	Tree Cover • Felled trees secured to bank to provide habitat, velocity refuges and bank protection. • Inexpensive if trees available on-site. • Must be adequately anchored to prevent transport and possible damage to downstream structures during floods. • Have the potential to cause bank erosion.

Technique	Application/Description
	Wing Deflectors • Log, root wad or stone protrusions from the channel bank providing diversity, cover and velocity refuges. • Can help stabilize banks by slowing and deflecting flows. • Failure from undermining or erosion of banks possible especially in sand-bed streams.
	Sills and Grade Controls • Log, stone or concrete structures placed across channel. • Can control invert degradation, improve bank stability, restore alluvial bottom, provide habitat diversity, cover and velocity refuges. • Can impede upstream fish movement. • Can be undermined, especially in sand-bed streams. • Crest design and orientation important to avoid wide shallow flows, bank erosion and upstream aggradation.

3.1.7 Undertake Major Drainageway Plan Improvements if Required

In addition to the six mandatory design elements discussed in Sections 3.1.1 through 3.1.6, additional major drainageway plan improvements may be required on a case-by-case basis.

3.2 Minor Drainageways

Constructed natural channels, including grass-lined channels or composite channels, shall generally be used for minor drainageways. However, constructed channels that are riprap-lined, concrete-lined or manufactured lining types may be necessary due to project constraints. The use of conduits is discouraged and must be approved on a case-by-case basis.

3.2.1 Constructed Natural Channels

Because the upstream drainage basin conditions are expected to change dramatically for minor drainageways, resulting in higher flows and low sediment loads, it is likely that creating a naturalistic channel design will require significant regrading of unimproved channels. This will generally require the removal and reestablishment of natural vegetation, rather than its preservation.

For constructed drainageways designed to emulate unlined natural channels, the parameters in Table 12-2 shall be achieved for both the low-flow and the 100-year event. Existing natural features should be protected to the extent practical. Hydraulic modeling shall be based on the channel and overbank definition shown in Figure 12-3 and on the roughness information identified in Table 12-6. Constructed natural channels must be analyzed for both higher velocity conditions, when projects are newly completed and vegetation may not have matured, and for higher flood potential and capacity conditions, when vegetation has fully matured and creates the greatest resistance to flow.

3.2.2 Grass-Lined Channels

Grass-lined channels are an option for minor drainageways, especially where the tributary area is relatively small and minimal baseflows are expected. Sod-forming native grasses suited to wetter conditions are recommended for grass-lined channels. See Chapter 14 for vegetation recommendations. If irrigated bluegrass sod is proposed, a small baseflow channel shall be provided and vegetated with the wetter, sod-forming native grasses. Hard-lined baseflow channels are not desired in grass-lined channels. Grade control structures or rock stabilization in the bottom of the channel may be necessary if velocities or longitudinal slopes exceed the values in Table 12-4.

Design criteria and guidance for grass-lined channels are provided in the Major Drainage Chapter of the UDFCD Manual, in addition to the key design features summarized in Table 12-4.

Table 12-4. Hydraulic Design Criteria for Grass-Lined Constructed Natural Channels

Design Item	Grass: Erosive Soils	Grass: Erosion Resistant Soils
Maximum 100-year velocity	5.0 ft/s	7.0 ft/s
Minimum Manning's "n" for capacity check	0.035	0.035
Maximum Manning's "n" for velocity check	0.030	0.030
Maximum Froude number	0.5	0.8
Maximum 100-year depth outside low-flow zone	5.0 ft	5.0 ft
Maximum channel longitudinal slope	0.6%	0.6%
Maximum side slope	4H:1V	4H:1V
Maximum centerline radius for a bend	2 x top width (200 ft min.)	2 x top width (200 ft min.)

¹ Velocities, Froude numbers and tractive force are average values for the cross section.

² "Erosion resistant" soils are those with 30% or greater clay content. Soils with less than 30% clay content shall be considered "erosive soils."

3.2.3 Composite Channels

Composite channels include a low-flow channel and a constructed floodplain that will normally convey flows much greater than undeveloped flows. The Major Drainage Chapter of the UDFCD Manual describes circumstances where the use of a composite channel may be appropriate and provides guidance for their design.

3.2.4 Wetland-Bottom Channels

There are circumstances where the use of a wetland-bottom channel may be appropriate. These channels are a special case of composite channels where it is intended that the lower portion of the low-flow channel be designed to support wetland plants. Guidance for wetland-bottom channels is also provided in the Major Drainage Chapter of the UDFCD Manual and Treatments BMPs Chapter in Volume 3 of the UDFCD Manual.

3.2.5 Bioengineered Channels

When bioengineered channel treatments are included in composite channels, they shall be designed using the guidance provided in the Major Drainage Chapter of the UDFCD Manual.

3.2.6 Constructed Channels

Constructed channels may be necessary when the upstream drainage basin is highly developed and design flows are significantly greater than undeveloped flows, when sediment loads are low, and where available right-of-way is restrictive. These channels retain few of the benefits of natural channels and primarily function as flood conveyance structures. Because these channels are generally steep and the flow is confined, design velocities tend to be higher, requiring a hardened channel lining to maintain stability. However, there are maximum velocity limitations on these channels; therefore, drop structures must be used to reduce design slope and lower velocities to acceptable limits. These structures will typically be designed for 100-year flows and will most often be lined with riprap, soil riprap, or concrete, but may also be lined with manufactured systems.

Because these types of channels eliminate any overbanks or floodplains, base-flow channels or low-flow channels do not normally provide a benefit. The use of base-flow or low-flow channels in these types of channels can help to pass sediment through the system and reduce maintenance requirements if sediment loads are present; however, in many cases, the available sediment load will be limited.

3.2.6.1 Riprap-Lined and Concrete-Lined Channels

The use of plain (not buried) riprap-lined or concrete-lined channels is generally discouraged, but they will be considered for minor drainageways on a case-by case basis. Design criteria for concrete-lined and riprap-lined channels are provided in the Major Drainage Chapter of the UDFCD Manual. Freeboard requirements for riprap and concrete-lined channels shall be the same as those given above for grass-lined channels. Additionally, if supercritical flow is present in concrete-lined channels, freeboard shall be computed in accordance with the Major Drainage Chapter of the UDFCD Manual.

4.0 Grade Control Structures

Grade control structures provide energy dissipation and are used to establish flatter design slopes and moderate flow velocities in the upstream channel reach. Table 12-5 provides typical maximum drop heights for grade control structures. Grade control structures are normally constructed as hardened drop structures, but may be implemented in other forms, such as rock riffles, with approval. Common approaches shall be considered when implementing grade control structures, as discussed below.

Table 12-5. Grade Control Drop Height Limits

Capacity of Grade Control Structure	Maximum Drop Height (feet)
Low-flow Discharge	1.5
Between Low-flow and 100-year	2.5
100-year and Greater	4.0

4.1 Low-Flow Drop Structures

Low-flow drop structures are grade control structures that extend only across the low-flow channel to provide control points to limit degradation at specific locations and to establish flatter thalweg slopes. During a flood event, portions of the flow will circumvent the structure and travel in the overbank portion of the channel. These structures are only appropriate for natural channel types or for constructed natural channels when overbank conditions do not exceed the allowable limits so that full-width drop structures are not necessary. When overbank conditions exceed allowable limits for vegetated channels in Table 12-2, it will be necessary to design a full-width, 100-year drop structure as described in Section 4.2.

Typically, low flows are contained within the hardened portion of these structures and fill the full cross section of the structure without freeboard. Low-flow drop structures are not appropriate within completely incised floodplains or very steep channels where the velocities shown in Table 12-2 cannot be achieved.

To provide a stable structure, secondary design flows must also be evaluated. The secondary design flow is the flow that causes the worst condition for flow around the sides of the structure, stability within the structure, or as flows return back into the low-flow channel downstream (i.e., a 5-year, 10-year, or 100-year event). Designers must evaluate site-specific hydraulics to determine the extent of surface protection and where in the cross section it may be appropriate to transition to softer types of protection such as vegetated soil riprap. One approach to analyze the hydraulics of low-flow drops is to estimate unit discharges, velocities and depths along overflow paths. The unit discharges can be estimated at the crest or critical section for the given total flow. Estimating the overflow path around the check can be difficult and requires judgment. The flow distribution option in HEC-RAS may be used to assist in evaluating minimal or reasonable damage to the floodplain below.

The minimum crest depth (from the invert of the crest to the top of the structure at the beginning of the overbank area) for low-flow drop structures is 1.5 feet. The maximum drop height of low-flow channel grade control structures shall generally be limited to 1.5 feet.

Seepage control is also an important consideration because piping and erosion under and around these structures can contribute to their failure. It is essential to provide a cutoff wall that extends laterally at least 5 to 10 feet into undisturbed bank and that has a depth appropriate to the profile dimension of the drop structure.

Check structures described in the UDFCD Manual are implemented within the UDFCD as temporary devices with the expectation that drop structures will replace the check structures as the channel degrades. This approach is not appropriate when long-term improvements must be completed with limited capital funds or for cost estimates for long-range basin plans. Rather than constructing temporary check structures, it is more appropriate to construct fewer permanent drop structures within a project reach with the goal of adding additional structures later. However, this approach is only appropriate if a funding source is available for completing the later improvements. In any case, channels must be designed for ultimate conditions so that adequate funding can be identified for permanent channel improvements as needed.

Design guidance for low-flow grade-control structures is provided in the Hydraulic Structures Chapter of the UDFCD Manual.

4.2 Full-Channel-Width 100-Year Drop Structures

Full-channel-width drop structures are structures that are designed to convey the major flood flow within the structure and to provide a stepped invert profile so that channel velocities (both in the low-flow channel and in the overbank area) do not exceed allowable limits. These structures are necessary in constructed natural channels and constructed channels when 100-year flood flow velocities exceed allowable limits. Each drop structure location is unique and designers should evaluate the required extent of hardened drop structure materials across the floodplain for each individual structure. Often grouted boulders do not need to extend to the limit of the 100-year floodplain, even where channels are incised to some degree and the floodplain has been encroached upon. Shear and velocity values typically decrease with increasing distance from the main channel; therefore, transitions to soil riprap and then to vegetation may be feasible. These floodplain hydraulic characteristics should be evaluated and hardened surfaces and soil riprap used only where necessary to minimize costs and enhance aesthetic and environmental qualities.

The Hydraulic Structures Chapter of the UDFCD Manual provides drop structure design considerations, procedures and details, discussion regarding various types of structures, and construction considerations.

4.2.1 Constructed Natural Channel Drop Structures

When deep channel incision and/or development in the floodplain or increased flood flows have already occurred, the potential for channel restoration may be limited. In such cases, drop and grade control structures may be necessary to convey the major flood without causing significant damage. The maximum allowed height for such structures is 4 feet. This criterion has been established to limit channel incision, minimize the amount of bank stabilization required, avoid developing excessive kinetic energy, avoid lowering of the groundwater table, and minimize the obtrusive appearance of massive structures.

In addition to these standard criteria, designers should consider the necessary extent of grouted rock or other hardened surface material. It may not be necessary for the hardened surface to extend across the entire 100-year waterway to provide 100-year protection. Instead it may be possible to transition to softer treatments such as vegetated soil riprap at the point in the floodplain where velocities and shear stresses are sufficiently reduced according to the criteria defined in Table 12-2.

4.2.2 Constructed Channel Drop Structures

Constructed channel drop structures are placed in channels that are fully hardened and under significant hydraulic stresses. These conditions require full-width, 100-year drop structures and shall be designed in accordance with the guidance provided in the UDFCD Manual.

4.3 Drop Structure Types

The use of drop structure types and configurations that are functional, natural-looking, provide for fish passage, and blend-in with the drainageway and surrounding environment are encouraged. The most common type of drop structure in Colorado's Front Range communities is the grouted sloping boulder drop structure. Grouted boulders can be used to develop more unique, natural looking configurations such as a horseshoe-arch shape or stepped configurations. Other drop types that have been used in the region include sheet pile drops, sculpted concrete drops, and soil cement drops. The sculpted concrete drops have become more popular for aesthetic reasons, particularly in upland prairie settings. The concrete is shaped, sculpted, and colored with earth tones to emulate natural rock outcroppings. Use of the following drop structure types is preferred:

- Grouted sloping boulder
- Grouted boulder in natural configurations
- Sculpted concrete.

Design guidance, detailed design criteria, and construction details have not been developed by the UDFCD for sculpted concrete drop structures. It is the responsibility of the design engineer to develop and provide detailed construction drawings, based on previous experience in the design of sculpted concrete drop structures or review of past designs that have been constructed in the Denver Metro area.

The use of soil cement and roller-compacted concrete drop structures may be allowed, but only on a case-by-case basis. Steady baseflows can quickly erode soil cement, especially when there is significant sediment being transported. Soil cement structures may be provided with a hardened low-flow channel to prevent erosion or should be reserved for ephemeral or intermittent channels. Specifications and construction quality control needed for soil cement and roller-compacted concrete are extensive and generally must be in accordance with standard specifications developed by organizations such as the Portland Cement Association.

Vertical drops greater than 2 feet in height are not permitted for safety reasons. In dry conditions, the vertical face presents a fall hazard. Under flowing conditions, reverse flows on the downstream face can form dangerous “keeper” hydraulic conditions. Vertical drops greater than 2 feet in height may be permitted, but drop heights should consider fish passage if the stream supports a fishery. Additionally, they should be constructed of natural or natural appearing materials such as grouted boulders. The use of sheet pile or cast-in-place concrete walls for these structures is generally discouraged for aesthetic reasons.

Other methods of constructing low-flow drop structures, including rock riffles, ungrouted boulder drops and boulder cross vanes, may also be acceptable when floodplain and hydraulic conditions are appropriate for their use and when properly designed. These types of structures will generally not be appropriate in situations where there has been significant encroachment into the floodplain, where an incised channel condition will exist, or where urbanization has significantly increased peak flood flows. Approval of the use of such structures will be on a case-by-case basis.

Where fish passage is a concern at grade control structures, additional information can be found in the references provided at the end of this chapter and in the Colorado Springs Manual. Designing to accommodate fish passage must first identify target species and then establish adequate flow depths, meet maximum allowable flow velocities and distances between refuges and meet maximum vertical drop heights (if any). A variety of configurations are possible, but given the very limited swimming and jumping capabilities of plains fish, use of separate fishways or ramps that allow steeper slopes across the main channel portion of a drop structure will often be the most economical approach. In addition to the swimming and jumping performance criteria previously mentioned, the design of separate fishways requires careful attention to flows and a crest design that ensures the entrance to the fishway has adequate depth and does not become obstructed by sediment or debris over time. A high level of care, attention to detail, and supervision will generally be required during construction of any fish passable structure to ensure the constructed passage meets stringent criteria.

4.4 Drop Structure Placement

The distance between drop structures varies with the difference between the bank slope and the design slope and the height of the upstream structure. The distance between drop structure crests is determined

by dividing the height of the upstream structure by the difference between the top of bank slope and the invert design slope. By intersecting the design slope with the toe of the face of the upstream drop structure, the proper relationship between the drop structures will be maintained. Drop structures must extend down below the design slope to provide protection from local scour and long-term degradation that might extend below the estimated design slope.

Drop structures may also need to be placed where necessary to protect upstream infrastructure or to control water surface elevations to divert flood flows into detention facilities or diversion channels.

5.0 Revegetation

Revegetation efforts and selection of appropriate vegetation are critical elements of all channel design projects. Chapter 14 of this Manual provides guidelines for revegetation efforts. These guidelines shall be followed for all major and minor drainageway design projects.

6.0 Easements, Ownership and Maintenance

6.1 Easements

Drainage easements are required in order to allow access for proper maintenance and operation of open channels. Drainage easements shall be granted to the party responsible for inspection and maintenance purposes, and shall be shown on the drainage plan, final plat and final development plan. Drainage easements shall be kept clear of impediments to flow and access.

Minimum easement widths shall provide for conveyance of design flow rates, the required freeboard, and access for maintenance. Narrow existing channels and high flow velocities merit consideration of easements that may be wider than the existing floodplain limits or minimum values. A specific exception shall be any banks allowed to remain in place at a slope steeper than 4H:1V. Such banks shall have the easement line set back from the top of the bank to allow for some lateral movement or future grading improvements to the bank. The easement line shall be no closer than the intersection of a 4H:1V line extending from the toe of the slope to the proposed grade at the top of the bank, plus an additional width of 15 feet for an access bench if access is not feasible within the floodplain.

6.2 Ownership

To ensure that drainageways and the associated conveyances are adequately preserved and properly maintained, all major and minor drainageways that convey flows from other properties should be placed on tracts of land owned by a public entity (e.g., special district, homeowner's association, county, and other regional agencies). If the drainageway runs through private land, the City will require a drainage easement for any improvements to the reach.

6.3 Maintenance

6.3.1 Design for Maintenance

Open channels and swales should be designed to minimize maintenance requirements and efforts and with adequate maintenance access to ensure continuous operational capability of the drainage system. When provisions for maintenance access are being developed, consideration must be given to the potential maintenance activities and the equipment normally used to perform those activities. Designs that rely on

the establishment of a vegetative cover, such as bioengineered or grass-lined channels, must include a plan for establishment, including temporary or permanent irrigation of the area.

Continuous maintenance access, such as with a trail, shall be provided along the entire length of all major drainageways. Depending on the channel size, tributary area, expected maintenance activities, and the proximity of local streets and parking areas, a continuous stabilized trail may be required along minor drainageways. The stabilized maintenance trail shall have a stabilized surface at least 8 feet wide and a minimum clear width of 12 feet for a centerline radius greater than 80 feet and at least 14 feet for a centerline radius between 50 and 80 feet. At drop structures, the minimum clear area shall be 20 feet. The minimum centerline radius shall be 50 feet. The maximum longitudinal slope shall be 10 percent. The responsible party may require paving with asphalt or concrete, otherwise, as a minimum the road shall be surfaced with 6 inches of CDOT Class 2 road base. Under certain circumstances, adjacent local streets or parking lots may be acceptable in lieu of a trail for major drainages.

6.3.2 Maintenance Responsibility

Maintenance responsibility lies with the owner of the land, except as modified by specific agreement. Maintenance responsibility shall be delineated on the Final Plat and described in the Final Drainage Report, or right-of-way conveyance documents. Maintenance of an open channel includes routine maintenance such as periodic sediment and debris removal. Channel bank erosion, damage to drop structures, low-flow channel deterioration, and other channel degradation must be repaired to avoid reduced conveyance capability, unsightliness, water quality issues, safety issues, and ultimate failure. Maintenance operations shall be in accordance with the approved Operations and Maintenance Manual (O&M Manual) for the project.

Table 12-6. Roughness Coefficients

Channel Description	Roughness Coefficient (n)		
	Minimum	Typical	Maximum
Natural Streams (top width at flood stage <100 feet)			
1. Streams on Plain			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as c, but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain Streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. Bottom: gravels, cobbles, and few boulders	See Jarrett's equation*		
b. Bottom: cobbles with large boulders			
Major Streams (top width at flood stage > 100 feet)			
1. Regular section with no boulders or brush	0.025		0.060
2. Irregular and rough section	0.035		0.100
Grass Areas **	**Flow Depth = 0.1-1.5 ft		Flow Depth > 3.0 ft
1. Bermuda grass, buffalo grass, Kentucky bluegrass			
a. Mowed to 2 inches	0.035		0.030
b. Length = 4 to 6 inches	0.040		0.030
2. Good Stand, any grass			
a. Length = 12 inches	0.070		0.035
b. Length = 24 inches	0.100		0.035
3. Fair Stand, any grass			
a. Length = 12 inches	0.060		0.035
b. Length = 24 inches	0.070		0.035

*Jarrett's equation: $n = 0.39 S_f^{0.38} R^{-0.16}$, where S_f equals friction slope and R equals the hydraulic radius.

** The n values shown for the grassed channel at the 0.1- to 1.5-ft depths represent average values for this depth range. Actual n values vary significantly within this depth range. For more information, see the *Handbook of Channel Design for Soil and Water Conservation* (SCS 1954).

