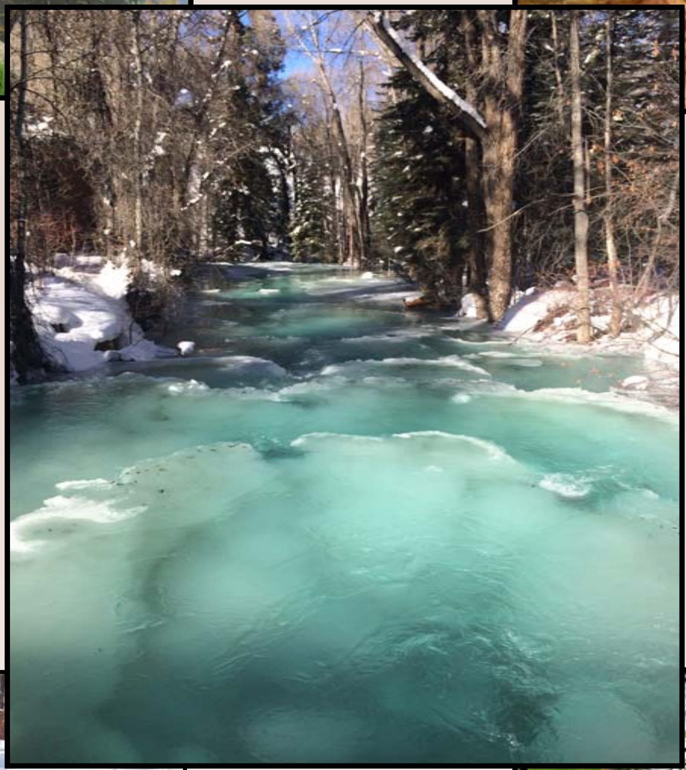
THE CITY OF ASPEN

Urban Runoff Management Plan

A Guide to Stormwater Management in the City of Aspen

Revised December 2014



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December 2014

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Objective of the Manual

The objective of this manual is to update the Urban Runoff Management Plan (Manual), which was originally developed in 1973 and has received periodic updates since. The Manual provides minimum standards and technical guidance for addressing stormwater runoff in the development and redevelopment of the City of Aspen. This Manual is an effective tool for designers and engineers to reduce both stormwater quality and quantity impacts, and protect downstream areas and receiving waters. This includes guidance on better site design practices, hydrologic techniques, criteria for the selection and design of structural stormwater controls and best management practices, drainage system design, and construction and maintenance information.

How to Use the Manual

The following provides a guide to the various chapters of the Manual.

Introduction – This chapter is intended to assist homeowners, planners, designers, architects, and engineers by briefly explaining the goals and requirements for stormwater management in the City of Aspen. This chapter includes the following sections:

- Section I – *The Need for Stormwater Management.* This section provides an overview of the impacts of urban stormwater runoff and the framework including state and federal laws, regulations and programs that are required of the City of Aspen or that may impact local stormwater management activities.
- Section II – *Stormwater Management Standards*. This section contains the stormwater management minimum standards and principles for new development and redevelopment sites in the City of Aspen.
- Section III – *Planning and Design*. This section provides an overview of design considerations for addressing stormwater quality and flood control requirements on a site.

Chapter 1 – Policy and Permit Requirements. This chapter establishes administrative procedures for the submission, review, and approval of grading and drainage plans, and to assure appropriate long-term maintenance.

Chapter 2 – Rainfall (Stormwater Hydrology). This chapter presents the rainfall and snowfall design information needed for storm and snowmelt runoff analyses in the City of Aspen.

Chapter 3 – Runoff (Stormwater Hydraulics). This chapter presents engineering topics and methods used in stormwater drainage, conveyance and facility design to calculate runoff.

Chapter 4 – Street Drainage System Design. This chapter provides technical guidance on the various elements of stormwater drainage design including street layouts, swales, gutters, inlets, pipes, manholes, culverts, and outlets.

Chapter 5 – Detention. This chapter covers the criteria and general procedures for the design and evaluation of stormwater storage (detention and retention) facilities.

Chapter 6 – Floodplains. This chapter outlines floodplain management guidelines that are intended to ensure that future improvements and developments do not impact or are not impacted by the floodplain and/or floodway.

Chapter 7 – Mudflows. This chapter discusses the potential and magnitude of mud floods and mudflows that may develop in Aspen due to rainfall events, snowmelt, or rain on snow events and provides guidance for development in mud flow hazard areas.

Chapter 8 – Water Quality. This chapter provides information on water quality in the Aspen area, guidance for better site design practices, water quality standards for development, guidance and criteria for selection and design of stormwater best management practices (BMPs) for water quality, and a toolkit of techniques that can be used to reduce the amount of stormwater runoff and pollutants generated from a site.

Appendix A – **Submittal Checklists.** This appendix contains the checklists that should be completed for different steps in the project approval process, including the Maintenance Agreement, as referred to in Chapter 1 – Submittal Requirements.

Appendix B – Equations and Examples. This appendix includes the derivation of equations used throughout the manual as well as some example problems that can be followed to understand how the equations are used.

Appendix C – Worksheets and Models. This appendix contains worksheets and direction for computer models for running several of the calculations needed for typical site design, such as the Rational Method, street flow analyses, and inlet sizing.

Appendix D – Floodplain Documents. This appendix includes the Floodplain Development Permit and FEMA Elevation Certificate.

Appendix E – Landscaping and Plant Selection Guidance. This appendix provides landscaping criteria and plant selection guidance for stormwater best management practices and facilities.

Introduction

I. The Need for Stormwater Management

Land development changes the physical, chemical and biological conditions of our waterways and water resources. It disrupts and alters the natural cycle of water, referred to as the land's hydrology. Clearing of trees and vegetation removes the plant life that slows, filters and returns rainfall to the air through evaporation and transpiration. Clearing of natural riparian (streambank) vegetation allows pollutants and litter carried in overland flow to enter streams unimpeded and greatly lowers streambank stability, which increases the potential for erosion. Grading flattens hilly terrain and fills in natural depressions that slow and provide temporary storage for rainfall and snowmelt. Construction scrapes topsoil and humus away, leaving the remaining subsoil compacted. Where rainfall once seeped into the ground, it now runs across surfaces. Buildings, roads, parking lots and other impervious surfaces further reduce infiltration of rainfall and snowmelt, increasing the amount of stormwater runoff and accelerating the speed with which it runs across land. This process affects flooding, natural and manmade conveyance capacity, and water quality. As stormwater runoff moves over surfaces, it pulls pollutants from the surface and carries them into streams, rivers, and lakes. Increased runoff can affect streams by depleting oxygen, increasing nutrient levels, adding toxic materials, carrying in sediment and trash, and increasing temperatures.

Flooding

Without a stormwater system, stormwater infrastructure, and stormwater management, the rainfall or snowmelt that accumulates on the ground would runoff, choosing its own path in its own time, regardless of the safety, welfare, or mobility of the public. Simple rain events would result in flooding of roads, buildings, parks, etc. Larger storm events would cause stream and river levels to rise out of their banks, pushing flood waters into neighborhoods, eroding the natural banks, etc. As mentioned above, flooding potential is increased by land development that creates additional impervious area. The purpose of stormwater management is to accommodate planned growth in a manner that protects public safety while sustaining ground water recharge, stable stream channels, the flood carrying capacity of streams and their floodplains, and ground water and surface water quality—to the maximum extent practicable.

The City of Aspen manages flood activity through the City's stormwater system. Runoff is collected and directed via conveyance systems comprised of streets, curbs, gutters, inlets, pipes, culverts, swales (roadside ditches), detention areas, ponds, wetlands, streams, into the Roaring Fork River, Hunter Creek, Maroon Creek, and Castle Creek. The City ensures proper drainage by developing and maintaining stormwater master plans for watershed improvements, designing and constructing flood control and drainage improvement projects, installing and maintaining the City's infrastructure, street sweeping, clearing obstructions from flow, and establishing and maintaining floodplains. The City also reviews land alteration, development, and redevelopment plans for compliance with stormwater management criteria detailed in this Manual. Reductions in runoff volumes and peak flow rates are required to achieve a balance between post-developed site conditions and the flow-carrying capacity of the City's infrastructure, rivers and floodplains. Lands that are downstream of a new development cannot be adversely impacted by increased runoff.