Chapter 13

Storage

Contents

1.0	Introduction.....	1
1.1	Stormwater Quality Considerations	1
1.2	Stormwater Volume Considerations	2
1.3	Downstream Impacts.....	2
2.0	Detention Requirements	2
2.1	General Requirements	2
2.2	Detention Requirements for Redevelopment	2
2.3	Detention Requirements for Expansion of a Developed Site	2
3.0	Types of Detention Storage Facilities	3
3.1	Scale of Implementation.....	3
3.1.1	Regional Detention	3
3.1.2	Sub-regional Detention	4
3.1.3	On-site Detention	4
3.2	Outlet Configurations.....	5
3.2.1	Full Spectrum Detention	5
3.2.2	Multi-level Outlet Configurations.....	6
4.0	Sizing Methodology	6
4.1	Volume.....	7
4.1.1	Flood Control Volume	9
4.1.2	EURV.....	9
4.1.3	Initial Surcharge Volume	10
4.1.4	Design Worksheets	10
4.2	Release Rates	10
4.2.1	Allowable Release Rates.....	10
4.2.2	EURV Release Rate	11
5.0	Detention Pond Design Guidelines.....	11
5.1	Pond Location and Configuration	11
5.1.1	Detention Pond Placement	11
5.1.2	Detention Ponds in Series	11
5.1.3	Interconnected Ponds	12
5.2	On-site Detention and Off-site Flows	12
5.3	Design Features	12
5.3.1	Discharge Location (Outlets)	12
5.3.2	Excavated or Embankment Slopes.....	13
5.3.3	Freeboard	13
5.3.4	Low-flow Channels.....	13
5.3.5	Bottom Slope	14
5.3.6	Wetland Vegetation (Constructed Wetland Pond)	14
5.3.7	Inlet Structures	14
5.3.8	Outlet Structures	14
5.3.9	Trash Racks.....	15
5.3.10	Emergency Spillway and Embankment Protection	16

5.3.11 Retaining Walls.....	17
5.4 Landscaping	17
5.5 Signage.....	18
5.6 Access Easements	19
5.7 Maintenance.....	19
5.7.1 Access	19
5.7.2 Other Improvements to Facilitate Maintenance	20
5.8 Construction Phasing	20
5.9 Downstream Channel Stabilization.....	20
6.0 Parking Lot Detention	21
6.1 Access Requirements	21
6.2 Maintenance Requirements	21
6.3 Depth Limitation	21
6.4 Emergency Spillway	21
6.5 Outlet Configuration	21
6.6 Flood Hazard Warning.....	21

Tables

Table 13-1. Detention Facility Sizing Methods	7
Table 13-2. Detention Volume Configurations	8

Figures

Figure 13-1. Regional Detention Concept.....	23
Figure 13-2. Sub-regional Detention Concept	23
Figure 13-3. On-site Detention Concept	24
Figure 13-5. Typical Low-flow Channel Details	26
Figure 13-7. Concept for Extended Detention Basin with a Benched Low-flow Channel	29
Figure 13-8. Concept for Integral Forebay at Pipe Outfall	30
Figure 13-9. Concept for Outlet Structure with Parallel Wingwalls and Flush Bar Grating.....	31
Figure 13-10. Concept for Outlet Structure with Flared Wingwalls and Handrail	32
Figure 13-11a. Emergency Spillway Profile at Roadway	33
Figure 13-11b. Emergency Spillway Profile at Embankment.....	33
Figure 13-11c. Emergency Spillway Protection.....	34
Figure 13-11d. Riprap Types for Emergency Spillway Protection	34

1.0 Introduction

Detention storage facilities are used to manage stormwater quantity, attenuating peak flows during flood events. Detention storage is necessary for new development, redevelopment and development expansion to mitigate the effects of increased runoff associated with development. These effects may include increased flooding potential, channel degradation and water quality degradation. In addition to providing flood control benefits, detention facilities can also be designed to enhance stormwater quality by incorporating design components to promote sedimentation, infiltration, and biological uptake.

The City of Woodland Park implemented requirements for detention for low-flows, minor and major events in 1994 via Resolution No. 299. The low-flow criteria is based on retaining (e.g. no discharge) 75% of the 2-year runoff volume based on a 0.8-inch, one-hour storm. The minor event is the 5-year event with a one-hour storm depth of 1.1 inches, and the outlet must be designed to release 5-year flows at or below historic levels. The major event is the 100-year event with a one-hour storm depth of 2.1 inches, and flows from this event must be released at a rate not to exceed the historic discharge rate. The storage volumes from these events must be added together to determine the total detention storage volume.

This chapter provides guidance for the analysis and design of storage facilities that are implemented independently or in combination with stormwater quality facilities. Additionally, this chapter provides guidance on “full-spectrum detention” designs that help to mitigate the effects of increased flow volumes on downstream channels. The UDFCD Water Quality Capture Volume (WQCV) approach and/or the Excess Urban Runoff Volume (EURV) approach that is the core of full spectrum detention may be used to satisfy the intent of City Ordinance No. 299 and may provide additional water quality and stream stability benefits relative to traditional multi-stage detention.

It is notable that the UDFCD WQCV, which corresponds to a rainfall depth of 0.6 inches, is very similar to the 75% of the 2-year, one-hour event that is the basis for the low-flow volume established in Resolution No. 299, Series 1994. The difference between the WQCV and the low-flow volume is that the low-flow volume is a retention volume (e.g. infiltration and/or evaporation of the captured volume without release via an outlet), while the WQCV is released via an outlet over an extended period ranging from 12 to 40 hours depending on BMP type. When soils are favorable for infiltration, the low-flow volume should be used. If soils have poor infiltration characteristics, the WQCV (and/or EURV) may be used as an alternative.

This chapter references the Storage Chapter of the UDFCD Manual for additional background, design parameters, and sizing methods. Criteria presented in the Storage Chapter of the UDFCD Manual shall govern except as modified or added to herein.

In addition to guidance on design of detention storage facilities, this chapter recognizes that detention facilities can require significant land area and be a prominent feature within land development plans. Detention storage planning and design should incorporate features that serve multiple purposes and that are integrated functionally and aesthetically into the land plan. Detention facilities must also be safe and maintainable. When properly designed and maintained, detention facilities can be viewed as community assets rather than liabilities.

1.1 Stormwater Quality Considerations

Detention facilities can be designed to provide both flow control and water quality benefits by providing extended detention and/or infiltration of small, frequently occurring events to enhance stormwater quality

as a part of the flood control facility. Water quality treatment may also be provided through runoff reduction techniques that have the potential to also affect detention storage facility sizing. Early in the planning process, opportunities to provide runoff reduction, stormwater quality management and flood control should be evaluated so that a comprehensive and coordinated approach can be developed. Extended detention and other water quality best management practices and runoff reduction practices are discussed in Volume 2 of the Colorado Springs Manual and Volume 3 of the UDFCD Manual, both of which are resources for stormwater quality planning and design in Woodland Park.

1.2 Stormwater Volume Considerations

In addition to the increase in peak flow rates, stormwater runoff volume increases with urbanization as a result of increased impervious areas, particularly impervious areas that are directly connected to the drainage system. The increase in runoff volume, especially for more frequent storm events, has the potential to disturb the downstream receiving stream's equilibrium and cause channel instability. Therefore, detention basin designs that help to mitigate the effects of increased runoff volumes, including retention and implantation of the low-flow volume, are preferred. Additionally, volume reduction practices upstream of detention facilities can be used in conjunction with flow control facilities to optimize mitigation and reduce costs.

1.3 Downstream Impacts

Even with comprehensive management of stormwater runoff, the effects of urbanization, including excess irrigation, increased snow melt runoff, reduced sediment loads (i.e., "sediment hungry" clear water runoff), and significant increases in stormwater runoff volumes are very difficult to fully mitigate. Therefore, some downstream channel instability can be anticipated due to development. This will require attention to channel improvements and right-of-way that may need to extend downstream beyond project limits.

2.0 Detention Requirements

2.1 General Requirements

Detention storage facilities are critical elements in the management of stormwater and shall be required for all new development, redevelopment, expansion or improvement projects. Detention facilities shall be designed to manage stormwater runoff for storms up to and including the 100-year event. In cases where project-specific conditions cause detention storage to be infeasible or ineffective, variances may be approved on a case-by-case basis through the variance process described in this Manual or through an approved planning process.

2.2 Detention Requirements for Redevelopment

Redevelopment of a site occurs when a change in the property use and/or function is desired, resulting in physical changes to the site. Unless detention is provided via a regional facility, the redevelopment of a site shall require that on-site detention be provided for the entire site, including those areas that previously had not provided detention due to the site being developed prior to the adoption of this Manual.

2.3 Detention Requirements for Expansion of a Developed Site

Expansion of a site occurs when additional area on the site is to be developed. The expansion of a site shall require that the current standards for detention for the entire site are met, where feasible. There are

two conditions that may arise for site expansion, depending upon whether or not detention has been provided for the existing site prior to expansion, including:

- Detention has been provided for the existing developed area. The new expansion shall require that additional detention be provided to accommodate the expanded development or that the existing facilities be modified to serve the full site development.
- Detention has not been provided for the existing developed area. Detention will be required for the full expansion and to the extent possible, for the existing site area that has previously been un-detained. A reasonable attempt to provide detention storage will be required for the previously developed, un-detained portion of the site or the release rates from the expansion area must be less than the allowable release rates to compensate for the un-detained area.

3.0 Types of Detention Storage Facilities

Detention storage facility designs can generally be characterized based on scale of implementation and outlet configuration, as discussed below.

3.1 Scale of Implementation

Typical development-related detention facilities can be classified as “regional”, “sub-regional” or “on-site.” Regional detention facilities typically serve a broad purpose within a watershed and manage flows from multiple parcels and, possibly, multiple development projects. Sub-regional ponds, which by definition serve multiple parcels, may also provide benefits in terms of attenuating flows from developed areas, but typically serve only one development project. Regional and sub-regional detention facilities typically require a commitment for maintenance by a public entity or a legally-binding maintenance agreement. On-site facilities typically only serve a single parcel, have localized benefits, and are maintained by the property owner or private entity.

Regional or sub-regional detention is the preferred approach at a subdivision or project scale instead of providing on-site detention at the time each lot is developed. For large subdivisions, regional or sub-regional detention should be implemented by the first sub-divider rather than passing on the responsibility for detention to owners of individual filings. The coordination of development phasing with the construction of detention facilities should be addressed within the basin plans.

Additional information is provided below for regional, sub-regional and onsite facilities. Each of these types may include water quality features or be used in conjunction with separate water quality features or runoff reduction techniques. When water quality treatment is included within a detention facility, its effect on the required flood control storage varies with the type of facility.

3.1.1 Regional Detention

Regional detention typically refers to facilities that are owned and maintained by the City that serve multiple development projects or multiple phases of a development project. A primary function of regional detention facilities is to mitigate the effects of developed runoff so that downstream natural channel features and floodplains can be preserved. The location of these facilities can also differentiate “minor” drainageways from “major” drainageways. Under natural conditions, significant drainageways tend to develop when the contributing area is between 100 to 160 acres. Therefore, regional detention facilities will typically be located with a contributing area of about 130 acres or more. Figure 13-1 illustrates a typical regional detention concept.

The following are required for regional detention facilities:

1. Regional detention facility shall be designed to accommodate the fully developed condition flows from the upstream watershed.
2. Regional detention facilities are required to be owned and maintained by a public entity, with ownership and maintenance responsibilities clearly defined to ensure the proper function of the facility in perpetuity.
3. Drainage easements or tracts for the facility, including access from a public street, shall be provided.
4. An approved Operations and Maintenance Manual is required.
5. The creation of a jurisdictional dam, according to the State Engineer's Office definition, is discouraged.
6. The facility shall be permitted under applicable environmental permits and clearances.
7. Construction of the regional facility must be coordinated with development in the upstream watershed. If the regional facility has not been constructed, temporary on-site detention (and water quality) shall be required to be provided with development projects until the regional facility is available.
8. The drainageways upstream of a regional facility shall be designed to convey fully-developed flows to the regional facility.
9. Roadway embankments may be used to create the storage volume. When this is the case, roadway embankment design should consider the implications of hydrostatic and hydrodynamic forces on the embankment, including the potential for piping and scour. Roadways under the jurisdiction of other agencies, such as CDOT, may be prohibited from being used as detention basin embankments or require special consideration and permission.

3.1.2 Sub-regional Detention

Sub-regional detention refers to facilities located upstream of a major drainageway (generally having a drainage area between 1 and 130 acres) and serving more than one parcel. Like regional facilities, sub-regional detention facilities may be constructed by a public entity such as a municipality or special district to serve several landowners in the upstream watershed or by a single landowner. For a sub-regional facility to be recognized in the determination of flow rates for downstream major drainageways, the facility must be publicly owned and maintained, or the owner must provide easements and a legally binding maintenance agreement. Figure 13-2 illustrates a typical sub-regional detention concept. The conditions listed previously for regional facilities shall be adhered to for sub-regional facilities.

3.1.3 On-site Detention

On-site detention refers to facilities serving one parcel, generally commercial or industrial sites draining areas less than about 20 acres. On-site detention is best suited for infill and redevelopment projects and in other areas where regional or sub-regional facilities are not able to be implemented. A primary function of on-site detention facilities is to reduce developed condition flows so that undersized downstream storm

drain and/or channel capacities are not exceeded. On-site detention may also provide an opportunity to provide water quality treatment features. Figure 13-3 illustrates a typical on-site detention concept.

On-site detention facilities will not be recognized in the determination of flow rates for downstream major drainageways because of difficulties with ensuring that these facilities are maintained and continue to function in perpetuity on private property.

General guidelines for on-site detention facilities include:

- Integrating Detention and Site Landscaping Requirements. Locating detention basins in areas reserved to meet site landscaping requirements is generally encouraged. Incorporating detention into landscaped areas generally creates detention facilities that are easier to inspect, are relatively easy to maintain, and can enhance the overall aesthetics of a site. Further discussion regarding landscaping improvements in detention facilities is provided later in this chapter. For some small sites, detention and water quality can often be provided using practices such as bioretention that provide for infiltration, storage and regulated outflow.
- Parking Lot Detention. Parking lot detention may be acceptable on commercial and industrial sites and can offset some of the storage volume that needs to be provided on landscaped areas. Parking lot detention will be allowed on a case-by-case basis.
- Underground Detention. Underground detention shall be considered only in cases where other alternatives using surface storage are demonstrated to be infeasible and will only be allowed through the variance process provided in this Manual (*i.e. as approved by the City Engineer*).
- Rooftop Detention. Rooftop detention is prohibited, except as may be allowed through the variance process provided in this Manual (*i.e. as approved by the City Engineer*).

3.2 Outlet Configurations

Detention storage facilities can also be classified by how the outlet structure is configured. Outlet structures that are designed to attenuate specific storm event peak flows, but do not address the full range of stormwater inflows are considered “multi-level” or “multi-stage” outlets. Outlet structures that are designed to better attenuate the full range of storm events are considered “full-spectrum” outlets. These outlets release an outflow hydrograph that more closely represents the undeveloped condition hydrograph. They also provide some mitigation of increased runoff volumes by releasing them over an extended period of time.

3.2.1 Full Spectrum Detention

Full Spectrum Detention (FSD) is a design concept introduced by UDFCD in 2005 (Urbonas and Wulliman 2005) that provides better control of the full range of runoff rates that pass through detention facilities than the conventional multi-stage concept. This concept also provides some mitigation of increased runoff volumes by releasing a portion of the increased runoff volume at a low rate over an extended period of time (up to 72 hours). This concept can be applied for any size drainage basin up to 640 acres and can be integrated into on-site, sub-regional or regional detention facility designs.

By providing an Excess Urban Runoff Volume (EURV) in the lower portion of the facility storage volume with an outlet control device similar to a Water Quality Capture Volume (WQCV), frequent and infrequent inflows are released at rates approximating undeveloped conditions. The EURV is based on the incremental difference between the developed and undeveloped runoff volume for the range of storms

that produce runoff from impervious land surfaces. Additional information on FSD is provided in the Storage Chapter of the UDFCD Manual.

Designing a detention basin to capture the EURV and release it slowly (at a rate similar to WQCV release rates) means that the frequent storms, smaller than approximately the 2-year event, will be reduced to very low flows near or below the sediment carrying threshold value for downstream drainageways. Additionally, by incorporating an outlet structure that limits 100-year runoff to the allowable release rate or to the undeveloped condition rate, the discharge hydrograph for storms between the 2-year and 100-year storm event will approximate the hydrograph for undeveloped conditions. This reduces the likelihood that runoff hydrographs from multiple detention facilities will combine to increase downstream discharges above undeveloped conditions and helps to more effectively mitigate the effects of urbanization.

3.2.2 Multi-level Outlet Configurations

Multi-level outlet configurations are most appropriate for on-site facilities to reduce peak flows, and may also be applied to regional or sub-regional facilities if a full spectrum approach (preferred) is not used. If a multi-level outlet configuration is used for a facility, at a minimum, it should be designed to retain the low-flow volume (75% of 2-year, one-hour storm volume) and to limit peak out flow rates for the 5-year and 100-year events to predevelopment levels.

In areas where soils are unfavorable for retention and infiltration of the low-flows volume, a multi-level design with controls for release of the WQCV, 5- and 100-year events may be used with approval of the City Engineer. In these cases, a full spectrum design, including the EURV, should first be considered as this would be expected to provide detention for a broader array of events, while using a simplified outlet structure.

4.0 Sizing Methodology

The detention facility sizing methodology varies depending on the contributing area, type of facility, and its intended function in the drainage system. To determine the appropriate methodology, the following questions should be answered:

1. What is the size of the basin area contributing to the facility?
2. Will the facility be regional, sub-regional or on-site?
3. Will the facility include retention of the low-flow volume or will the WQCV/EURV be provided as an alternative?
4. Will the facility have a full-spectrum or multi-level outlet configuration?

Considering these factors, the pond characteristics including location, volume, allowable release rates, multi-use opportunities, and other design features can be determined. Determining final detention storage facility characteristics typically requires an iterative process to achieve the design goals with the minimum storage requirements. The Storage Chapter of the UDFCD Manual describes a design procedure that can be applied for various types of detention storage facilities.

The UDFCD Manual provides approximate, simplified methods (empirical equations) that are adequate for smaller basins. More complex methods are available for larger, regional facilities. Use of the more complex methods may reduce the calculated required volume of the facility.

Table 13-1 summarizes the types of detention facilities and acceptable methods for determining their size and allowable release rates.

Table 13-1. Detention Facility Sizing Methods

Type	Tributary Area	Volume	Allowable Release Rate
Regional	130 to 640 acres	Hydrograph routing required for total volume; empirical equations allowed for EURV (EURV includes WQCV).	Undeveloped runoff rates.
Sub-regional	Less than 130 acres	Hydrograph routing or empirical equations allowed for total volume; empirical equations allowed for EURV (EURV includes WQCV).	Undeveloped runoff rates.
On-site	Less than 20 acres	Empirical equations, simplified FAA or hydrograph routing allowed. Add 50% of WQCV for multi-level facilities. (Do not add WQCV for FSD facilities.)	Undeveloped runoff rates.

4.1 Volume

The required total detention storage volume is based on the type and function of the facilities and may include a combination of these storage elements:

- **Flood Control Volume.** This storage element is normally the largest portion of the total storage and may be subdivided into separate portions for design purposes depending on the type of storage facility. In FSDs, the flood storage is equal to the entire volume and is inclusive of the EURV and the WQCV. In multi-level facilities, design volumes (and outlet release configurations) must be determined for the 5- and 100-year events. To determine the total flood control volume for a multi-level facility, the low-flow volume should be added to the 100-year flood control volume.
- **Excess Urban Runoff Volume (EURV).** This storage element is only implemented in an FSD facility and takes the place of the WQCV and low-flow volumes that are used in multi-stage designs. The required volume is based on empirical equations developed by UDFCD. Typically, this volume is about twice as large as the WQCV for Type C or D soils, or slightly larger than the total 2-year runoff volume. It is not necessary to increase the total storage volume by the EURV. The EURV is incorporated into the flood control storage volume.
- **Low-Flow Volume.** The low-flow volume is defined by City Resolution No. 299, Series 1994 as 75% of the 2-year, one-hour runoff volume. The minimum standard for detention design in Woodland Park is retention (and subsequent infiltration) of the low-flow volume and control of the 5- and 100-year peak flow rates to predevelopment levels.
- **Water Quality Capture Volume (WQCV).** This storage element and methods for determining the WQCV are described in Volume 3 of the UDFCD Manual. The WQCV is intended to capture most runoff events and reduce their pollutant load prior to discharging into drainageways. The WQCV is similar to the low-flow volume in terms of total runoff volume; however, the WQCV is

released over an extended period, ranging from 12 to 40 hours (depending on BMP type), while the low-flow volume is a retention volume that infiltrates and/or evaporates. For standalone water quality application (i.e. no minor/major detention), the WQCV is the recommended basis of design. However, in detention storage facilities, providing the low-flow retention volume or the EURV is preferred to using a multi-level WQCV design. The size of this storage element depends primarily on the amount of tributary impervious area and can be reduced by implementing development practices that reduce the effective imperviousness. The WQCV should only be used in multi-level designs when it is infeasible to retain and infiltrate to low-flow volume or to design a FSD with the EURV for water quality. The standard detention requirements for Woodland Park (retain 75% of 2-year, one-hour volume and detain 5- and 100-year events to pre-development levels) or FSD are preferred to a design using the WQCV and 5- and 100-year controls. The City Engineer has the authority to allow for a multi-level WQCV design if other alternatives are found to be infeasible.

- **Initial Surge Volume.** This storage element is calculated as a small percentage of the WQCV, EURV or low-flow volume and is included within these storage volumes. This small volume is provided within or adjacent to the outlet structure and above the micropool to allow nuisance flows to collect so that the low-flow channel is free to drain and the pond bottom does not become saturated and difficult to maintain.

A single facility may include a combination of these storage elements or the storage elements may be segregated into separate facilities, as shown in Figure 13-4. Table 13-2 shows common configurations of these storage volume components for detention approaches that may be used in Woodland Park. Segregating the storage elements may be beneficial if a project is being phased or when adequate land is not available to combine all of the elements in one facility.

Table 13-2. Detention Volume Configurations

Detention Volume Component*	Allowable Detention Approaches		
	Standard Detention (Per Resolution 299, Series 1994)	WQCV Multi-Stage	Full-Spectrum Detention
Water Quality Capture Volume (WQCV)		X	X (Included in EURV)
Low-Flow (Retain 75% of 2-year, one-hour event)	X		X (Included in EURV)
Excess Urban Runoff Volume			X
Minor Event (5-year, one-hour storm)	X	X	X (Included in EURV and Flood Control Volume)
Major Event (100-year, one-hour storm)	X	X	X (Included in EURV and Flood Control Volume)

*Initial Surge Volume to be provided for all approaches as part of low-flow volume, WQCV or EURV to contain nuisance and frequent flows to designated portion of pond bottom.

4.1.1 Flood Control Volume

UDFCD has developed empirical equations for estimating the total required storage volume that can be applied to on-site, multi-level ponds or to on-site or sub-regional FSD ponds. The empirical equations include:

$$V_i = K_i A \quad \text{Equation 13-1}$$

For NRCS soil types B, C and D.

$$K_{100} = (1.78 \cdot I - 0.002 I^2 - 3.56) / 900 \quad \text{Equation 13-2}$$

$$K_5 = (0.77 \cdot I - 2.65) / 1,000 \quad \text{Equation 13-3}$$

For NRCS soil Type A:

$$K_{100A} = (-0.00005501 \cdot I^2 + 0.030148 \cdot I - 0.12) / 12 \quad \text{Equation 13-4}$$

Where:

V_i = required volume, with i = year storm, acre-feet

K_i = empirical volume coefficient, with i = year storm

i = return period for storm event, years

I = fully developed tributary basin imperviousness, %

A = tributary basin area, acres.