Impacted River

Urban development in Aspen is a contributor to the watershed's effect on the Roaring Fork River. According to the *Roaring Fork State of the Watershed Report* (SoWR) (Roaring Fork Conservancy and Ruedi Power and Water Authority 2008), nearly 20 percent of the riparian (river bank) habitat and more than 15 percent of instream habitat in the Upper Roaring Fork sub-watershed is classified as "severely degraded," while the areas upstream and downstream of Aspen were ranked "high quality" or only "slightly modified." Potential impacts of Aspen's urban development, without proper mitigation, on the Roaring Fork River include:

Stream Hydrology: Urban development affects the environment through changes in the size and frequency of storm runoff events. For example, in Aspen for an undeveloped site, snowmelt/rainfall events would be expected to generate runoff approximately 30 times during a typical year. For a developed, 100 percent impervious site, approximately 80 snowmelt/rainfall events per year would generate runoff. Development also changes base flows of the stream and stream flow velocities during storms resulting in a decrease in travel time for runoff. Peak flow rates and runoff volume increase as a result of urbanization resulting in more surface runoff and larger loads of some constituents found in stormwater.

Stream Morphology (physical characteristics): When the hydrology of the stream changes, it results in changes to the physical characteristics of the stream. Such changes include streambed erosion and sediment buildup, stream widening, and stream bank erosion. As the stream profile degrades and the stream tries to widen to accommodate higher flows, channel bank erosion increases along with increases in sediment loads. These changes in the stream bed also result in change to the habitat of aquatic life.

Stream Water Quality and Aquatic Ecology: Water quality is impacted through urbanization as a result of erosion during construction, changes in stream morphology, and washing off of accumulated deposits from the urban landscape. For example, runoff from downtown Aspen could include petroleum hydrocarbons from vehicles, vegetation debris from leaf fall, metals and solids from tire wear and streets, fine particulate matter and metals from atmospheric deposition on impervious surfaces and other pollutants. Water quality problems include turbid water, nutrient enrichment, bacterial contamination, and increases in organic matter loads, metals, salts, oil/grease, pesticides and herbicides. In addition, there may be temperature increases and increased trash and debris transported by stormwater runoff to streams and lakes.

Table 8.1 lists the common constituents in stormwater runoff and their impacts.

Table 8.1 Urban Runoff Pollutants

Constituents	Sources	Effects
Sediments—TSS, turbidity, dissolved solids	Construction sites, urban runoff, landfills, atmospheric deposition	Habitat changes, stream turbidity, recreation and aesthetic loss, contaminant transport, bank erosion
Nutrients—nitrate, nitrite, ammonia, organic nitrogen, phosphate, total phosphorus	Lawn runoff, atmospheric deposition, erosion	Algae blooms, ammonia toxicity, nitrate toxicity
Pathogens—total and fecal coliforms, fecal Streptococci viruses, E.coli, Enterococcus	Urban runoff, illicit sanitary connections, domestic/wild animals	Ear/intestinal infections, recreation/aesthetic loss
Organic enrichment—BOD, COD, TOC and DO	Urban runoff	Dissolved oxygen depletion, odors, fish kills
Toxic pollutants—metals, organics	Urban runoff pesticides/herbicides, underground storage tanks, hazardous waste sites/historic mining (Smuggler Mountain Superfund), landfills, illegal disposals, industrial discharges	Toxicity to humans and aquatic life, bioaccumulation in the food chain
Source: United States Environmental Protection Agency (USEPA) Handbook: Urban Runoff Pollution Prevention and Control Planning, 1993 with adaptations for City of Aspen.		