These equations can be applied to calculate the total detention storage for drainage basins up to about 130 acres. When more than one soil type or land use is present in the drainage basin, the storage volume must be weighted by the proportionate areas of each soil type and/or land use. For FSDs, the EURV need not be added to this volume. See the Storage Chapter of the UDFCD Manual for a full description of this method.

4.1.2 EURV

UDFCD has developed empirical equations for estimating the EURV portion of the storage volume that can be applied to on-site, sub-regional or regional FSD ponds.

The empirical equations are as follows:

For NRCS Soil Group A:

$$EURV_A = 1.1 (2.0491(I/100) - 0.1113) \quad \text{Equation 13-5}$$

For NRCS Soil Group B:

$$EURV_B = 1.1 (1.2846(I/100) - 0.0461) \quad \text{Equation 13-6}$$

For NRCS Soil Group C/D:

$$\text{EURV}_{\text{CD}} = 1.1 (1.1381(I/100) - 0.0339) \quad \text{Equation 13-7}$$

Where:

EURV_K = Excess Urban Runoff Volume in watershed inches, K=A, B or C/D soil group

I = basin imperviousness, %.

These equations apply to all FSD facilities, and the EURV need not be added to the flood control volume or to the WQCV. When more than one soil type or land use is present in the drainage basin, the EURV must be weighted by the proportionate areas of each soil type and/or land use. If hydrologic routing is used to size the flood control volume, the EURV remains the same as calculated by these equations and is included in the pond's stage/storage configuration for modeling.

4.1.3 Initial Surcharge Volume

The initial surcharge volume is approximately 0.3 to 0.5 percent of the WQCV and should be approximately 4- to 12-inches deep.

4.1.4 Design Worksheets

The Full Spectrum Worksheet in the UD-Detention Spreadsheet performs all of these calculations for the standard designs. For multi-level ponds, the flood control volumes are calculated for the two design storm frequencies: the major storm (100-year) and the minor storm (5-year).

4.2 Release Rates

Release rates from detention facilities vary with the type of facility and with the storage volume type, as follows:

- WQCV. The WQCV release rate is determined based on a 40-hour drain time for extended detention basins. The purpose of this slow release rate is to provide time for pollutants to settle and for the rate of discharge to be less erosive. The method for determining outlet sizing to achieve the necessary drain time is described in Volume 3 of the UDFCD Manual.
- Low-flow Volume. The low-flow volume equivalent to 75% of the 2-year, one-hour storm runoff volume is intended to be retained and subsequently infiltrated and/or evaporated. The low-flow volume is generally similar to the WQCV, but is retained rather than release via an outlet over an extended period.
- EURV. The EURV release rate is determined based on a 72-hour drain time. The purpose of this slow release rate is to reduce the potential for downstream erosion and to release flows that more closely mimic undeveloped conditions.
- Flood Storage Volume. The flood storage release is determined by the peak flow rates for the undeveloped/pre-disturbance site for relevant storm frequencies (5- and 10-year, one-hour event). For multi-level facilities, the design rates are based on specific return frequencies. For FSDs, only the 100-year rate is required for design. In both cases, it has been estimated that intermediate rates will also be released at rates approximately equal to the undeveloped rates.

4.2.1 Allowable Release Rates

The allowable release rates for detention pond design shall be determined based on undeveloped condition rates of runoff calculated using the methods defined in Chapter 6, Hydrology. Only the 100-year rate is used for FSD design, and only the 5- and 100-year are used for multi-level design. The release rates from the proposed pond must be equal to or less than the calculated undeveloped condition release rates.

4.2.2 EURV Release Rate

The EURV is intended to fully drain within a 72-hour period after the end of the storm. This is accomplished by a control plate placed in the outlet structure with the appropriate orifice (hole) sizes and spacing similar to those used for the release of the WQCV. UDFCD has estimated that the area of the holes in the control plate based on Equation 13-8.

$$A_o = 88V^{(0.95/H^{0.085})}/T_D^{(S^{0.09})}H^{(2.6S^{0.3})} \quad \text{Equation 13-8}$$

Where:

- A_o = area per row of orifices spaced on 4-inch centers (in²)
- V = design volume (WQCV or EURV, acre-ft)
- T_D = time to drain the prescribed volume (hrs)
(i.e., 40 hours for WQCV or 72 hours for EURV)
- H = depth of volume (ft)
- S = slope (ft/ft)

The Full Spectrum Worksheet in the UD-Detention Spreadsheet performs these calculations for the standard designs.

5.0 Detention Pond Design Guidelines

In addition to the basic characteristics of location, function, volume, and release rates, several other design aspects must be considered to properly plan, design and maintain detention facilities.

5.1 Pond Location and Configuration

5.1.1 Detention Pond Placement

Detention ponds function best when they are strategically placed according to a plan that identifies proposed land uses, roadway alignments, and topographic features. The preservation of downstream natural features and the floodplain is also an important consideration for the placement of ponds. The placement of ponds adjacent to roadway embankments reduces the cost of pond construction. Using the fewest number of ponds required to accomplish their intended function within a drainage basin also reduces the cost and requires the fewest acres of land. Therefore, detention storage typically functions best if configured in one or a few larger sub-regional or regional ponds. Fewer, larger ponds rather than many small ponds is also advantageous for maintenance.

5.1.2 Detention Ponds in Series

Locating detention ponds in series (one pond draining into another downstream pond) is inherently inefficient and increases the required storage volume of the downstream facilities and is discouraged. This is especially true for FSD ponds because the EURV portion of a downstream FSD facility will

collect additional runoff from the upstream pond and may be full when needed to detain runoff from the downstream basin.

If runoff is detained by two or more detention facilities in sequence before leaving the site, hydrograph detention routing analyses must be used to determine the effect of sequential detention and to determine the detention capacity that is needed to reduce runoff peaks to the specified allowable release rates at the end of the system.

5.1.3 Interconnected Ponds

When sequential detention ponds are located in close proximity, separated by a short culvert or pipe at a roadway crossing, or when sequential ponds have similar invert elevations, the ponds may need to be evaluated as interconnected ponds. This situation could also occur if downstream tailwater conditions cause variable backwater effects that influence the discharge of the detention pond outlet. In these situations, the water surface elevation downstream can reduce the discharge rate from the upper pond and, in some cases, reverse flow can occur from downstream into the upstream pond. Analysis of this condition is much more complex because the ponds are hydraulically dependent and the water surface elevations continuously vary and change the discharge characteristics. It is the responsibility of the design engineer to ensure that the appropriate analyses are performed and submitted when ponds are interconnected or affected by downstream tailwater conditions.

5.2 On-site Detention and Off-site Flows

Two approaches are generally acceptable for addressing off-site flows that must be conveyed through a site and the potential impacts to the on-site detention. These approaches include:

- **Separate Conveyance Systems.** In this approach, off-site runoff is conveyed to a point downstream of the on-site detention pond outfall. The detention pond is sized based only on the tributary area of the site. Off-site flows and the detained runoff can be conveyed in the same system downstream of the detention pond.
- **Design for Off-site Flows.** An alternative method is to design the detention pond for the entire upstream watershed area, including the future development flows from off-site areas without giving any credit to off-site detention facilities. This method may be appropriate if the off-site tributary area is relatively small, but it becomes less feasible as the off-site tributary increases.

The benefits of detention facilities provided in the off-site area may be considered in some cases, if there is sufficient justification. In those cases, the design engineer shall utilize hydrograph routing methods to size the on-site detention to account for the additional detention facilities on the off-site area and the differences in timing of the various hydrographs.

5.3 Design Features

5.3.1 Discharge Location (Outlets)

Detention ponds shall be designed to discharge into a storm sewer, drainageway, or other designated drainage system that is reasonably available. Analyses must demonstrate that the receiving drainage system (where the pond discharges) has the capacity to convey the detention pond flows.

When a suitable outlet is not available, and with prior approval, detention ponds may discharge into the gutter of a street, such as through a chase section, when the minor storm peak flow from the tributary area

is less than 3.5cfs and the street has adequate capacity to convey the excess runoff within the allowable limits. A transition from the outlet to a curb chase will normally be required and the chase section shall be designed to convey the discharge at a low velocity. The location of the outlet shall be designed to minimize potential problems or conflicts with other improvements. Discharge into the gutter will not be allowed on local streets, or in cases where structures along the street have finished floor elevations below the street elevation.

5.3.2 Excavated or Embankment Slopes

All excavated or embankment slopes from the pond bottom to the 100-year water surface elevation shall be no steeper than 4 feet horizontally to 1 foot vertically (4H:1V). Excavated slopes above the 100-year water surface elevation and the slope on the downstream side of embankments must be 3H:1V or flatter. Embankments shall be provided with a top width of at least 10 feet. All earthen slopes shall be covered with topsoil and revegetated as described in Chapter 14, Revegetation.

It is the responsibility of the design engineer to ensure that the design of any earthen embankment is based on specific recommendations determined by a qualified geotechnical engineer. Additionally, the embankment heights and pond size shall not place the structure under the jurisdiction of the Office of the State Engineer, unless specific approval is provided. The potential for piping failure through the embankment or along penetrations of the embankment, such as the outline conduit, shall be mitigated by the design methods consistent with State Engineer dam design criteria.

5.3.3 Freeboard

The minimum required freeboard for detention facilities is 1.0 foot above the computed water surface elevation when the emergency spillway is conveying the design flow.

5.3.4 Low-flow Channels

Detention ponds collect both wet and dry weather flows from the upstream basins, including excess irrigation water that can keep pond bottoms wet and difficult to maintain. Therefore, grassed-bottom detention ponds shall include a low-flow channel sized to convey a minimum of 1 percent of the 100-year peak inflow. The low-flow channel shall be constructed of concrete, concrete with boulder edges, soil riprap, or any combination thereof and shall have a minimum depth of 0.5 feet. The minimum longitudinal slope shall be 0.5 percent to ensure that non-erosive velocities are maintained adjacent to the low-flow channel when the design capacity is exceeded.

Low-flow channels in detention ponds either drain through a WQCV or an EURV to the pond outlet structure where the discharge rate is constrained. This can cause flows to pond at the end of the low-flow channel, deposit sediment, and saturate the surrounding pond bottom. Therefore, the invert elevation of the low-flow channel must be set above the initial surcharge volume near the pond outlet to confine this nuisance ponding to a small area of the pond bottom and reduce maintenance requirements.

Unlined (or wetland) low-flow channels may be allowed on a case-by-case basis. The unlined low-flow channel shall be at least 1.5-feet deep below adjacent grassed benches and shall be vegetated with herbaceous wetland vegetation or riparian grasses, appropriate for the anticipated moisture conditions. The minimum longitudinal slope shall be 0.5 percent and the minimum width of the grassed bench adjacent to the low-flow channel shall be 12 feet on at least one side for equipment access. The side slope below the bench shall be no steeper than 4H:1V and the maximum bottom width of the channel shall be 12 feet if equipment can access one side of the channel or 24 feet if equipment can access both sides.

Typical cross-sections of low-flow channels are shown in Figure 13-5. Typical pond configurations with a concrete low-flow channel and a benched low-flow channel are shown in Figures 13-6 and 13-7.

5.3.5 Bottom Slope

For grassed detention facilities, the pond bottom shall be sloped at least 4 percent for the first 25 feet and at least 1 percent thereafter to drain toward the low-flow channel or outlet, measured perpendicular to the low-flow channel. The benches above unlined low-flow channels, if approved, shall slope at least 1 percent toward the low-flow channel.

5.3.6 Wetland Vegetation (Constructed Wetland Pond)

A soft bottom or constructed wetland pond bottom can be used in place of a dry pond bottom, but special considerations must be made for maintaining an adequate depth of water to allow wetland plants to survive. These types of ponds also require special attention to provide access to the bottom for maintenance. Additionally, the upstream drainage basin must be evaluated to determine whether an adequate amount of flow will be provided to support the vegetation.

5.3.7 Inlet Structures

Runoff shall enter a detention facility via a stabilized drainageway, drop structure, or storm sewer. Riprap rundowns are generally not accepted due to a history of erosion problems. Capturing sediment before it enters the detention facility is important for reducing maintenance requirements inside the facility. Forebays provide locations for debris and coarse sediment to drop out of the flow and accumulate, extending the functionality of the pond features. Forebays shall be sized based on the methods described in Volume 3 of the UDFCD Manual. Figure 13-8 illustrates a concept for storm sewer outfalls entering a forebay at the inlet to a detention facility. Forebay designs must facilitate maintenance by providing adequate access and by having concrete bottoms.

Flows entering ponds often have high energy. Therefore, some form of energy dissipation may be necessary at a pond inlet. To determine the hydraulic characteristics of the inlet structures and energy dissipation devices at an entrance to a pond, the designer may account for tailwater effects of water in the pond during the minor (5-year) and major (100-year) events. The elevation of the low-flow volume, WQCV or the EURV can be used as a minimum tailwater condition for energy dissipation calculations for these events.

A safety barrier, such as a railing of sufficient height, shall be provided around the perimeter of inlet structures whenever the difference in the elevation from the surface to the bottom of the structure is 30 inches or greater.

5.3.8 Outlet Structures

Detention basin outlets shall be designed to control facility discharges at the allowable release rates. Additionally, outlet structures shall be provided with safety/debris grates to reduce the potential for debris plugging, designed for ease of maintenance, equipped with safety features, and designed with favorable aesthetics.

For designs using the WQCV or EURV to drain more effectively, a “micropool” must be located in front of the screen for the outlet control plate. The purpose of a micropool is to create a permanent pool of water on which debris will float, allowing flow to pass through the lower portion of the screen to the control plate. It is preferable to contain the micropool integral to the concrete portion of outlet structures.

Figures 13-9 and 13-10 provide examples of integral micropools: one with parallel wingwalls with a flush bar grating and the other with flared wingwalls and handrails, respectively. Extending micropools out into the pond bottom creates areas that may contain standing water for extended periods of time and be difficult to maintain. External micropools (extending beyond the concrete outlet structures) shall only be used if a constant baseflow exists sufficient to maintain the micropool level and will be allowed only on a case-by-case basis. Although there is no volume requirement for micropools, they must have a surface area of 10 square feet or more and be at least 2.5-feet deep.

An “initial surcharge volume” is critical to the proper functioning of a pond outlet and must be provided. This volume provides a limited amount of storage for very low flows passing through the pond and allows the low-flow channel and pond bottom to flow freely and remain drier for maintenance. It is preferable that this volume may be contained within the outlet structure above the micropool, but may extend out beyond it as necessary. When this volume extends beyond the micropool, a concrete curb, rock edge or other feature must separate it from the bottom of the WQCV/EURV volume so that it can be identified and preserved. The bottom of this volume can be lined with concrete or vegetated. This volume is considered part of the WQCV or the EURV and does not need to be added to the other design volumes. A more detailed discussion of this feature is provided in Volume 3 of the UDFCD Manual. An initial surcharge volume is not necessary for Constructed Wetland Ponds or Retention Ponds.

The flood-control outlet shall be sized to discharge the allowable 100-year release rate when the 100-year detention volume is completely full. The outlet structure weir crest (formed by the top of the concrete) shall have adequate capacity to pass design flows so that flow control is maintained at the appropriate control device for the design event.

A safety barrier, such as a railing of sufficient height, shall be provided around the perimeter of outlet structures wherever the difference in the elevation from the top of the structure to the bottom of the structure is 30 inches or greater.

A sealant must be specified behind the orifice plate to prevent leakage around the control plate. All hydraulic sizing, concrete structure dimensions, reinforcing, and metalwork details for outlet structures shall be the responsibility of the design engineer.

5.3.9 Trash Racks

The design of trash racks protecting outlet control devices shall comply with the safety grate criteria discussed in the Culverts Chapter of the UDFCD Manual. The trash rack or screen protecting the control plate orifices must extend to the bottom of the micropool so that flow can pass through the rack below the level of any floating debris and pass through the orifices.

Bar grating may be used on parallel sloping wingwalls, either as the primary debris grate (if orifices are at least 2.5 inches in diameter) or as a coarse screen and safety grate in lieu of handrail. Sloping bar grating shall have a lockable hinged section of at least 2 square feet to allow access to the orifice plate or well screen. Manhole steps shall be provided on the side of the wingwall directly under the hinged opening. The bearing bars for the steel bar grating shall be designed to withstand hydrostatic loading up to the spillway crest elevation (assuming the grate is completely clogged and bears the full hydrostatic head), but not be designed for larger loads (like vehicular loads) so that the hinged panels are not excessively heavy. Panels of trash racks or bar grating shall be no more than 3-feet wide and all parts of the grating and support frames shall be hot-dipped galvanized steel. Trash racks or bar grating shall be attached to the outlet structure.

The configuration and dimensions of trash racks and grates should allow debris to be raked off using standard garden tools or other commonly available equipment.

5.3.10 Emergency Spillway and Embankment Protection

Detention storage may be created by a roadway embankment or by a freestanding embankment as conceptually represented by Figures 13-11a and 13-11b. Whenever a detention pond facility uses an embankment to contain water, the embankment shall be protected from catastrophic failure due to overtopping. Overtopping can occur when the pond outlet becomes obstructed or when a storm larger than a 100-year event occurs. Erosion protection for the embankment may be provided in the form of a buried soil-riprap layer at the spillway crest and on the entire downstream face of the embankment or a separate emergency spillway constructed of buried, soil riprap, grouted boulders or concrete. In either case, the protection shall be constructed to convey the 100-year developed condition flow from the upstream watershed without accounting for any flow reduction within the detention facility.

The crest elevation of the emergency spillway shall be set at or above the calculated 100-year water surface elevation. A concrete wall shall be constructed at the emergency spillway crest extending at least to the bottom of the riprap and bedding layers located immediately downstream. The crest wall shall be extended at the sides up to 1 foot above the emergency spillway design water surface as shown in Figure 13-11c.

Riprap embankment protection shall be sized based on methodologies described in *Development of Riprap Testing in Flumes: Phase II Follow-up Investigations* (Abt et al. 1988) to determine the D_{50} dimension. According to this method:

$$D_{50} = 5.23 S^{0.43} (1.35 C_f q)^{0.56} \quad \text{Equation 13-9}$$

Where:

- D_{50} = median rock size (in)
- S = longitudinal slope (ft/ft)
- C_f = concentration factor (1.0 to 3.0)
- q = unit discharge (cfs/ft)

When:

- η (porosity) = 0.0 (i.e., for buried soil riprap)

The unit discharge shall be determined by dividing the design flow by the crest width, excluding the side slopes. According to this method, the types of riprap needed for typical embankment slopes and design flows are shown in Figure 13-11d. The riprap types shown were determined assuming that there is no interstitial flow (i.e., no flow between the rocks—soil riprap with filled voids and porosity=0) and that the “concentration factor” (C_f) is equal to 2.0. For plain riprap with interstitial flow, the method requires an interactive process described in Abt et al. (1988). The range for each type shown is based on the D_{50} dimension at the midpoint between the D_{50} for adjacent types. Riprap characteristics such as rock size distributions, thickness, hardness, specific gravity, angle of repose, etc., shall be as described in this Manual. For design conditions outside of the parameters or conditions represented in Figure 13-11d, the designer shall propose an appropriate alternative approach that may include grouted boulders or concrete protection. Alternative approaches must be submitted for approval prior to incorporation into designs.

The emergency spillway is also needed to control the location and direction of any overflows. The emergency spillway and the path of the emergency overflow downstream of the spillway and embankment shall be clearly depicted on the drainage plan. Structures shall not be permitted in the path of

the emergency spillway or overflow. The emergency overflow water surface shall be shown on the detention facility construction drawings. When emergency overflows will pass over a roadway, the depth of flow shall not be greater than 1 foot over the street crown.

5.3.11 Retaining Walls

The use of retaining walls within detention basins is discouraged due to the potential increase in long-term maintenance costs and concerns regarding the safety of the general public and maintenance personnel. Retaining walls shall only be considered for on-site facilities. If retaining walls are proposed, footings shall be located above the low-flow volume, WQCV or EURV, as applicable. Wall heights not exceeding 30 inches are preferred, and walls shall not be used along more than 50 percent of the pond circumference. If terracing of retaining walls is proposed, adequate horizontal separation shall be provided between adjacent walls. The horizontal separation shall ensure that each wall is loaded by the adjacent soil, based on conservative assumptions regarding the angle of repose. Separation shall consider the proposed anchoring system and equipment and space that would be needed to repair the wall in the event of a failure. The failure and repair of any wall shall not impact or affect loading on adjacent walls. In no case shall the separation be less than 2 times the adjacent wall height, such that a plane extended through the bottom of adjacent walls shall not be steeper than 2H:1V. The maximum ground slope between adjacent walls shall be 4 percent.

Walls shall not be used where live loading or additional surcharge from maintenance equipment or vehicle traffic could occur. The horizontal distance between the top of a retaining wall and any adjacent sidewalk, roadway, or structure shall be at least three times the height of the wall. The horizontal distance to any maintenance access drive not used as a sidewalk or roadway shall be at least 4 feet. Any future outfalls to the pond shall be designed and constructed with the detention basin out to a distance sufficient to avoid disturbing the retaining walls when the future pipeline is connected to the outfall.

Any wall exceeding a height of 30 inches requires perimeter fencing, safety railing, or guardrail, depending on the location of the wall relative to roadways, parking areas, and pedestrian walkways. Walls exceeding a height of 4 feet (measured from the bottom of the footing to the top of the wall) may require a Building Permit. The design engineer is responsible for compliance with any permitting requirements under the Uniform Building Codes.

A Professional Engineer licensed in the State of Colorado shall perform a structural analysis and design the retaining wall for the various loading conditions the wall may encounter, including the differences in hydrostatic pressure between the front and back of the wall. A drain system should be considered behind the wall to ensure that hydrostatic pressures are equalized as the water level changes in the pond. The wall design and calculations shall be stamped by the professional engineer. The structural design details and requirements for the retaining wall(s) shall be included in the construction drawings.

Retaining walls shall not be used within the limits of any impermeable lining of water quality basins or detention ponds.

5.4 Landscaping

The integration of detention facilities and site landscaping requirements is important for making facilities more aesthetically acceptable, consistent with adjacent land uses and compatible with overall stormwater management goals. The type and quantity of landscaping materials should be considered to ensure that the capacity of the pond is maintained and that maintenance activities can be performed with minimal disruption of vegetated areas. Recommendations for pond grading and landscaping include:

1. Wherever possible, involve a landscape architect in the design of detention facilities to provide input regarding layout, grading, and the vegetation plan.
2. Create a pond with a pleasing, curvilinear, natural shape that is characterized by variation in the top, toe, and slopes of banks and avoid boxy, geometrical patterns. A “golf course look” is more attractive than straight lines and straight slopes.
3. Grass selection and plant materials are important considerations in softening the appearance of a detention area and blending it in with the surrounding landscaping and natural features. Selected species should be suitable for the particular hydrologic conditions in the pond. Wetland or riparian species should only be selected for the bottom areas subject to frequent and prolonged inundation. Bluegrass rarely works well in the lowest portion of a pond. Guidelines for revegetation, along with recommended seed mixes, are provided in the Chapter 14, Revegetation.
4. Multi-purpose detention facilities are encouraged that incorporate recreational features such as passive open space areas and pedestrian paths. Active recreational facilities should be located in upland areas to avoid usage conflicts resulting from periodic inundation.
5. To reduce the potential for clogging of debris grates, no straw mulch shall be used within the EURV or WQCV of a detention basin. Instead, erosion control blankets shall be installed for a width of at least 6 feet on either side of concrete low-flow channels or up to a depth of 1 foot in soil riprap or benched low-flow channels. The blankets shall comply with the materials and installation requirements for erosion control blankets (straw coconut or 100 percent coconut). Site-specific conditions may require additional blanket or other erosion control measures.
6. Trees or shrubs consistent with the landscape plan or the surrounding natural environment may be planted within the pond volume above the EURV or the 2-year water surface, whichever is higher. Trees such as Cottonwood, Willow, and Aspen shall not be planted below the 100-year water surface or on the embankment slopes of a detention pond to avoid nuisance spreading of root systems within the facility.
7. Revegetation requirements described in Chapter 14, Revegetation, shall apply to detention facilities. These requirements go beyond plant species selection and include proper soil preparation, irrigation, weed control and other considerations.

5.5 Signage

Two signs, each with a minimum area of 3 square feet, shall be provided around the perimeter of all detention facilities. The signs shall be fabricated of durable materials, such as metal or plastic, using red lettering on a white background with the following message:

WARNING
THIS AREA IS A STORMWATER FACILITY
AND IS SUBJECT TO PERIODIC FLOODING

5.6 Access Easements

Easements or tracts shall be provided to ensure access for the maintenance and operation of detention facilities. Access rights shall be granted for inspection, maintenance and reconstruction purposes, and shall be conveyed to the local agency. The boundaries of easements or tracts to be conveyed shall be shown on the drainage plan, final plats and final development plan. All easements shall be conveyed by appropriate legal documents such as plats or grant of easements. Drainage easements and tracts shall be kept clear of obstructions to flow and shall allow unconstrained maintenance access. The minimum easement requirements for detention ponds include the area necessary for storage, including freeboard, associated facilities, excavation and embankment slopes, and adequate maintenance access around the perimeter. Access from public right-of-way to the pond easement or tract shall also be provided in an easement or tract.

5.7 Maintenance

Detention facilities shall be designed to facilitate ongoing maintenance operations. The maintenance of detention facilities shall be performed by the property owner, or as otherwise designated by maintenance agreement. Maintenance operations shall be in accordance with the approved operations and maintenance manual (O&M Manual) for the facility, which is required as a part of the submittal process. Routine maintenance of detention facilities shall include mowing, structural repairs, and sediment and debris removal. Non-routine maintenance may include the repair and/or replacement of outlet structures, trickle channel, outlet pipes, channel slopes, and other related facilities. When appropriate maintenance is not provided, the local government agency may provide the necessary maintenance and shall assess the associated cost to the property owner. All detention facilities, with or without retaining walls, shall be designed in accordance with the maintenance requirements.

5.7.1 Access

A stable access and working bench shall be provided so that equipment can be used to remove accumulated sediment and debris from the detention pond and perform other necessary maintenance activities at all components of the facility. Unless otherwise approved, the horizontal distance from the working bench to the furthest point of removal for the forebay, bottom of the detention basin, or outlet structure shall be no more than 24 feet. The working bench and access drive shall slope no more than 15percent, and be at least 10feet wide for a centerline radius greater than 80 feet and at least 12feet wide for a centerline radius between 50and 80feet. The minimum centerline radius shall be 50feet. Unless otherwise required by a pavement design, the working bench and access drive shall be constructed as follows:

- Below any permanent water surface: A reinforced concrete bottom slab at least 6 inches thick shall be provided as a working platform. The surface of the concrete shall be provided with a grooved finish to improve traction, with grooves oriented to drain water away to one or both sides. Concrete shall be placed on at least 6 inches of gravel base compacted subgrade.
- Below the low-flow, WQCV or EURV water surface: The access ramp shall be reinforced concrete as specified above, or at least a 12-inch thick layer of aggregate base course or crushed gravel over compacted subgrade.
- Above the low-flow, WQCV or EURV and below the 100-year water surface: An access ramp shall be reinforced concrete as specified above or provide at least an 8-inch-thick layer of aggregate base course or crushed gravel over compacted subgrade. Reinforced turf grass, meeting applicable criteria, will be considered in this zone for an access drive on a site-specific basis. If

used, a system of marking the edges is required so that its location is evident to maintenance crews. Also, shrubs, trees, sprinkler heads and valve boxes shall not be located in the reinforced turf grass area.

Pavement designs for access drives shall be submitted for review and approval based onsite soil conditions and H-20 loading.

Retaining walls shall be laid out in a manner that avoids access restrictions. Likewise, handrails or fences shall permit vehicular access. The entrance to an access drive from a roadway or parking lot shall be located so that traffic safety is not compromised. A means of limiting public access to the site, such as bollards and a chain or a gate, shall be provided at the entrance to the access drive.

5.7.2 Other Improvements to Facilitate Maintenance

Other improvements that could facilitate future maintenance operations are encouraged. These may include:

1. Providing adequate room for staging the equipment involved in clean-out operations.
2. Providing a power receptacle adjacent to the detention pond to enable dewatering operations using an electric pump. Electric pumps are quieter and require less attention in the event pumps need to operate overnight.
3. For larger, natural sites, it may be worthwhile to reserve a suitable location for disposing of sediment that is cleaned out of the pond. This has to be carefully thought through, however, to make sure it is feasible to dump the material on-site, allow it to dry, then spread it and re-seed and mulch the area, without causing erosion problems. This approach must be approved and adequately described in the O&M Manual, if allowed.

5.8 Construction Phasing

It may be possible to delay the construction of detention ponds if development upstream of the planned pond site is limited relative to the fully-developed land use plan. However, development tends to destabilize downstream channels due to an increase in flows, but also due to a reduction in available sediment ("clear water" discharges). Estimates of the impact of development on downstream channels shows that even a small change in minor storm flows can begin to change downstream channel characteristics. Therefore, some limited upstream development may occur prior to construction of sub-regional or regional detention facilities. However, improvements to channels between the developed area and the pond site may need to be improved to prevent degradation.

5.9 Downstream Channel Stabilization

Even with the construction of detention ponds that release pre-development flow rates, it is anticipated that downstream channels will tend to become unstable due to the increase in the volume of stormwater released and the reduction in the amount of available sediment. To avoid degradation in downstream channels, channel stabilization improvements should be extended downstream of developed areas or detention facilities. Completing these channel improvements may require the acquisition of offsite right-of-way. Additionally, consideration must be given to the capacity of the channel improvements with respect to future development.

6.0 Parking Lot Detention

Where on-site detention is approved, portions of the site used for parking or landscaping may be inundated to provide some of the storage required.

6.1 Access Requirements

Easements for parking lot detention shall be provided, including the area of the parking lot that is inundated by the 100-year water surface elevation and the outlet structure and conveyance facilities. Easements shall also be provided from public right-of-way to the pond facilities.

6.2 Maintenance Requirements

The property owner shall be required to ensure that the parking lot detention are maintained in accordance with the approved Operations and Maintenance Manual (O&M Manual) for the project.

6.3 Depth Limitation

The 100-year design water surface shall not flood the parking area by more than 9 inches. When FSD is applied, the maximum allowable design depth above pavement surfaces for the EURV is 3 inches. The WQCV shall be located entirely out of the pavement area, possibly in one or more landscaped parking islands or adjacent landscaping.

6.4 Emergency Spillway

An emergency spillway sized for the 100-year peak inflow rate shall be provided with a crest elevation set at the 100-year water surface elevation and a maximum flow depth over the emergency spillway of 6 inches. No freeboard above the emergency spillway 100-year water surface elevation is required. The finished first floor elevation of any adjacent structures shall be at least 1.0 foot above the 100-year emergency overflow water surface elevation (equivalent to 18 inches above the 100-year pond water surface).

The emergency spillway should be integrated into the site plan and landscaping and can be vegetated over stabilization material such as soil riprap or a geotextile. Embankment protection may be eliminated if the depth of flow and velocities for the 100-year flow are low enough to avoid erosion during overtopping.

6.5 Outlet Configuration

The outlet configuration for WQCVs and EURVs shall be designed in accordance with criteria shown in Volume 3 of the UDFCD Manual for the type of facility selected. Outlets for the EURV and 100-year events shall limit peak flows to the allowable release rates.

6.6 Flood Hazard Warning

All parking lot detention areas shall have a minimum of two signs posted identifying the area of potential flooding. The signs shall be fabricated of durable materials, such as metal or plastic, using red lettering on a white background and shall have a minimum area of 1.5 square feet and contain the following message:

**WARNING
THIS AREA IS A DETENTION POND
AND IS SUBJECT TO PERIODIC FLOODING
TO A DEPTH OF 9 INCHES OR MORE**

Signs shall be located at the edge of the parking area adjacent to where flooding may occur and facing the parking area. Any suitable geometry of the signs is permissible. The property owner shall be responsible to ensure that the sign is provided and maintained at all times.