Although the Roaring Fork River, Maroon Creek and Castle Creek are headwaters streams with water quality far better than many streams in the nation, they nonetheless are impacted by Aspen's stormwater runoff. The SoWR identified excessive sedimentation as a primary source of impacts to the Roaring Fork River and data collected by the City of Aspen from 2003 to 2006 show total suspended solids concentrations consistently higher than 130 mg/L and on many occasions (six out of twelve samples) in excess of 1000 mg/L. Primary sources of sediment in runoff include erosion from steep slopes (including Aspen Mountain), sand from winter application, sediment from construction sites, urban runoff from impervious areas where particulates accumulate to sediment, and natural "background" sources of sediment. Sediment deposition in streambeds can degrade and even eliminate habitat for aquatic insects that fish, including trout, rely on for food and reproduction. Sediment loads dramatically lower water quality and stream ecosystem integrity.

Other water quality parameters cited in the Roaring Fork Conservancy report in the vicinity of Aspen include iron, lead, selenium, cadmium, pH, nitrite, total phosphorus and dissolved oxygen. Sources of metals in runoff include vehicular traffic areas including roads and parking areas, atmospheric deposition, and historic mining activities.

State and Federal Regulations

Aspen isn't alone in these impacts from urban stormwater runoff. As a result of the impacts of development and stormwater runoff described above, numerous federal and state programs and regulations have been created to deal with the problems of urban runoff and nonpoint source pollution. Given the fact that local communities typically make the land use and development decisions which create runoff problems and the need for stormwater infrastructure, it is at the local level where these problems must be addressed. Therefore, federal and state legislation inevitably influence the responsibilities of local governments in managing stormwater runoff in their communities.

The federal government recognized that changes in stormwater runoff contribute to increased quantities of water-borne pollutants and alterations in hydrology that are harmful to public health and safety as well as to the natural environment. In 1972, the Federal Water Pollution Control Act established regulations for point sources of water pollution, including requiring those who discharge pollutants into surface waters to get a National Pollutant Discharge Elimination System (NPDES) permit from the Environmental Protection Agency (EPA). In the Water Quality Act of 1987, Congress required that municipal stormwater discharges, a nonpoint source of water pollution, must also obtain an NPDES permit. The Municipal Separate Storm Sewer System (MS4) NPDES permit establishes guidelines for municipalities to minimize pollutants in stormwater runoff to the "maximum extent practicable."

Other regulatory programs and their key provisions are summarized below.

- **National Flood Insurance Program -** Established under the National Flood Insurance Act of 1968 and broadened with the passage of the Flood Disaster Act of 1973, the National Flood Insurance Program (NFIP) provides federally-supported flood insurance to the residents of communities that voluntarily adopt and enforce regulations to reduce future flood damage. As part of the program, the federal government defines minimum standards for floodplain development that the local communities must adopt to be eligible for program benefits. More information on the NFIP and floodplain management in general is provided in Chapter 6.

- **Colorado State Water Quality Standards** - Basic standards applicable to surface waters of Colorado: "…shall be free of substances attributable to human-caused discharge (point source or non-point source) in amounts, concentrations, or combinations which...
    - Produce color, odor, or other conditions in such a degree as to create a nuisance or impart
    - Any undesirable taste to significant edible aquatic species; or
    - Are toxic to humans, animals, plants, or other aquatic life; or
    - Are harmful to the water-quality-dependent functions of the waters."

Sustainable Development

Conventional development and construction processes are increasingly identified as potentially adverse to the environment. Sustainable development is generally understood to mean development that occurs with the goal of meeting human needs while ensuring efficient use of resources and preserving environmental quality, natural resources and livability for present and future generations. The City of Aspen has taken progressive steps in requiring buildings to be built with energy efficiency and reduce reliance on future operational resources, such as non-renewable energies, water, and toxic materials. Sustainable development encourages the use of benign materials that have not placed a demand on limited resources or caused environmental damage through their harvest or manufacturing processes. Consideration is even given to deconstruction and recyclability, so that when a building's use becomes obsolete, it be disassembled and the basic materials reused or recycled.