Figure 13-1. Regional Detention Concept

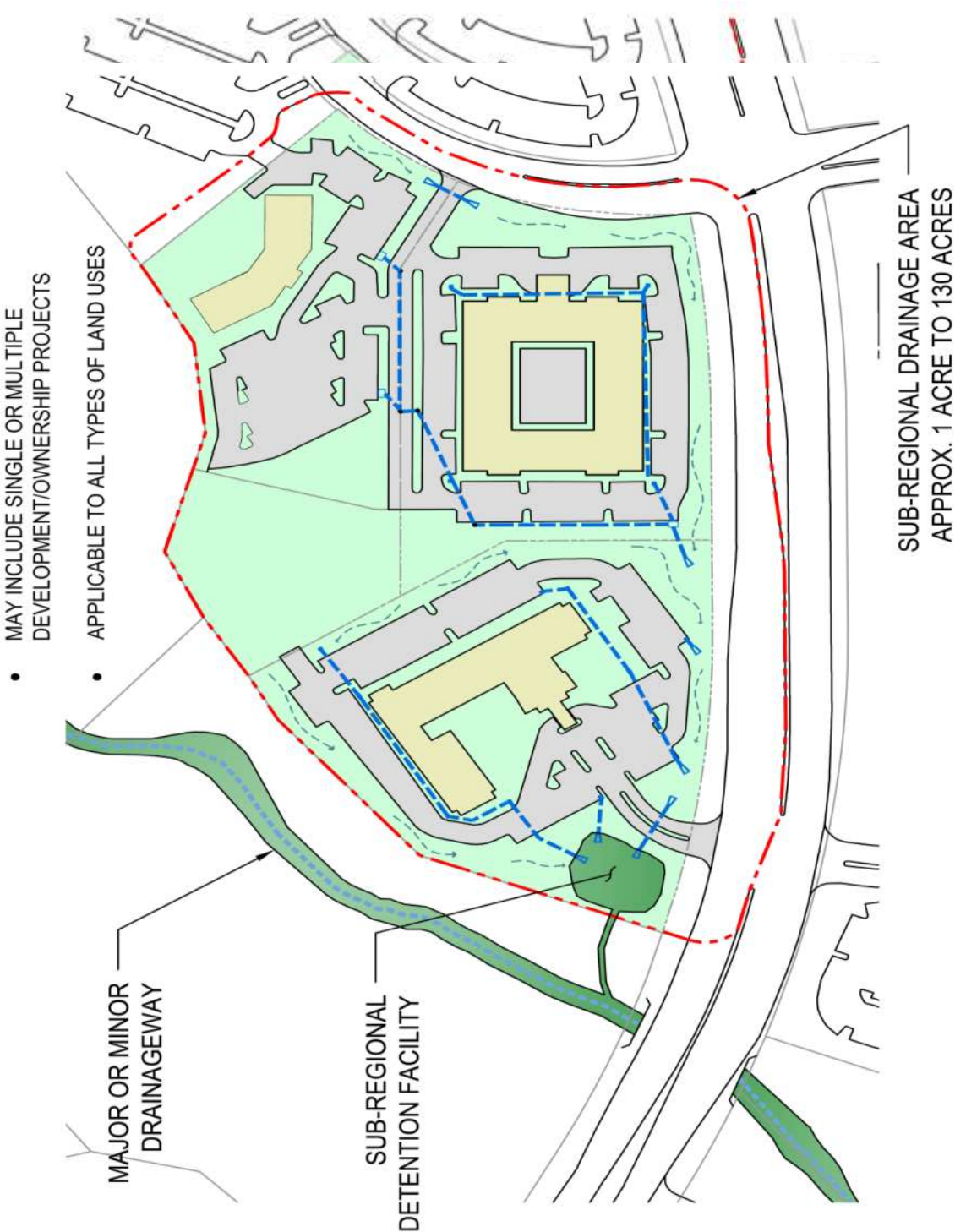


Figure 13-2. Sub-regional Detention Concept

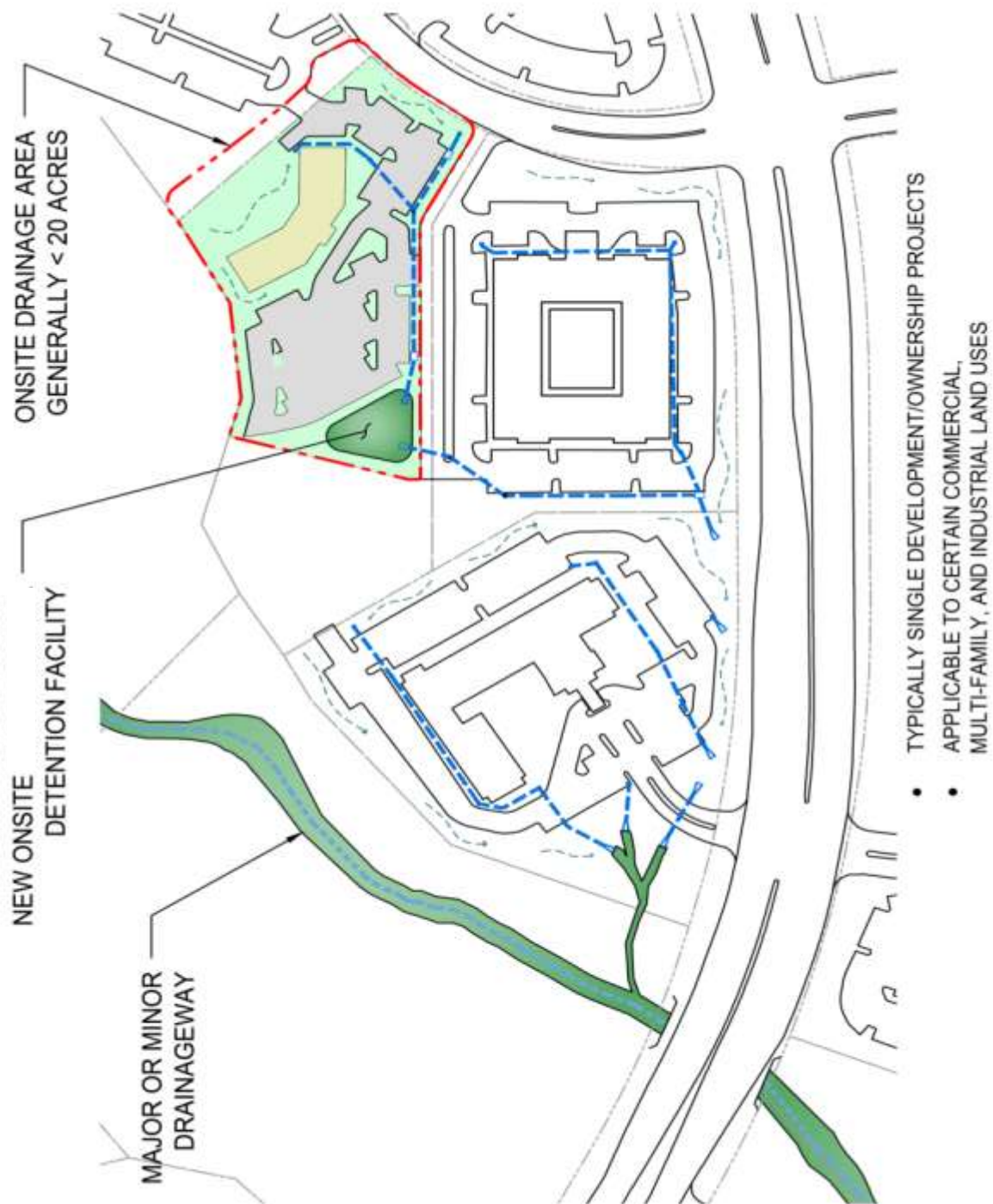


Figure 13-3. On-site Detention Concept

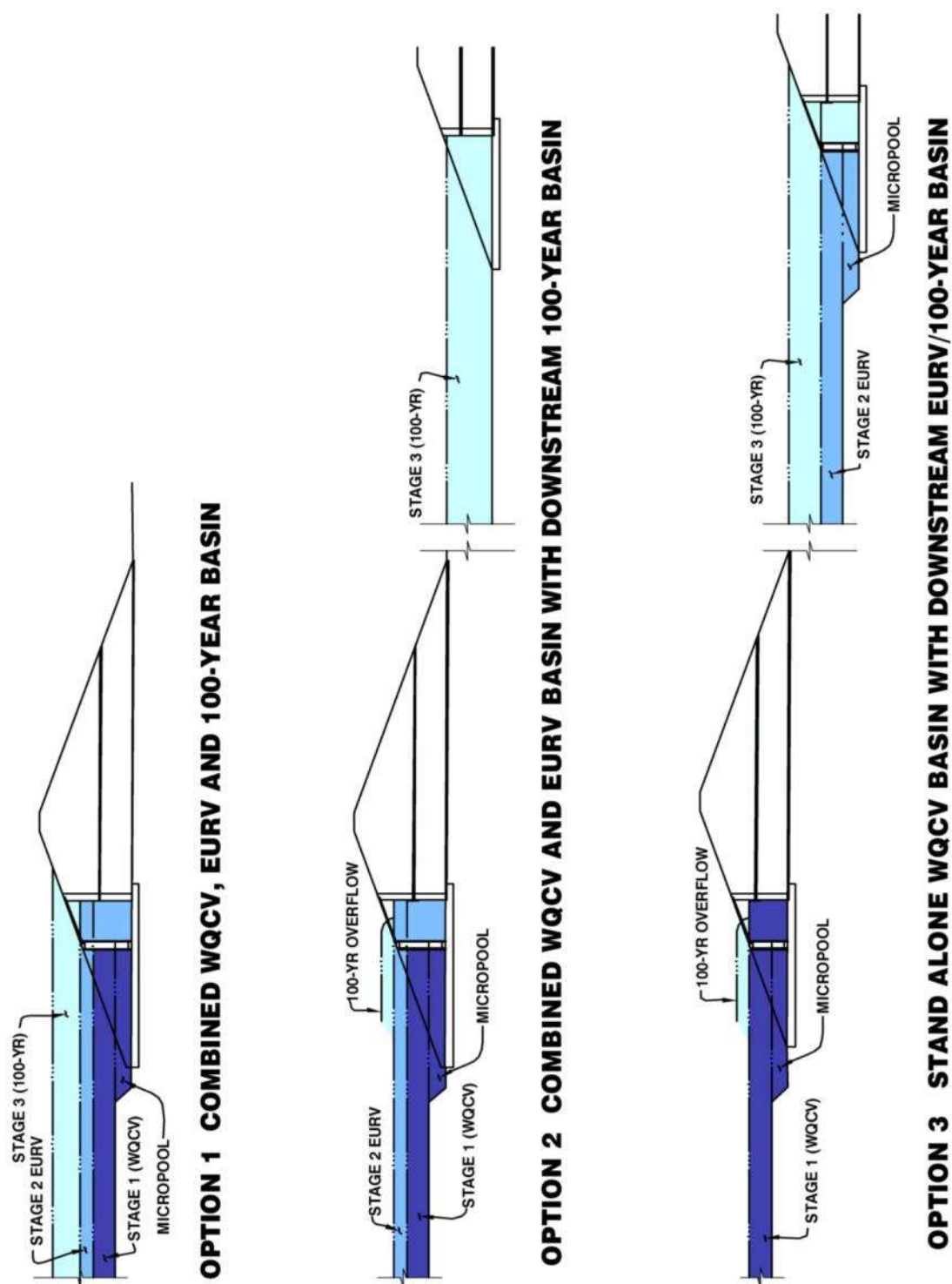


Figure 13-4. Design Options for Detention Basins

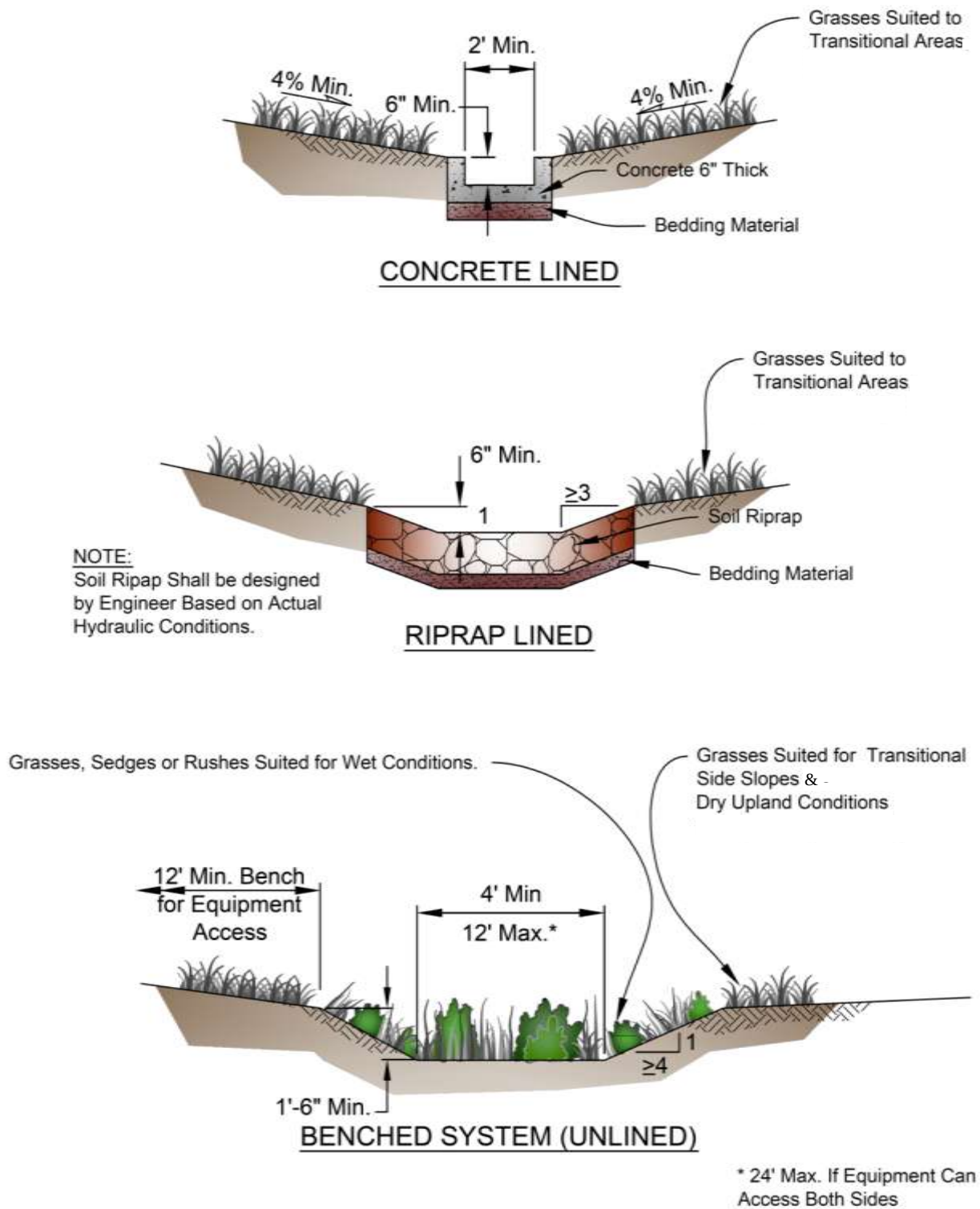


Figure 13-5. Typical Low-flow Channel Details

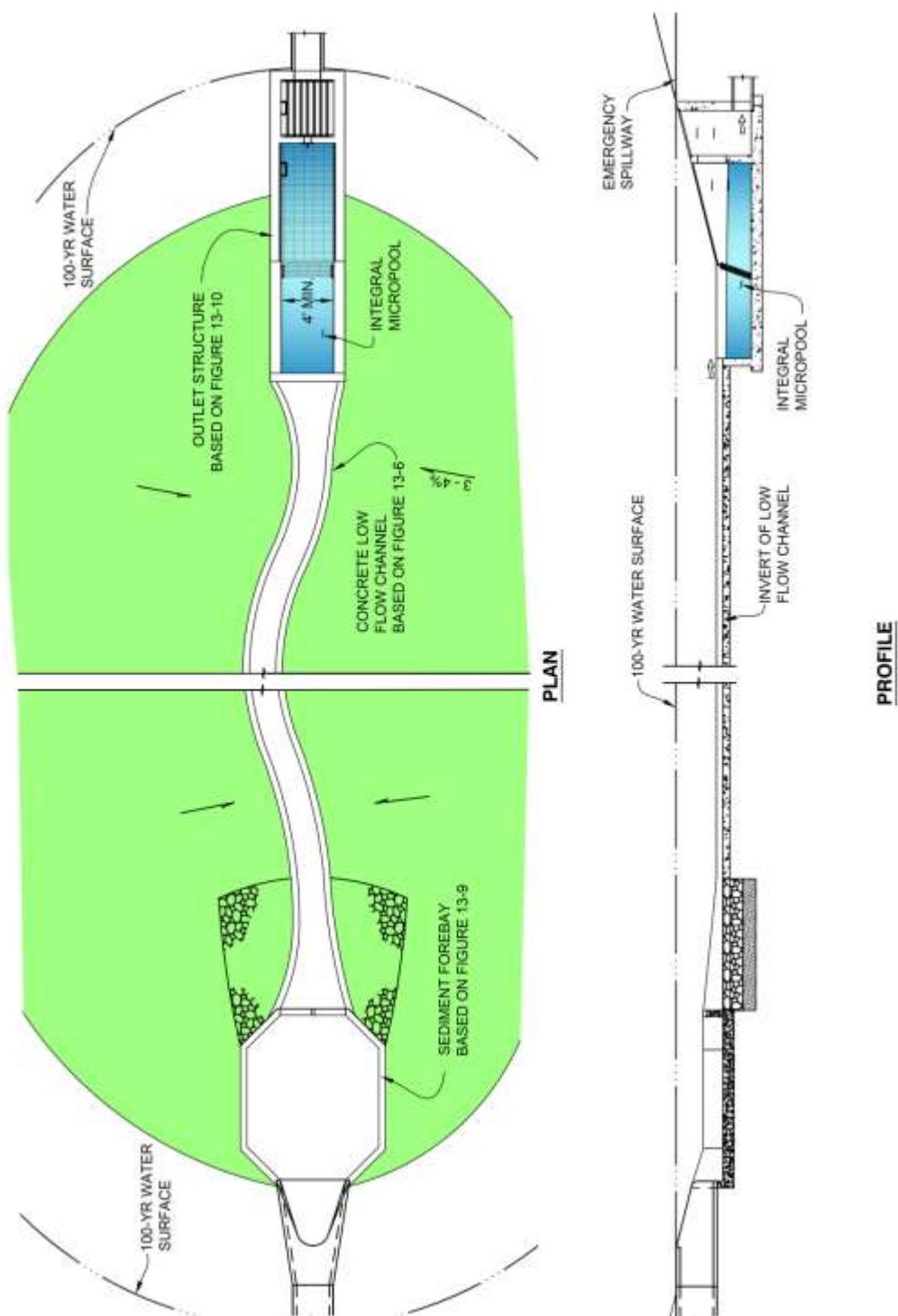


Figure 13-6. Concept for Extended Detention Basin with a Concrete Low-flow Channel

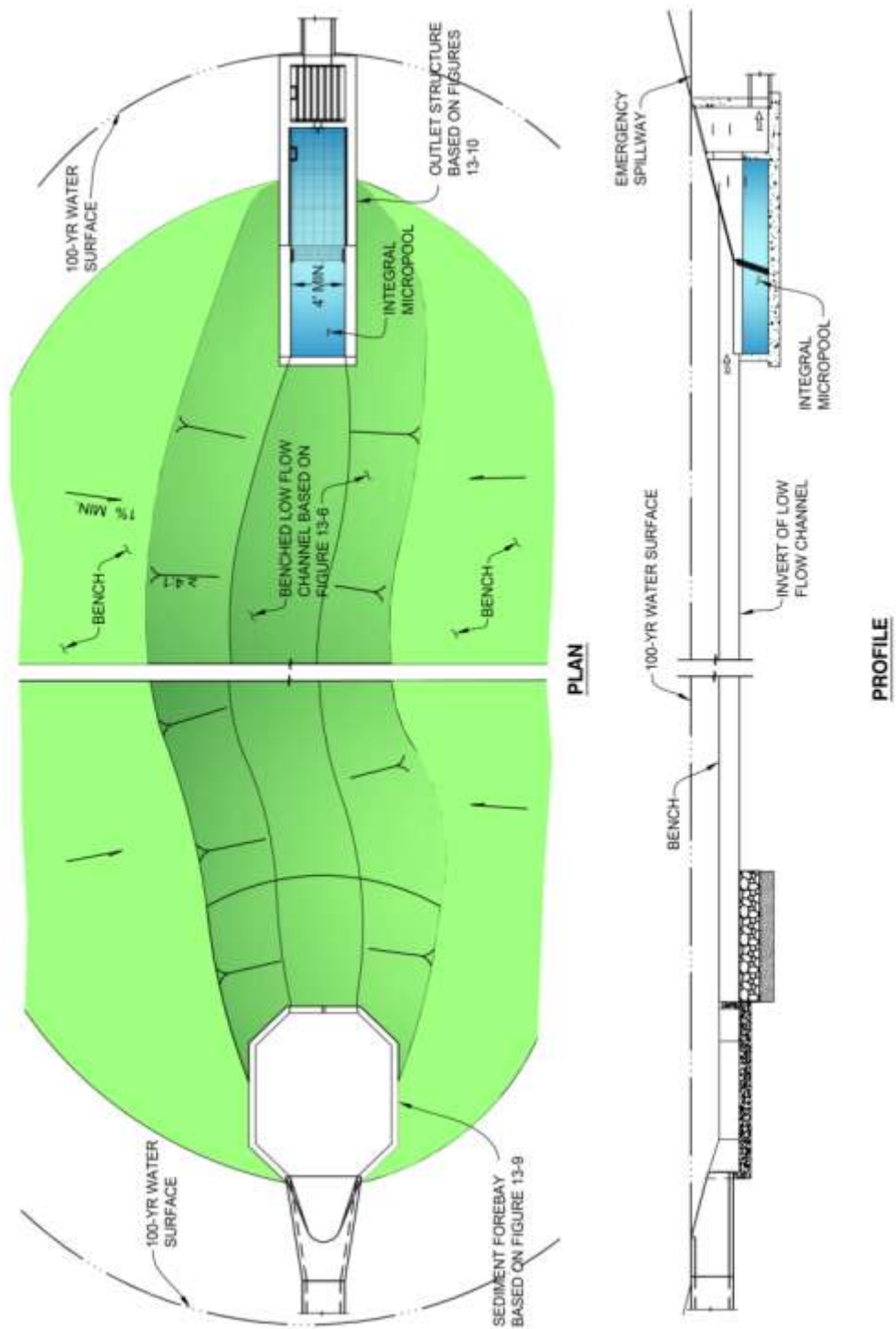


Figure 13-7. Concept for Extended Detention Basin with a Benched Low-flow Channel

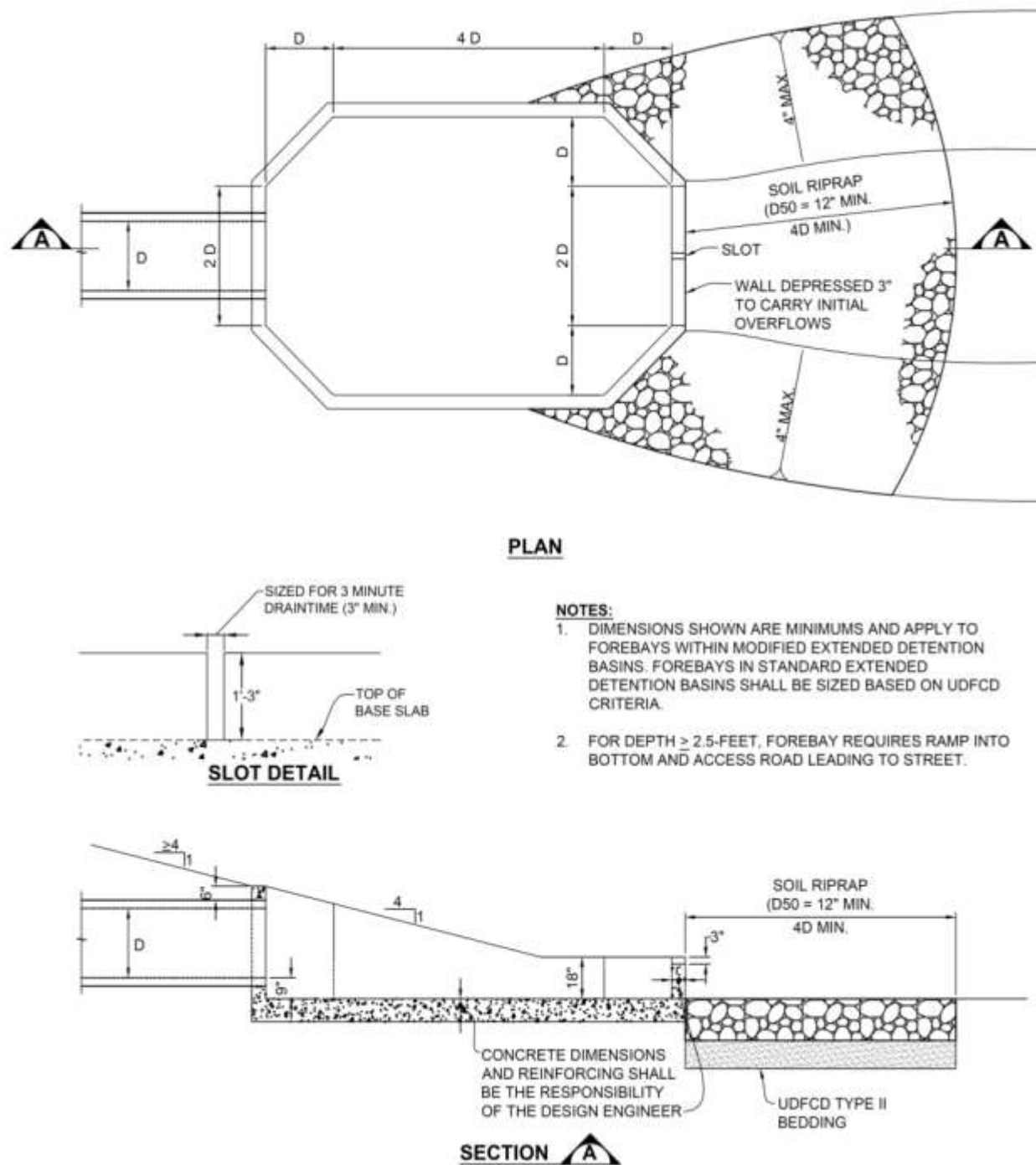


Figure 13-8. Concept for Integral Forebay at Pipe Outfall

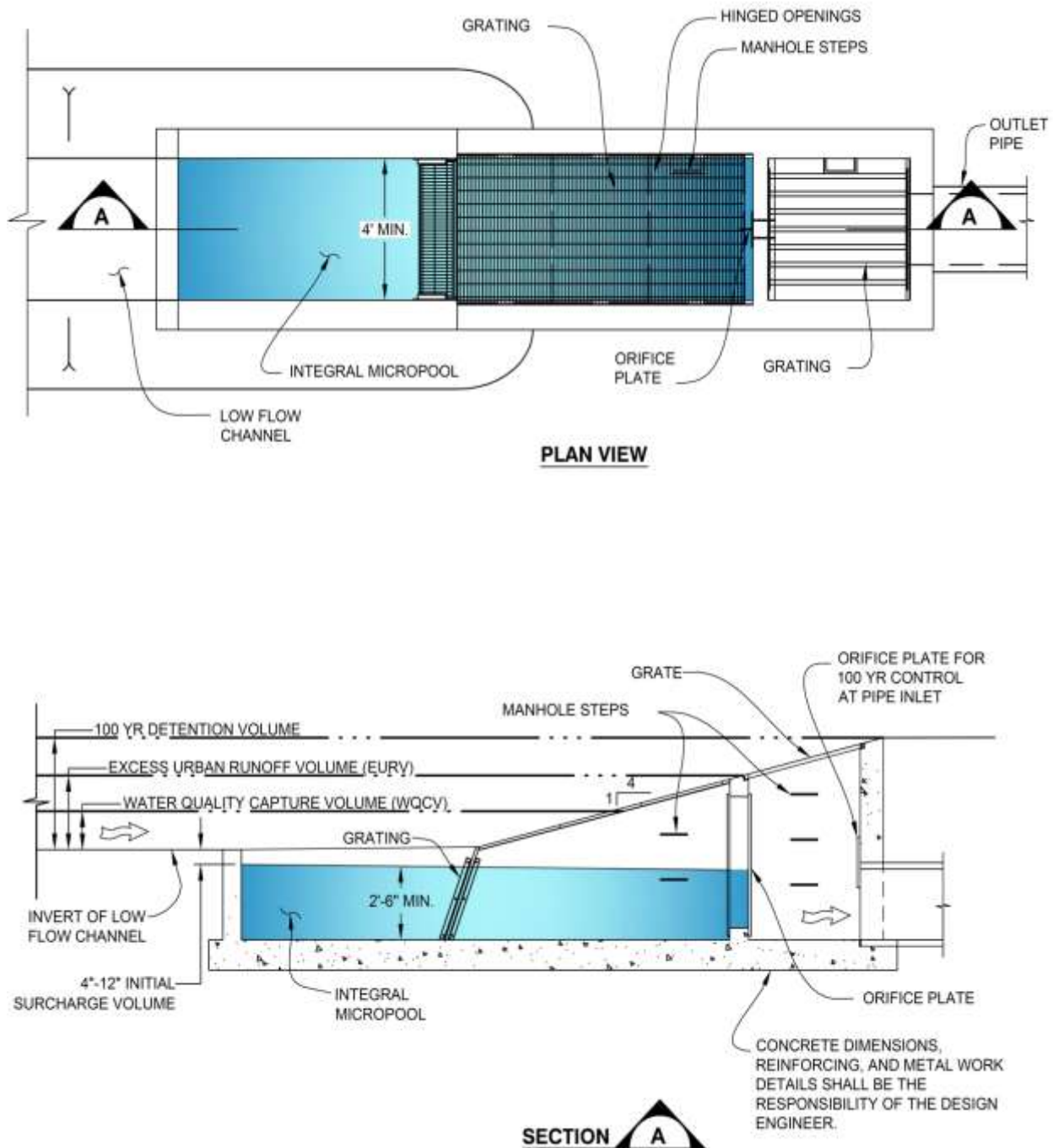


Figure 13-9. Concept for Outlet Structure with Parallel Wingwalls and Flush Bar Grating (Integral Micropool Shown)

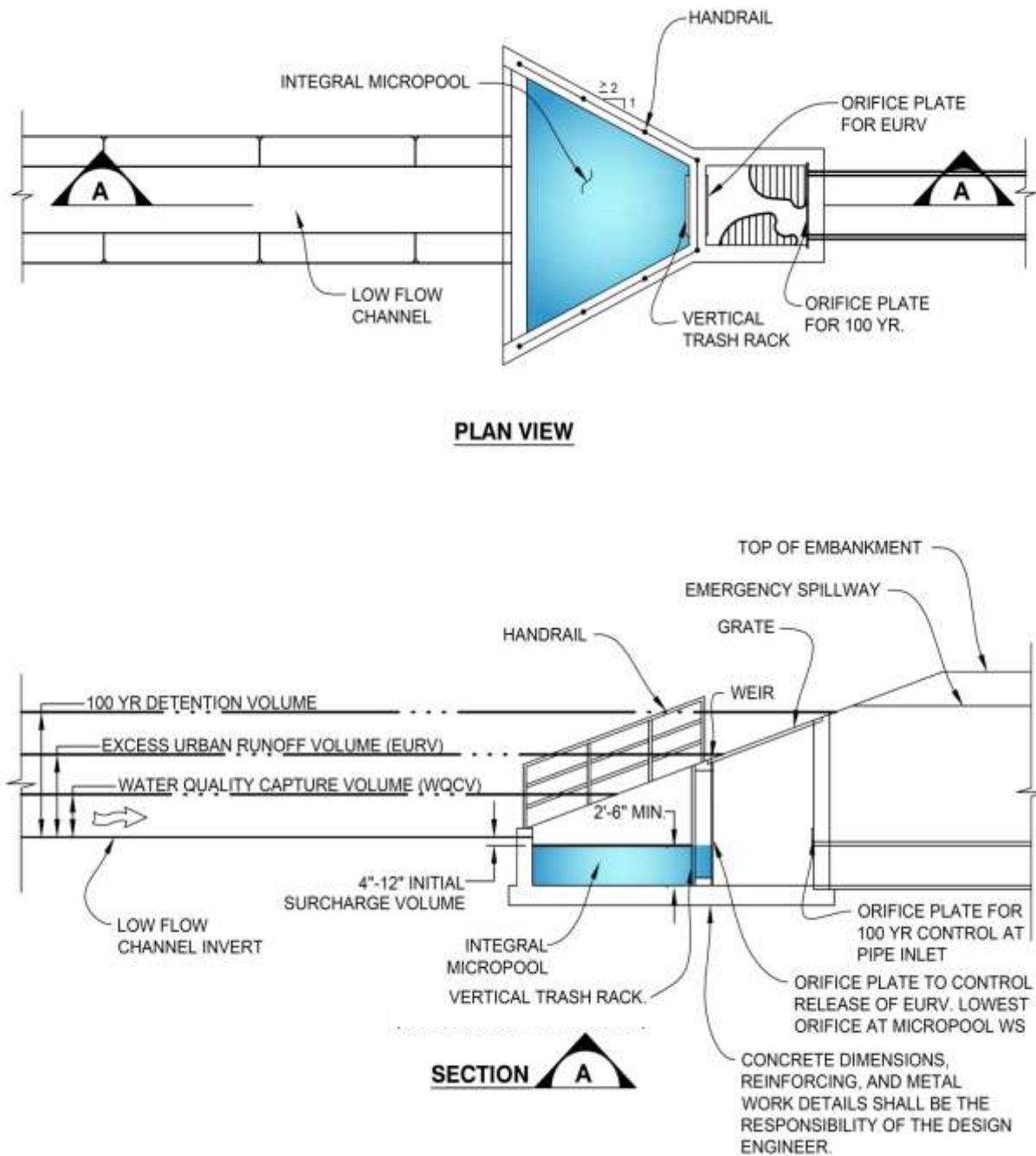


Figure 13-10. Concept for Outlet Structure with Flared Wingwalls and Handrail
(Integral Micropool Shown)

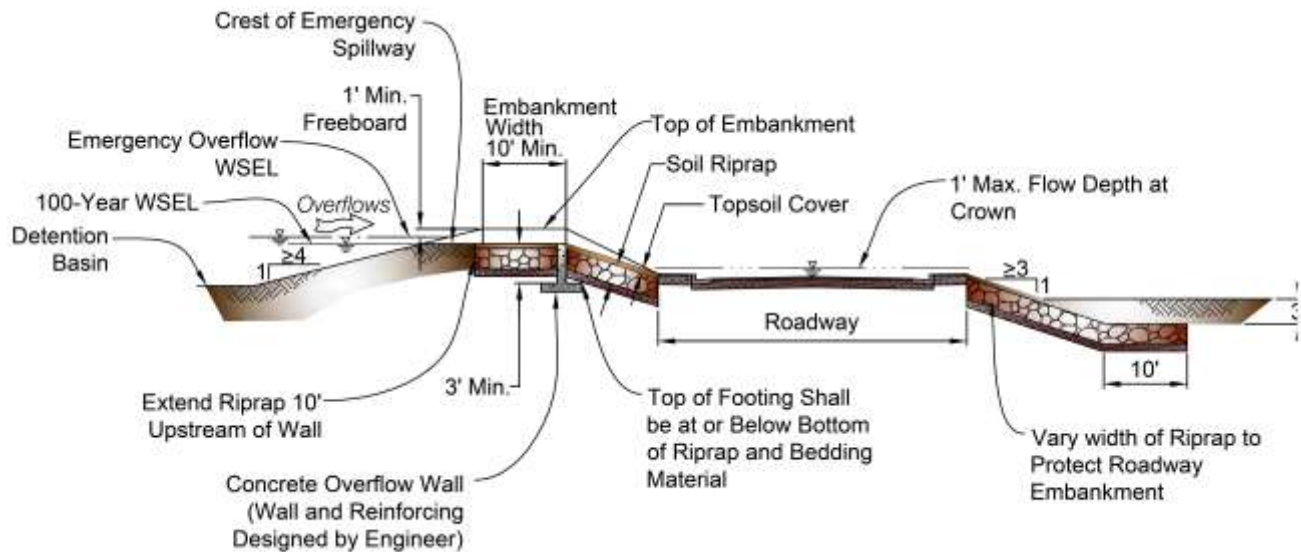


Figure 13-11a. Emergency Spillway Profile at Roadway

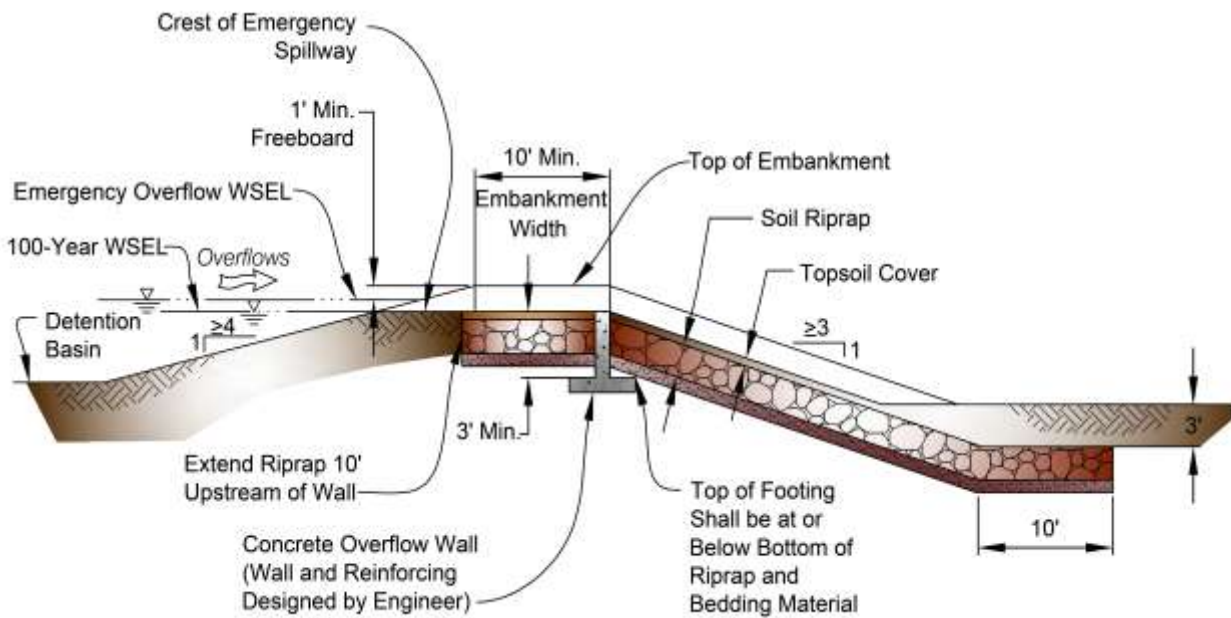


Figure 13-11b. Emergency Spillway Profile at Embankment

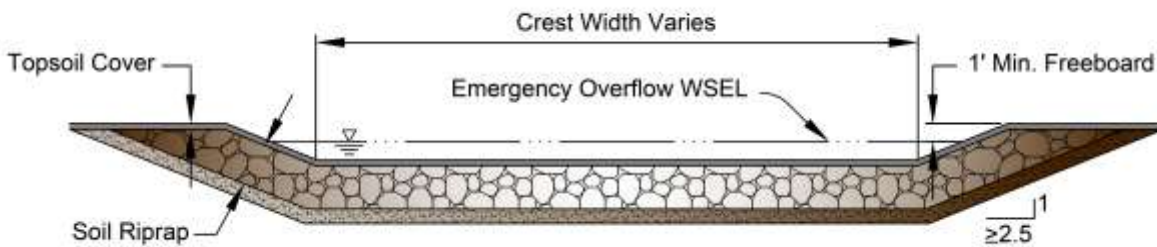


Figure 13-11c. Emergency Spillway Protection

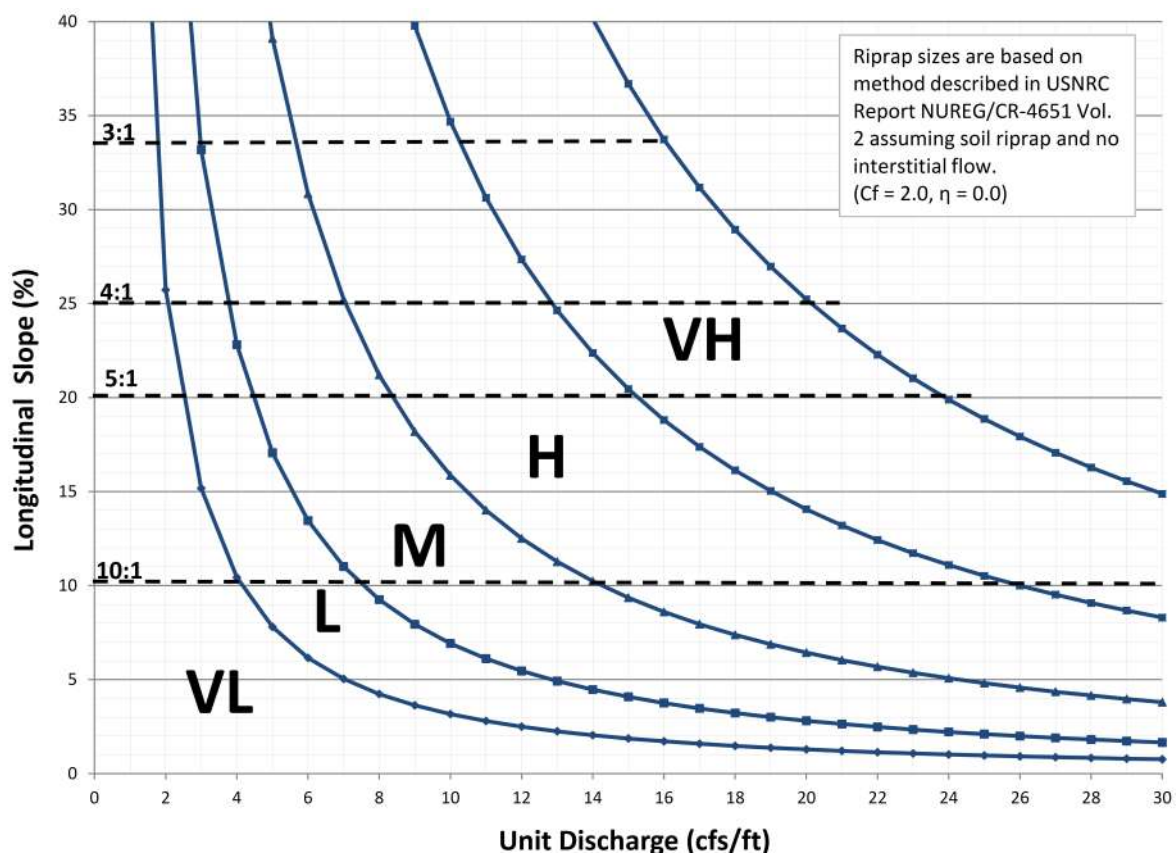


Figure 13-11d. Riprap Types for Emergency Spillway Protection

Chapter 14

Revegetation

Contents

1.0	Introduction.....	1
2.0	Understanding Site Vegetation	1
2.1.0	Common Drainageway Plant Communities	1
2.1.1	Upland.....	1
2.1.2	Non-Wetland Riparian	2
2.1.3	Wetlands	2
3.0	Site Preparation.....	3
3.1	General Guidelines for Site Preparation.....	3
3.2	Initial Hydrologic Evaluation.....	3
3.3	Initial Weed Condition Evaluation and Control	4
3.3.1	Control of Annual Weeds	6
3.3.2	Control of Biennial and Perennial Weeds	6
3.3.3	Additional Weed Control Guidance for Wetland Areas.....	6
3.4	Topsoil Preservation.....	7
3.5	Soil Testing	7
3.6	Soil Amendment.....	11
3.6.1	Soil Amendment for Upland and Riparian Areas	11
3.6.2	Soil Amendment for Wetland Areas	12
3.6.3	Addressing Soil Compaction.....	12
3.6.4	Seedbed Firming	13
4.0	Plant Material Selection.....	13
4.1	General Guidelines.....	13
4.2	Shrubs and Trees.....	14
4.3	Seed Mixes.....	16
4.4	Wetland Plant Containerized Stock.....	18
4.5	Willow Cuttings and Poles.....	18
5.0	Seed and Plant Installation.....	20
5.1	General Guidelines.....	20
5.2	Planting Details	20
5.2.1	Willow Planting Details	20
5.2.2	Beaver Protection Detail	20
5.3	Mulching.....	22
5.4	Irrigation.....	22
5.5	Performance Standards for Vegetation Establishment	23
6.0	Maintenance.....	23
6.1	On-Going Monitoring and Management	23
7.0	Conclusion.....	24

Tables

Table 14-1. Site Preparation Activities for Revegetating Upland, Riparian and Wetland Habitats.....	3
Table 14-2. Proven Treatment Methods and Timing of Treatment for Common Weeds	5
Table 14-3. Viable Topsoil Composition for Colorado Native Plant Establishment in Upland Areas	10
Table 14-4. Recommended Upper Elevation Riparian Trees and Shrubs.....	15
Table 14-5. Low Grow Grass Mix	16
Table 14-6. Recommended Seed Mix for Wet Conditions ¹	16
Table 14-7. Recommended Seed Mix for Transition Areas.....	17
Table 14-8. Recommended Seed Mix for Upland Areas	17
Table 14-9. Recommended Plants for Constructed Wetlands and Detention Pond Shorelines ¹	18

Figures

Figure 14-1. Soil Textural Triangle.....	8
--	---

1.0 Introduction

Revegetation is critical to the proper functioning of drainage infrastructure such as grass-lined channels, detention basins, retention ponds, wetland basins, riparian areas, and upland areas along streams where channel improvements have been completed. Revegetation is also necessary to stabilize adjacent areas which were disturbed during construction. Successful revegetation is required to close-out common regulatory permits associated with working in waterways, including stormwater discharge permits required for certain construction activities and U.S. Army Corps of Engineers (USACE) 404 permits. Because of Woodland Park's variable precipitation, strong summer sun, short growing season, 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. This chapter provides information on methods and plant materials needed for revegetation of drainage facilities and riparian areas.

2.0 Understanding Site Vegetation

Developing and understanding of the site vegetation will facilitate drainageway work and lead to more successful project outcomes. The following subsections can be used as a guide to develop an understanding for these conditions.

2.1.0 Common Drainageway Plant Communities

There are three general habitat types or "planting zones" encountered on drainage-related projects: upland, non-wetland riparian and wetland areas. 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 both habitat types, whereas on other streams wetland areas may be narrow or absent.

Basic descriptions of each habitat type are provided in the following subsections. 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, 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.

2.1.1 Upland

Native upland areas in the Woodland Park include 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 in Woodland Park is generally xeric, requiring minimal rainfall to persist. 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 maintenance. Depending on weather and location, supplemental irrigation may be required during plant establishment.

The upland planting zone is located between the overbank elevation and the flood-prone elevation (i.e., the upper edge of the floodplain). On average, this zone floods every 10+ years. Consequently, it is exposed to erosive water forces only during large flood events. This zone is generally over 2 feet from groundwater and plant species rely on surface water and available precipitation as their water source.

2.1.2 Non-Wetland Riparian

Non-wetland riparian areas are located adjacent to rivers, streams, creeks, ponds and other waterbodies or their adjacent wetlands. Non-wetland riparian areas are shaped by the dynamic forces of water and are regularly flooded by rivers and streams. They provide a variety of ecosystem services including 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 critical to urban areas.

The riparian zone is found between the bankfull elevation and the overbank elevation. 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. Within the developed landscape, large, inflexible trees and shrubs should not be planted in this zone because they may exacerbate flooding and otherwise negatively alter flows during a high flow event.

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. This vegetation depends on access to water but can handle occasional dry periods once established. The riparian ecosystem is a transitional area between wetland and upland ecosystems.

Although riparian ecosystems represent only 3% of western habitat overall, this ecosystem is crucial for over half of the bird species and a majority of mammalian, amphibian and reptile species (The Wildlife Society 1983). 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.

2.1.3 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.

The wetland zone along stream channels is located between the average water elevation and the bankfull discharge elevation. The lower section (near the streambank) is exposed to the highest velocity flows and therefore can exhibit the most erosion (NRCS 2001b). The higher section (transitions into the lower riparian zone) is inundated much less frequently and is exposed to less erosive forces. In high velocity streams, the lower 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 foothills wetland species include sandbar willow (*Salix exigua*) and redosier dogwood (*Cornus 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

3.1 General Guidelines for Site Preparation

Initial evaluation of site conditions and appropriate site preparation are fundamental to successful revegetation for upland, riparian and wetland habitat types. Table 14-1 identifies various site preparation activities pertinent to the plant community types identified in Section 2 of this chapter.

Table 14-1. Site Preparation Activities for Revegetating Upland, Riparian and Wetland Habitats

Revegetation Guidance Topic	Applicability to Habitat Type		
	Upland	Riparian	Wetland
Initial Hydrologic Evaluation		✓	✓
Initial Weed Evaluation and Control	✓	✓	✓
Topsoil Preservation (including Existing Wetland Soil)	✓	✓	✓
Soil Testing	✓	✓	✓
Soil Amendment	✓	✓	✓
Seed Bed Preparation	✓	✓	✓
Tree Protection	✓	✓	✓

3.2 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. Ideally, 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. This will not be feasible for many projects and if limited groundwater data are available (i.e., from geotechnical reports or only one year of monitoring), it may be necessary to infer groundwater depths by studying plant distribution and drainage patterns.

As part of the wetland planning process, wetland areas should be designed to have water at the surface for at least two weeks during the growing season. For riparian area planning, it is important to recognize that riparian 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.

3.3 Initial Weed Condition Evaluation and Control

Weed infestations that prevent the establishment of the desired native vegetation should be controlled. In some cases, non-native aggressive grasses may also need to be controlled. 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 14.2. 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 an important step 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. However, weed management cannot often be accomplished ahead of construction activities and will have to be an on-going process as the planted/seeded vegetation establishes. Weed control after revegetation of the site is more difficult due to the presence of establishing plants. While construction activities are still on-going, maintaining weed control over the entire site, including on the topsoil stockpile, will greatly reduce weed pressure once the topsoil is replaced and revegetation commences.

Table 14-2. Proven Treatment Methods and Timing of Treatment for Common Weeds

Common Name	Scientific Name	CO Weed List Rating	Spring Treatment	Summer Treatment	Fall Treatment
Wetland Weeds					
Canada thistle	<i>Cirsium arvense</i>	B	H,MM	MM	H, MM
Common teasal	<i>Dipsacus fullonum</i>	B	H		H
Eurasian watermilfoil	<i>Myriophyllum spicatum</i>	B	BI, H	MP	MP
Purple loosestrife	<i>Lythrum salicaria</i>	A	MD, MP, H, BI		
Tamarisk	<i>Tamarix ramosissima</i>	B	BI, H ¹	H ¹	H ¹
Riparian Weeds					
Leafy spurge	<i>Euphorbia esula</i>	B	BI, H		H
Poison hemlock	<i>Conium maculatum</i>	C	HP, H	HP	H
Quackgrass	<i>Elymus repens</i>	B			H
Russian olive	<i>Elaeagnus angustifolia</i>	B	H ¹	H ¹	H ¹
Upland Weeds					
Bindweed	<i>Calystegia sepium</i>	NL	BI, MP ²	H	H
Bouncingbet	<i>Saponaria vaccaria</i>	B		H	H
Bull thistle	<i>Cirsium vulgare (Savi) Tenore</i>	B	MP ² , BI, H, BG ³	MM, BG ³	H, BG ³
Chinese clematis	<i>Clematis orientalis</i>	B	BG, MP	H	
Common burdock	<i>Arctium minus</i>	C	MP ² , MM, H, BI	MM	MM, H
Common mullein	<i>Verbascum Thapsus</i>	C	H		H
Dalmation toadflax	<i>Linaria dalmatica</i>	B	BI, MP ² , H		H
Diffuse Knapweed	<i>Centaurea diffusa</i>	B	MP ² , BI, H	MM, MC, H	H
Downy brome (Cheat grass)	<i>Bromus tectorum</i>	C			H
Kochia	<i>Kochia scoparia</i>	NL	MP ²	MM, H	
Myrtle spurge	<i>Euphorbia myrsinites</i>	A	H	H	H
Musk thistle	<i>Carduus nutans</i>	B	BI, MP ² , MC, H, BG ³	MM, BG ³	H, BG ³
Perennial pepperweed	<i>Lepidium latifolium</i>	B	MP ² , H, BG		
Plumeless thistle	<i>Carduus acanthoides</i>	B	BI, MP ² , H,MC, BG ³	MM, BG ³	H, BG ³
Puncturevine (Goathead)	<i>Tribulus terrestris</i>	C	MP ² , BI, H	MD, H	
Redstem filaree	<i>Erodium cicutarium</i>	B	MP ² , H		H
Russian knapweed	<i>Acroptilon repens</i>	B	H		H
Russian thistle	<i>Salsola tragus</i>	NL	MP ² , BG, H	H	
Scotch thistle	<i>Onopordum acanthium</i>	B	MD, MP ² , H, BG ³	MM, BG ³	BG ³ , H
Yellow starthistle	<i>Centaurea solstitialis</i>	A	MP ² , MM, BI, BG, H		
Yellow toadflax	<i>Linaria vulgaris Mill</i>	B	MP ² , BI		H
Whitetop (Hoary cress)	<i>Cardaria draba</i>	B	MM, H		H

Table Notes: ¹Grazing with sheep, goats and horses- no cattle. ²Pull young seedlings. ³Cut 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. For example, if herbicide treatment during a calendar year involves over 20 linear miles or 80 acres of water (i.e., surface area), then a compliance certification is required.

3.3.1 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 (*Bromus 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.

3.3.2 Control of Biennial and Perennial Weeds

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. Spring and fall are good times for spot herbicide treatment of developing rosettes (first year stage) of many biennial species and some perennials weeds. This can be done before construction begins or before revegetating a site. 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*) when the plants are still small in size. Always follow herbicide label recommendations for best treatment times and chemical mixtures for specific weed species.

3.3.3 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) may be applied prior to planting and seeding. Repeat application of herbicide every two weeks on any remaining green growth. Allow two to three weeks prior to planting.

3.4 Topsoil Preservation

During construction activities, topsoil should be stripped and stockpiled separately from sub-soil and wetland soil. The quantity of topsoil that can be preserved and stockpiled varies, depending on the particular site. 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.

In order to preserve soil microbes, which are helpful with plant establishment, it is best to limit topsoil stockpiles to a height of 10 feet. Many local jurisdictions have requirements on duration and heights of stockpiles. Once stockpiled, the topsoil can be protected from erosion and weed infestations by seeding with a sterile non-native grass or a native seed mix, depending on how long it will remain.

For wetlands, topsoil may be salvaged from a wetland that will be destroyed (on-site or at another location). 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. NRCS recommends that stockpiles should be kept for less than four weeks and should measure less than 3 x 3 feet (height/width). Wetland topsoil should not be stockpiled during the summer because it will compost, and the seeds and propagules will be killed.

3.5 Soil Testing

Soil testing of both native and imported topsoil is recommended to select appropriate plant species for a site and to determine if and what types of soil amendment will be beneficial. Soil samples can be delivered or mailed 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 14-3 provides general guidance for viable topsoil composition for the establishment of native plants in upland areas in Colorado.

For upland areas in the Colorado foothills, 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 14-1). A 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.

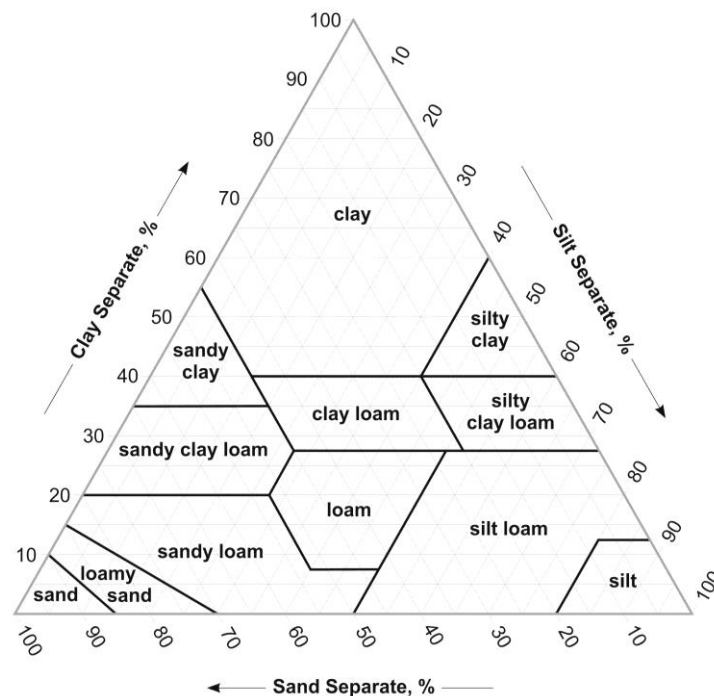


Figure 14-1. Soil Textural Triangle

When collecting soil samples and reviewing analysis results, follow these guidelines:

- Soils should be evaluated during design (visually by a qualified member of design team or by lab analysis) and soils tests should be obtained during construction because grading activities and the process of stripping and stockpiling can result in very different conditions.
- Soil samples should be collected by the vegetation specialist or contractor. Observation of the soil source areas in the field is necessary to assist with determination of quality of the soil as a topsoil source.
- 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 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 vegetation specialist or other qualified landscape professional who is familiar with the project so that the proper soil amendments are applied for the type of vegetation that will be seeded/planted.

Local companies and laboratories in Colorado that conduct soil testing include:

ACZ Laboratories, Inc.
2773 Downhill Drive
Steamboat Springs, CO 80487

Analytica Environmental
Laboratories, Inc.
12189 Pennsylvania Street
Thornton, CO 80241
303.469.8868

Colorado Analytical Laboratory
240 South Main Street
Brighton, CO 80601
303.659.2313

Colorado State Soil, Water and
Plant Testing Laboratory
Room A319 NES Building
Fort Collins, CO 80601
970.491.0561

Table 14-3. 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 dia. range)	25 to 65	5	
Silt (0.002-0.5 mm dia. range)	20 to 50	30	
Clay (<0.002 mm dia. range)	20 to 30	25	

3.6 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 14-3. Wetland areas typically do not require soil amendments. Soil amendment considerations for upland and riparian areas are presented in the following sections.

3.6.1 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 project ecologist or other qualified landscape professional 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 contaminate 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. 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.

Upland grassland topsoil is often characterized as having low-nutrient soils; therefore, soil fertilizers may not be necessary for successful native plant species revegetation. If the original topsoil from a site was 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 microorganisms. Other chemical corrections are not generally needed.

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 then be incorporated 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 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.

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.

3.6.2 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 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).

3.6.3 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.

3.6.4 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 $\frac{1}{4}$ to $\frac{3}{4}$ inch only (NRCS 2011b).
- For wetland areas, the surface is considered firm enough when a person's footprint penetrates $\frac{1}{4}$ to $\frac{1}{2}$ 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 may be helpful 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.

4.0 Plant Material Selection

4.1 General Guidelines

This section provides guidelines and recommendations on plant materials for revegetation of components of the drainage corridor. There are different revegetation requirements for the various parts of these areas. For example, the bottom, side slopes and area immediately adjacent to a detention facility have different moisture regimes and soil types; therefore, they should be planted with different plant species. Different plant forms (e.g., grasses, shrubs, trees) may also be limited to specific areas to enable proper functioning of the facility. For example, planting trees and shrubs along the bottom of a channel can reduce the hydraulic capacity of the channel, increase maintenance requirements and cause the plugging of downstream bridges and culverts when uprooted by higher flows.

To the extent feasible, these guidelines should be followed when developing a planting plan:

1. Plant material selection

- The form(s) of vegetation and species used should be adapted to the soils and moisture conditions and intended use (e.g., conveyance of flow, side slope, etc.) of the area.
- Native perennial species should be used to the extent possible.
- Except along formal park settings, use of bluegrass and other species requiring irrigation and high maintenance should be avoided.

- Sod-forming grasses are preferred over bunch grasses.
- To the extent feasible, containerized nursery stock from local sources should be used for wetland herbaceous species, and all woody trees and shrubs.
- Wetland plantings should not include cattails—although certain members of this genus are native to Colorado, they often develop invasive growth habits and choke out other species.
- Maintenance requirements should be considered in plant selection (e.g., tall grasses should not be used in urban areas unless regular mowing will occur).

2. Seed mixes

- Recommended seeding rates specified as pounds pure live seed per acre (lbs PLS/acre) should be used.

4.2 Shrubs and Trees

Trees and shrubs add diversity to a planting plan and value for wildlife and birds. Trees and shrubs that impede flow and reduce the capacity of the structure should not be planted in the bottom of a drainage channel. Cottonwood pole plantings and coyote (or sandbar) willow cuttings may be used to establish cottonwood trees and willows in appropriate locations, especially in soils with a shallow groundwater table within 12 to 36 inches of the surface.

To meet specific site conditions, the species of trees and shrubs to should be chosen to match site conditions. The primary site conditions to consider include expected depth to water and aspect. As a general rule of thumb, plants that are already present and healthy in the site vicinity should be considered as candidate species. Table 14.4 provides a list of tree and shrub species that may be suitable for drainageway planting in Woodland Park.

Table 14-4. Recommended Upper Elevation Riparian Trees and Shrubs

Regionally Occurring Trees	
Common Name	Scientific Name
Canyon maple	<i>Acer grandidentatum</i>
Boxelder maple	<i>Acer negundo</i>
Mountain alder	<i>Alnus tenuifolia</i>
Utah serviceberry	<i>Amelanchier utahensis</i>
River birch	<i>Betula fontinalis</i>
Western birch	<i>Betula occidentalis</i>
Colorado blue spruce	<i>Picea pungens</i>
Ponderosa pine	<i>Pinus Ponderosa</i>
Narrow-leaf cottonwood	<i>Populus angustifolia</i>
Balsam poplar	<i>Populus balsamifera</i>
Douglas fir	<i>Pseudotsuga menziesii</i>
Peach-leaved willow	<i>Salix amygdaloides</i>
Mountain ash	<i>Sorbus scopulina</i>
Green ash	<i>Fraxinus pennsylvanica</i>
Regionally Occurring Shrubs	
Common Name	Scientific Name
Rocky Mountain maple	<i>Acer glabrum</i>
Saskatoon serviceberry	<i>Amelanchier alnifolia</i>
Shadblow serviceberry	<i>Amelanchier canadensis</i>
Red osier dogwood	<i>Cornus stolonifera</i> (syn.: <i>C. sericea</i>)
Hawthorn	<i>Crataegus erythropoda</i>
Twinberry	<i>Lonicera involucrate</i>
Potentilla	<i>Potentilla fruticosa</i>
American plum	<i>Prunus americana</i>
Pin cherry	<i>Prunus pensylvanica</i>
Chokecherry	<i>Prunus virginiana melanocarpa</i>
Gambel's oak	<i>Quercus gambelii</i>
Golden currant	<i>Ribes aureum</i>
Common gooseberry	<i>Ribes inerme</i>
Smooth sumac	<i>Rhus glabra</i>
Rocky Mountain sumac	<i>Rhus glabra cismontana</i>
Woods rose	<i>Rosa woodsii</i>
Coyote willow	<i>Salix exigua</i>
Mountain snowberry	<i>Symphoricarpos oreophilus</i>

4.3 Seed Mixes

Unlined portions of the drainage corridor that are disturbed during construction should be actively revegetated. Seed mixes should be selected based on site conditions and management goals. A good rule of thumb is to select seed mixes that include plants with a broad range of tolerance for limiting conditions. For example, a wetland seed mix may include some species that thrive in very wet conditions as well as species that can tolerate periods of drought.

Recommended seed mixes for wet, transitional and upland areas are included in Tables 14-5 through 14-8.

Table 14-5. Low Grow Grass Mix

Common Name	Scientific Name	Growth Form ¹
Ephraim Crested Wheatgrass	<i>Agropyron cristatum (L.) A. Gaertn</i>	Bunchgrass
Sheep Fescue	<i>Festuca ovina</i>	Bunchgrass
Perennial Rye	<i>Lolium perenne</i>	Bunchgrass
Chewing Fescue	<i>Festuca rubra subsp. commutata</i>	Bunchgrass
Canada Bluegrass	<i>Poa compressa</i>	Sod-forming

Notes: ¹Characteristics: Grows 8-12 inches tall, Requires little to no maintenance, Grows well in elevations up to 10,000 ft.

Seeding Rate: New seeding – Dryland: 20-25 lbs/acre, Irrigated 40 lbs/acre; Overseeding – Dryland: 10-15 lbs/acre, Irrigated 20 lbs/acre.

Source: Arkansas Valley Seed, www.avseeds.com.

Table 14-6. Recommended Seed Mix for Wet Conditions¹

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre Drilled	Lbs PLS/Acre Broadcast or Hydroseeded
Redtop ¹	<i>Agrostis gigantea</i>	Warm	Sod	5,000,000	0.1	0.2
Switchgrass (Pathfinder)	<i>Panicum virgatum</i>	Warm	Sod/Bunch	389,000	2.2	4.4
Western wheatgrass (Arriba)	<i>Pascopyrum smithii</i>	Cool	Sod	110,000	7.9	15.8
Indian saltgrass	<i>Distichlis spicata</i>	Warm	Sod	520,000	1.0	2.0
Woolly sedge	<i>Carex lanuginose</i>	Cool	Sod	400,000	0.1	0.2
Baltic rush	<i>Juncus balticus</i>	Cool	Sod	109,300,000	0.1	0.2
				TOTAL	<u>11.4</u>	<u>22.8</u>

¹For portions of facilities located near or on the bottom or where wet soil conditions occur. Planting of potted nursery stock wetland plants 2-foot on-center is recommended for sites with wetland hydrology.

Table 14-7. Recommended Seed Mix for Transition Areas

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre Drilled	Lbs PLS/Acre Broadcast or Hydroseeded
Sheep fescue (Durar)	<i>Festuca ovina</i>	Cool	Bunch	680,000	1.3	2.6
Western wheatgrass (Arriba)	<i>Pascopyrum smithii</i>	Cool	Sod	110,000	7.9	15.8
Alkali sacaton	<i>Spolobolus airoides</i>	Warm	Bunch	1,758,000	0.5	1.0
Slender wheatgrass	<i>Elymus trachycaulus</i>	Cool	Bunch	159,000	5.5	11.0
Canadian bluegrass (Ruebens) ^{1, 2}	<i>Poa compressa</i>	Cool	Sod	2,500,000	0.3	0.6
Switchgrass (Pathfinder)	<i>Panicum virgatum</i>	Warm	Sod/ Bunch	389,000	1.3	2.6
				TOTAL	<u>16.8</u>	<u>33.6</u>

¹For side slopes or between wet and dry areas.

²Substitute 1.7 lbs PLS/acre of inland saltgrass (*Distichlis spicata*) in salty soils.

Table 14-8. Recommended Seed Mix for Upland Areas

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/ Acre Drilled	Lbs PLS/Acre Broadcast or Hydroseeded
Sheep fescue	<i>Festuca ovina</i>	Cool	Bunch	680,000	0.6	1.2
Canby bluegrass	<i>Poa canbyi</i>	Cool	Bunch	926,000	0.5	1.0
Thickspike wheatgrass (Critana)	<i>Elymus lanceolatus</i>	Cool	Bunch	154,000	5.7	11.4
Western wheatgrass (Arriba)	<i>Pascopyrum smithii</i>	Cool	Sod	110,000	7.9	15.8
Blue grama (Hachita)	<i>Chondrosum gracile</i>	Warm	Sod	825,000	1.1	2.2
Switchgrass (Pathfinder)	<i>Panicum virgatum</i>	Warm	Sod/ Brush	389,000	1.0	2.0
Side-oats grama (Butte)	<i>Boutelou curtipendula</i>	Warm	Sod	191,000	2.0	4.0
				TOTAL	<u>18.8</u>	<u>37.6</u>

4.4 Wetland Plant Containerized Stock

Wetland vegetation should be established in constructed wetlands, wetland bottom channels and along the shoreline of detention ponds if desired. Such vegetation serves multiple functions, including enhanced pollutant removal, shoreline stabilization, aesthetics, and wildlife and bird habitat. Recommended plants for wetlands are shown in Table 14-9 by water depth. Containerized stock is recommended for wetland plantings. Wetland plants should be spaced at no greater than 18 inches on center (O.C.).

Table 14-9. Recommended Plants for Constructed Wetlands and Detention Pond Shorelines¹

Depth of Water (ft)	Common Name	Scientific Name	Notes
0-1.5	Soft stem bulrush Hard stem bulrush Arrowhead Alkali bulrush Smart weed	<i>Scirpus validus</i> <i>Scirpus acutus</i> <i>Sagittaria latifolia</i> <i>Scirpus maritimus</i> <i>Polygonum persicaria</i>	- Planted plants should extend above water - Plants will invade deeper water with time - Within micropool stage
0.25-0.5	Three-square Spike rush	<i>Scirpus americanus</i> <i>Eleocharis palustris</i>	- Planted plants should extend above water - Within WQCV³ stage
0-0.25	Rice cut grass Nebraska sedge Soft rush Baltic rush Torrey's rush Foxtail barley	<i>Leersia oryzoides</i> <i>Carex nebrascensis</i> <i>Juncus effuses</i> <i>Juncus balticus</i> <i>Juncus torreyi</i> <i>Hordeum jubatum</i>	- Species will adjust to moisture conditions with time - Within EURV⁴ stage
Height above Groundwater ² 0-1 0-3	Milkweed Switchgrass Prairie cordgrass	<i>Asclepias incaornata</i> <i>Panicum virgatum</i> <i>Spartina pectinata</i>	- Best to plant near water where soil is wet - Colorful wildflower

¹Containerized stock is recommended for wetland plantings. Cattails are not recommended due to their aggressive growth.

²Depth from surface to reliable groundwater that must be present.

³WQCV = Water Quality Capture Volume

⁴EURV = Excess Urban Runoff Volume

4.5 Willow Cuttings and Poles

Live stakes, willow cuttings and poles are straight branches or saplings that have been cut and pruned from dormant living plant material (plants that have lost their leaves). General procedures for obtaining these live cuttings include:

- **Single live stakes:** Live branches that will be trimmed and cut to length for this installation should be a minimum of 2½-ft long and a minimum of ½ inch in diameter for bare ground installation and a minimum of 3½-ft long for riprap joint planting. These cuttings should be free from side branches, and the terminal bud must remain undamaged. The root end of each cutting should be cut at a 45-degree angle. This serves as an indicator of which end of the stake to tamp into the ground or riprap and also facilitates the tamping process.

- **Willow bundling:** For willow bundle applications, live branches should be trimmed and cut to a minimum of 4-ft long and a minimum of 3/8 inch in diameter. These units should be free from side branches. The root end of each cutting should be cut at a 45-degree angle. This serves as an indicator of which end of the stake to insert into the ground or riprap.

General harvesting guidelines include:

1. **Timing of harvest and installation:** Live willow staking, bundling and poling should be performed on dormant plants in the late fall or between February 1 and April 1, prior to leafing out. Cuttings should be placed in water deep enough to cover at least the lower 6 inches of the cuttings immediately after harvest and planting should occur as soon as possible after collection.
2. **Harvesting site:** Live cuttings should be taken from a local, naturally occurring site where permission to harvest has been obtained from the landowner. No more than 30% of available branches should be harvested at a site. The harvesting site must be left clean and tidy. Excess woody debris should be removed from the site and disposed of properly or cut up into 16-inch lengths and evenly distributed around the site.
3. **Species of live cut materials:** Willow species should be *Salix exigua* (Sandbar willow) or approved alternative. Willow cuttings should be at least 1/4 inch in diameter and cottonwood poles no less than 3/4 inch in diameter.
4. **Cutting:** The use of weed whips with metal blades, loppers, brush cutters and pruners is recommended, provided that they are used in such a manner that they leave clean cuts. The use of chain saws is not recommended. Live plant materials should be cut and handled with care to avoid bark stripping and trunk wood splitting. Cuts should be made 8 to 10 inches from the ground and at a flat or blunt angle.
5. **Binding and storage:** Live branch cuttings should be bound together securely with twine at the collection site, in groups, for easy handling and for protection during transport. Live branch cuttings should be grouped in such a manner that they stay together when handled. Outside storage locations should be continually shaded and protected from the wind. Cuttings should be held in moist soils or kept in water until ready for planting. Cuttings should be protected from freezing and drying.

Refrigeration is an acceptable method of storage, when necessary. Plants should be stored in moist, cool (<40° F) and dark conditions. Plants should be placed horizontally when refrigerated. Refrigerated plants are often less viable than freshly cut plants, so it is better to use freshly cut plants when possible. Refrigerated branch cuttings should be soaked in water for a minimum of 48 hours before planting.

6. **Arrival Time and Inspection:** Cuttings should arrive on the job site within 8 hours of cutting or removal from refrigerated storage. Upon arrival at the construction site, live branch cuttings should be inspected to ensure that they are in acceptable condition for planting. Cuttings not installed on the day of arrival at the job site should be sorted and protected (kept in water and in cold storage) until installation.

5.0 Seed and Plant Installation

5.1 General Guidelines

General guidelines and recommendations for revegetation include:

1. Seed mixtures should be sown at the proper time of year for the mixture. Generally, there are two optimal seeding periods during the year. The first period is in the spring, April to May. The second period is in late summer to early fall, August to September.
2. If feasible, seed should be drill-seeded to promote ideal seed depth.
3. Broadcast seeding or hydro-seeding may be substituted on slopes steeper than 3:1 or on other areas not practical to drill seed.
4. Seeding rates should be doubled for broadcast seeding or increased by 50% if using a Brillion drill or hydro-seeding.
5. Broadcast seed should be lightly hand-raked into the soil.
6. Seed depth should be 1/3 to 1/2 inch for most mixtures.
7. Seeded areas should be mulched and the mulch should be adequately secured.
8. If hydro-seeding is conducted, mulching should be conducted as a separate, second operation.
9. Containerized nursery stock should be kept in a live and healthy condition prior to installation.
10. Containerized trees and shrubs should be installed according to the planting details provided by either the grower or as found in the Colorado Springs Drainage Manual.
11. Live stakes, poles and willow bundles should be installed when dormant (late winter and early spring).
12. If beaver are known to be in the area, beaver protection should be provided for trees and shrubs.

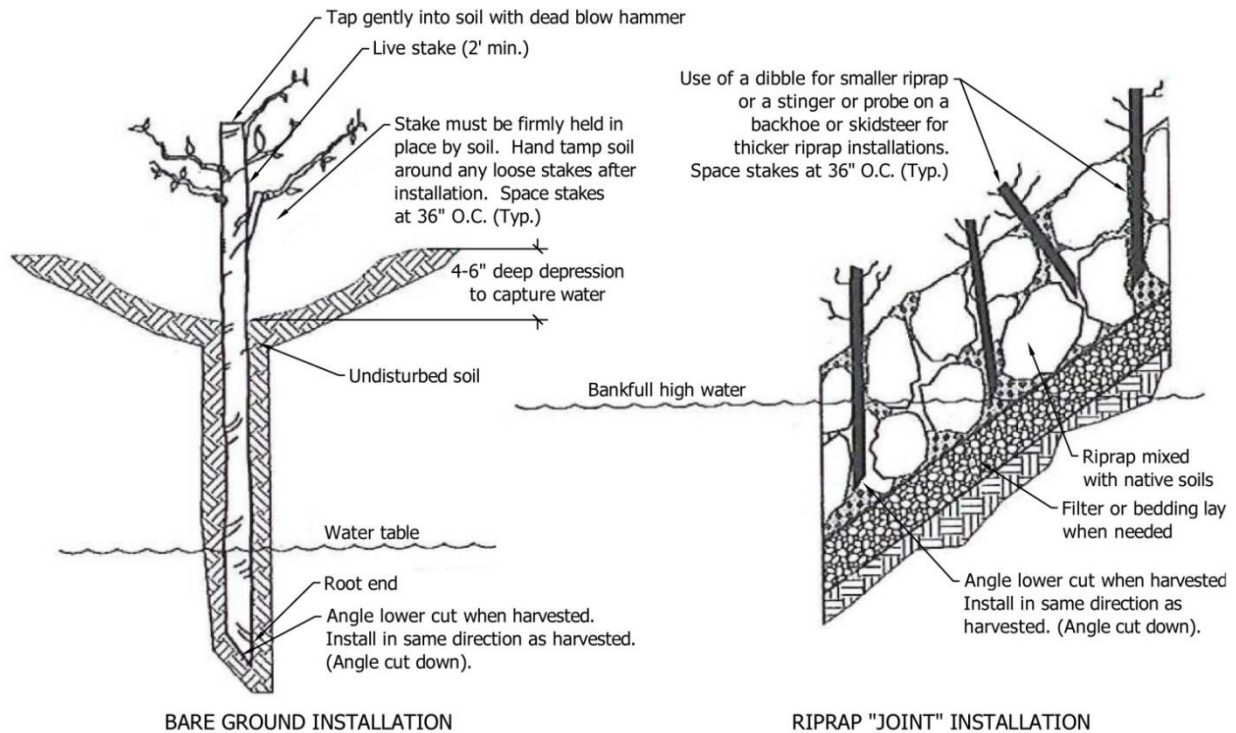
5.2 Planting Details

5.2.1 Willow Planting Details

Figures 14-2 through 14-3 provide details for single willow planting and willow bundle planting, respectively.

5.2.2 Beaver Protection Detail

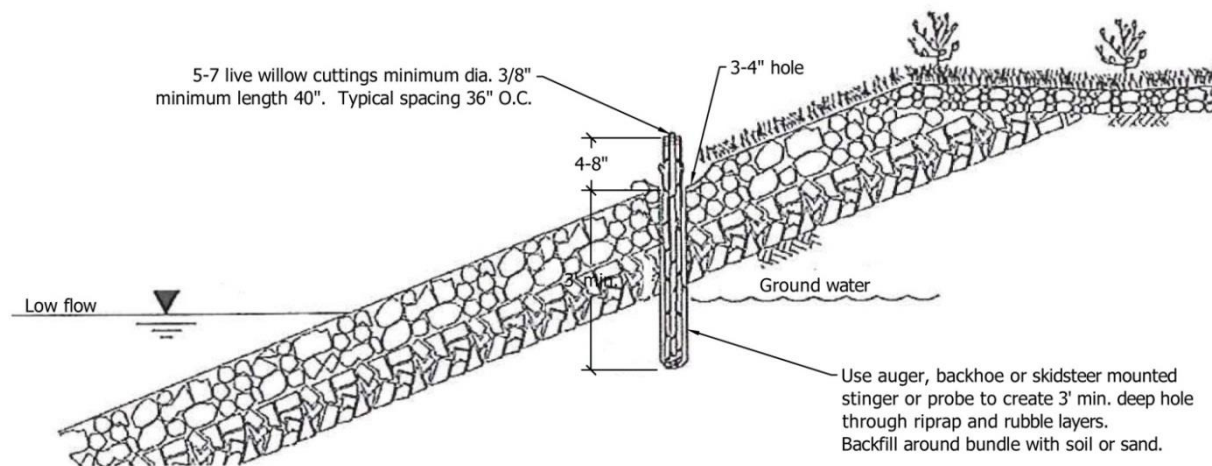
Figure 14-4 provides a detail for beaver protection.



SINGLE WILLOW STAKE DETAIL

SPACING FOR USE IN GRANULAR SOILS WITH AVAILABLE GROUND WATER

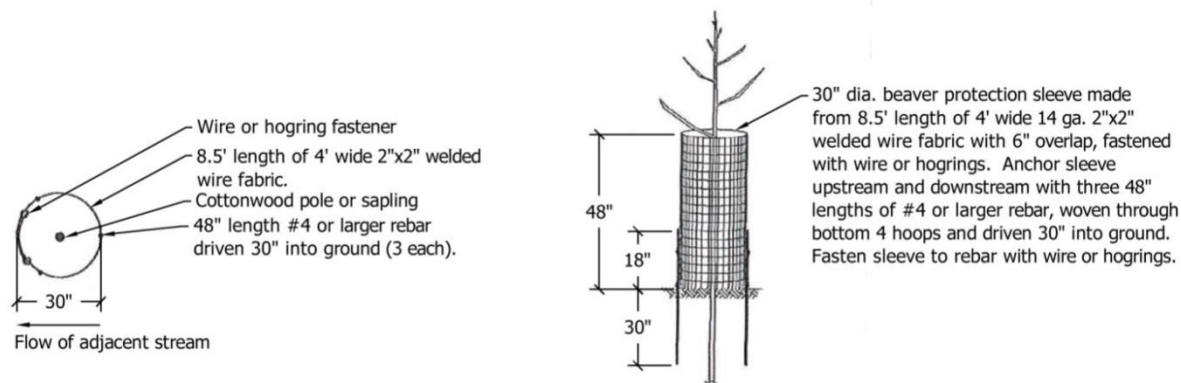
Figure 14-2. Single Willow Stake Detail



WILLOW BUNDLING DETAIL

FOR USE IN GRANULAR SOILS WITH AVAILABLE GROUND WATER

Figure 14-3. Willow Bundling Detail



BEAVER PROTECTION DETAIL

Figure 14-4. Beaver Protection Detail

5.3 Mulching

Planted areas should be mulched immediately following planting, but in no case later than 14 days from planting. Mulch conserves water and reduces erosion. The most common type of mulch is straw that is crimped into the soil to hold it. However, crimping may not be practical on slopes steeper than 3:1. Mulching guidelines include:

1. Only certified weed-free and certified seed-free straw mulch should be used (grass hay often contains weedy exotic species). Mulch should be applied at 2 tons/acre and adequately secured by crimping, tackifier, or used of rolled erosion control products such as netting or erosion control blankets.
2. Crimping is appropriate on slopes of 3:1 or flatter and must tuck mulch fibers into the soil to a depth of 3 to 4 inches.
3. Tackifier or rolled erosion control products such as properly secured netting or erosion control blankets should be used on slopes steeper than 3:1. See Volume 3 of the UDFCD Manual for a discussion on rolled erosion control products.
4. Hydraulic mulching may also be used on steep slopes or where access is limited. Wood cellulose fibers mixed with water at 2,000 to 2,500 pounds/acre and organic tackifier at 100 pounds/acre should be applied with a hydraulic mulcher.
5. Wood chip mulch should be applied to planted trees and shrubs.

5.4 Irrigation

Irrigation may be necessary to help all revegetated areas become established. Further, depending on specific goals for an area, ongoing irrigation may be necessary. Consultation with an irrigation specialist will help identify specific project needs. The following are presented as initial considerations.

1. **General Guidelines.** Due to the semi-arid climate and drying winds in Woodland Park, evapotranspiration exceeds natural precipitation. Supplemental irrigation is often required for plant establishment; therefore, except for drought tolerant plantings, supplemental irrigation is required during the plant establishment period. Depending on the site and the plant species selected, a permanent irrigation system may or may not be required.
2. **Moisture.** Maintaining acceptable moisture levels is essential to initiating germination and continuing the growth of the seedlings. Once germination occurs and growth begins, moisture is necessary for continual seedling growth. Temporary above-ground irrigation systems, such as watering by water trucks, or permanent underground systems can enhance germination and ensure success. Depending on site objectives, permanent irrigation may be necessary to sustain desired plant species.

5.5 Performance Standards for Vegetation Establishment

Plant material establishment performance standards should be implemented as a part of revegetation efforts. This will help to make sure that the erosion control goals for the project are achieved. Recommended performance standards include:

1. After 1 year, a minimum 70% aerial plant cover should be required. The Contractor's financial surety should not be released until this standard is achieved. Aerial plant cover should be measured using the Point Intercept Sampling Method (USDA Forest Service 2006) and results should be verified.
2. Woody plants, both trees and shrubs, should be maintained for 2 years. After this time, dead or dying plant material should be replaced.
3. When reseeding is needed to meet these performance standards, the Contractor must prepare a revegetation plan and submit it for approval to demonstrate an understanding of the specifications and define measures that will be taken to improve success. Measures to improve success could include retesting soil to develop additional soil amendment recommendations; scarifying the ground to reduce compaction, implementing a temporary irrigation plan, and allowing another year for establishment.

6.0 Maintenance

6.1 On-Going Monitoring and Management

General guidelines that should be included as a part of a vegetation establishment and maintenance plan include:

1. Following installation, the installation contractor should maintain the vegetated site for 2 years.
2. Sites should be inspected monthly during the first two growing seasons following planting. Immediate attention to a problem identified during these inspections (e.g., weed infestation, failure of seed to germinate) can facilitate an adaptive management response that requires less effort than if the problem is allowed to fester.
3. While plants are becoming established (normally the first year), pedestrian access to and grazing on recently revegetated areas should be limited with temporary fencing and signage.
4. As soon as possible, weed infestation should be managed using appropriate mechanical, chemical or biological methods.

5. Stakes and guy wires for trees should be maintained and dead or damaged growth should be pruned.
6. Mulch should be maintained by adding additional mulch and redistributing mulch, as necessary.
7. Areas of excessive erosion should be repaired and stabilized.
8. If natural hydrology is insufficient, trees and shrubs should be watered monthly or more frequently as needed from April through September until established.

7.0 Conclusion

Successful revegetation requires a multi-phase effort targeted to the relevant ecosystem type. Successful revegetation projects will address proper site preparation, plant material selection and installation, mulching, maintenance and post-revegetation monitoring. Early involvement of an ecologist, landscape architect or other qualified landscape professional can help improve the likelihood of a successful revegetation effort. Additionally, post-construction monitoring can help to identify problems such as weeds that can be corrected while they are at a more manageable stage.

Chapter 15

References

- Abt, S., Wittler, R., Ruff, J., LaGrone, D., Khattak, M., Nelson, J., Hinkle, D. and D. Lee, 1988. *Development of Riprap Testing in Flumes: Phase II Follow-up Investigations*. NUREG/CR-4651, ORNL/TM-10100/V2. Prepared for Oak Ridge National Laboratories. Prepared by Colorado State University.
- American Association of State Highway and Transportation Officials (AASHTO), 2002. *Standard Specifications for Highway Bridges (17th ed.)*. Washington, DC..
- _____, 2007. Highway Drainage Guidelines. Chapter 7: *Hydraulic Analysis for the Location and Design of Bridges*. Washington, DC. AASHTO.
- Bell, F. H. 2002. *City of Colorado Springs Landscape Code and Policy Manual*. Prepared by Fawn Hayes Bell, ASLA, Urban Design Site Planning, Landscape Architecture, 1619 Wood Avenue, Colorado Springs, Colorado 80907, (1st Printing 1998), (Second Printing 2002).
- Bruland, G.L., and C.J. Richardson. 2005. Spatial variability of soil properties in created, restored and paired natural wetlands. *Soil Sci. Soc. Am. J.* 69:273–284.
- Bantilan-Smith et al. 2009. A comparison of the vegetation and soils of natural, restored, and created coastal lowland wetlands in Hawai‘i. *Wetlands* 29:1023–1035
- City of Colorado Springs, Colorado, 2009. *Streamside Design Guidelines*. (Revised).
- City of Colorado Springs, 2013. *Drainage Criteria Manual, Volumes 1 and 2*. City Engineering/Stormwater.
- City of Woodland Park, 1996. *City of Woodland Park Stormwater Management Program (1996)*. Prepared by URS Corporation.
- Colorado Department of Transportation. 2004. *Drainage Design Manual*. <http://www.coloradodot.info/programs/environmental/water-quality/documents/drainage-design-manual>. CDOT.
- _____, 2012. Concrete and Metal End Sections. M-603-10. CDOT.
- Colorado Division of Wildlife (n.d.). “Species of Concern” website: <http://wildlife.state.co.us/WildlifeSpecies/SpeciesOfConcern>. Accessed November 2011.
- Colorado Natural Areas Program. 1998. Native Plant Revegetation Guide for Colorado. Caring for the Land Series, Vol. 3. October. Colorado State Parks, Colorado Department of Natural Resources, Denver, CO.
- Colorado State University, 2010. Extension Soil Sampling Fact Sheet No. 0.500. Issued June 1997, Revised March 2010.

- Fajardo, G.I. 2006. Physical and Chemical Soil Properties of Ten Virginia Department of Transportation Mitigation Wetlands. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.
- Federal Emergency Management Agency (FEMA), 1995. *Managing Floodplain Development in Approximate Zone A Areas - A Guide for Obtaining and Developing Base (100-yr) Flood Elevations*. FEMA Publication 265. Accessible at www.fema.gov.
- FEMA National Floodplain Insurance Program webpage: <http://www.fema.gov/national-flood-insurance-program>. Accessed September 20, 2012.
- _____. 2009. *Flood Insurance Study--Teller County Colorado, and Incorporated Areas*. Federal Emergency Management Agency.
- Federal Highway Administration (FHWA), 1978. *Hydraulics of Bridge Waterways Hydraulic Design Series No. 1*. Washington, DC: U.S. Department of Transportation, Federal Highway Administration
- _____. 1981. *Design of Encroachments on Flood Plains Using Risk Analysis*. Washington, DC. U.S. Department of Transportation, FHWA.
- _____. 1988. *Technical Advisory on Scour at Bridges*. Washington, DC: U.S. Department of Transportation, FHWA.
- _____. 1990. *Highways in the River Environment*. Washington, DC. U.S. Department of Transportation, FHWA.
- _____. 2001. *Evaluating Scour at Bridges*. Washington, DC. U.S. Department of Transportation, FHWA.
- _____. 2001. *Stream Stability at Highway Structures*. Washington, DC. U.S. Department of Transportation, FHWA.
- _____. 2011. *HY 8 Culvert Hydraulic Analysis Program*. Washington, DC: U.S. Department of Transportation, FHWA.
- _____. 2012. *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5. HIF-12-026. Washington, DC: U.S. Department of Transportation, FHWA. http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=7&id=13
- Federal Interagency Stream Restoration Working Group, 2001. *Stream Corridor Restoration, Principles, Processes and Practices*. (Adopted as Part 653 of the National Engineering Handbook). Revised August.
- Ficke, A.D. and C.A. Myrick, 2007. *Fish Barriers and Small Plains Fishes: Fishway Design Recommendations and the Impact of Existing Instream Structures, Final Project Report*. Colorado State University. June.
- Goodwin, K., Marks, G., and R. Sheley. 2006. *Revegetation Guidelines for Western Montana: Considering Invasive Weeds*. Prepared for the Missoula County Weed District with funding assistance from the Center for Invasive Plant Management and the Montana Noxious Weed Trust Fund. Missoula, MT.

- GreenCO and Wright Water Engineers, 2008. *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (www.greenco.org).
- Guo, J.C.Y. 1999. *Streets Hydraulics and Inlet Sizing*. Water Resources Publications, Littleton, CO.
- Henderson, F. M. 1966. Open channel flow. McMillan. New York.
- Julien, P. Y. 2002. River Mechanics. Cambridge University Press.
- Kelso, T. and S. Tolve, 2006. *Conservation Values and Management of the Venetucci Farm Riparian Corridor. A Report to the Pikes Peak Community Foundation*. Prepared by Department of Biology, Department of Colorado College. February.
- Natural Resources Conservation Service. 1997. Wetland Restoration and Enhancement, Northwest Freshwater Wetlands Student Workbook. National Employee Development Center, U.S. Department of Agriculture. January.
- Sanja Perica, Deborah Martin, Sandra Pavlovic, Ishani Roy, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Michael Yekta, Geoffrey Bonnin, 2013. NOAA Atlas 14 Volume 8 Version 2, Precipitation-Frequency Atlas of the United States, Midwestern States. NOAA, National Weather Service, Silver Spring, MD.
- THK Associates, Inc. and Matrix Design Group, 2011. *The Fountain Creek Corridor Restoration Master Plan*. October 18, 2011.
- United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). 2009. *Soil Survey of Pike National Forest, Eastern Part, Colorado, Parts of Douglas, El Paso, Jefferson and Teller Counties (CO640)*. Accessed from <http://websoilsurvey.nrcs.usda.gov>.
- _____. 2012. *Soil Survey of Teller-Park Area, Colorado, Parts of Park and Teller Counties (CO638)*. Accessed from <http://websoilsurvey.nrcs.usda.gov>.
- _____. 1998. Soil Quality Resource Concerns: Soil Biodiversity. U.S. Department of Agriculture. Washington, D.C. January.
- _____. 2001a. Plant Materials Technical Note No. 3. Tips for Planting Trees and Shrubs: Revegetation and Landscaping. U.S. Department of Agriculture, Portland, OR. February.
- _____. 2001b. Riparian/Wetland Project Information Series No. 16: Riparian Planting Zones in the Intermountain West. U.S. Department of Agriculture. (Revised, March).
- _____. 2003. Technical Note Plant Materials No. 13: Harvesting, Propagating, and Planting Wetland Plants. U.S. Department of Agriculture, Boise, ID. *An Illustrated Guide to Field Technique*. USDA, 1994. December.
- _____. 2008. Engineering Field Handbook, Chapter 13: Wetland Restoration, Enhancement, or Creation. U.S. Department of Agriculture. April.

- _____. 2011a. Technical Note Plant Materials No. 38: Description, Propagation, and Establishment of Wetland – Riparian Grass and Grass-like Species in the Intermountain West. U.S. Department of Agriculture, Boise, ID – Salt Lake City, UT. October.
- _____. September 2011b. Technical Note Plant Materials No. 74: Seedbed Preparation for Conservation Plantings. U.S. Department of Agriculture, Denver, CO.
- United States Geological Survey (USGS), 2013. *Streamstats*. Retrieved from <http://streamstats.usgs.gov/> June 17, 2013.
- United States Army Corps of Engineers (USACE), Albuquerque District, 2009. *Fountain Creek Watershed Study Watershed Management Plan*. January.
- United States Department of Agriculture (USDA) Forest Service, 2006. *Point Intercept (PO) Sampling Method, USDA Forest Service Gen. Tech. Rep. RMRS-GTR-164-CD*. Prepared by John Caratti.
- Urban Drainage and Flood Control District (UDFCD), 2001. *Denver Urban Storm Drainage Criteria Manual, Volumes 1 & 2*. UDFCD, Denver, CO. Revised April 2008.
- _____, 2010. *Denver Urban Storm Drainage Criteria Manual, Volume 3 Water Quality*. UDFCD, Denver, CO.
- Watson, C.C., D.S. Biedenbarn, and B.P. Bledsoe. 2002. [Use of Incised Channel Evolution Models in Understanding Rehabilitation Alternatives](#). Journal of the American Water Resources Association 38:151-160.
- Wulliman, James and Ben Urbonas, 2005. Peak Flow control for Full Spectrum of Design Storms, Urban Drainage and Flood Control District web site <http://udfcd.org>
- University of California Davis, 2013. Weed Research and Information Center website. <http://wric.ucdavis.edu/index.htm>. Online resource for weed management research.

CITY OF WOODLAND PARK

RESOLUTION NO. 773, SERIES 2014

A RESOLUTION ADOPTING THE CITY OF WOODLAND PARK DRAINAGE CRITERIA MANUAL

WHEREAS, the City of Woodland Park has adopted a document known as the City of Woodland Park Engineering Specifications on February 3, 2011; and

WHEREAS, the City of Woodland Park's Engineering Specifications requires that all open channels, culverts, ponds, and storm sewers be designed in accordance with the Pikes Peak Area Council of Governments Areawide Urban Runoff Control Manual prepared in 1980; and

WHEREAS, the City of Woodland Park has now developed its own Drainage Criteria Manual using current industry standards and practices; and

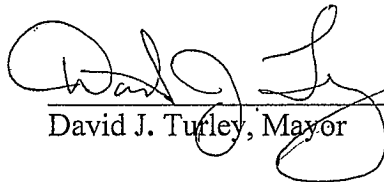
WHEREAS, the proposed new Drainage Criteria Manual was posted to the City website from November 4, 2013 until December 31, 2013 for public review and comment, and modifications made pursuant to the public comments; and

WHEREAS, it is the desire of the City Council of the City of Woodland Park to adopt the newly developed Drainage Criteria Manual, so as to provide more current criteria and guidance with which to regulate the design, materials and construction practices for all drainage infrastructure,

NOW, THEREFORE, BE IT RESOLVED BY THE CITY COUNCIL OF THE CITY OF WOODLAND PARK, COLORADO, THAT:

The City of Woodland Park hereby adopts the City of Woodland Park Drainage Criteria Manual. Said manual shall be subject to review for updates, amendments and additions as needed. Updates, amendments and additions shall be approved by City Council by Resolution.

The foregoing Resolution was adopted at a regular meeting of the City Council, held in Woodland Park, Colorado on the 20th day of February, 2014.



David J. Turley, Mayor

ATTEST:



Cindy Morse, City Clerk