In keeping with the principle to develop in ways that reduce impacts on the environment, stormwater management is a key player that is gaining increasing recognition. To develop sustainably, sites should be designed to more closely mimic natural processes and reduce reliance on the use of structural management techniques to treat stormwater runoff. Developments should be responsible for reducing the amount of stormwater and stormwater pollutants created from their site to the maximum extent practicable. The goals of the City's stormwater management program, very simply put, are to reduce runoff, minimize the potential for pollutants to mix with runoff, and provide treatment for pollutants in remaining runoff. This manual introduces better site design practices and requires treatment of stormwater runoff to remove pollutants. This philosophy refocuses design from the structural management of runoff as an afterthought to the mimicking of natural processes as part of a total site design. More information on how this is accomplished is explained below in Section II – Principles and in Chapter 8 of this Manual.

Using the environmentally sensitive site design techniques outlined in this Manual can help to reach sustainable development goals by:

- Reducing the amount of polluted stormwater that enters the Roaring Fork River and its tributaries,
- Reducing impervious surface so stormwater can infiltrate to remove pollutants and recharge groundwater,
- Reducing the demand on the City's storm system and the cost of constructing expensive pipe systems,
- Increasing urban green space,
- Fostering positive connections between people and nature,
- Improving air quality and reducing air temperatures,
- Addressing requirements of federal and state regulations to protect public health and restore and protect watershed health, and
- Increasing opportunities for industry professionals.

II. Stormwater Management Standards

For a number of reasons—including public health and safety, environmental, economic, legal liability, regulatory responsibility and to improve quality of life—the City of Aspen has a vested interest and need to effectively deal with the effects of development and stormwater runoff in the City. The focus of City's stormwater program is how to effectively deal with the impacts of urban stormwater runoff through effective and comprehensive *stormwater management*.

Stormwater management attempts to cope with the impacts of development on runoff volumes, runoff velocities, and water quality through a variety of techniques. These techniques include practices used during construction to limit erosion and sediment transport and practices built to control stormwater runoff peaks, volumes and velocities after construction, in order to mitigate downstream flooding, channel erosion, and water pollution.

Proper management of construction-related and post-construction stormwater runoff minimizes damage to public and private property and infrastructure; safeguards the public health, safety, and general welfare; and protects water resources and aquatic wildlife. The intent of stormwater management requirements in the City of Aspen is to promote proper management of stormwater runoff, both during and following construction. To that end, this Manual establishes design and review criteria for the construction, function, and use of non-structural and structural stormwater best management practices (BMPs) that may be used to meet the minimum development standards as well as provisions for the long-term responsibility for and maintenance of structural and non-structural BMPs to ensure that they continue to function as designed, are maintained appropriately, and protective of public safety. This manual also establishes administrative procedures for the submission, review, approval and disapproval of stormwater management plans, and to assure appropriate long-term maintenance.

This Manual has been developed to provide guidance on the latest and most relevant stormwater management strategies and practices in the nation. The following is a summary of the minimum standards. This summary should only serve as a guideline for general understanding of stormwater management requirements in Aspen and for development of a conceptual design. Detailed and specific requirements are included throughout the Manual that have the potential to significantly impact a site's design. It is recommended that the entire Manual be followed for accurate design and grading and drainage plan approval.

Minimum Standards:

1. Better Site Design – Site designs should preserve the natural drainage and treatment systems, reduce the generation of additional stormwater runoff and pollutants, and increase infiltration of stormwater into the ground rather than into hard infrastructure to the fullest extent practicable. Guidelines for reducing the impact of developing and better site design techniques are discussed in Chapter 8.

2. Water Quality Capture Volume (WQCV) – New development and redevelopment shall treat a volume of water equal to the 80^{th} percentile runoff event for their site. This volume has been sized to remove 90% of particles greater than 60 microns in size by releasing the WQCV over a 12-hour period. The WQCV is determined based on the site's impervious area and can be reduced as impervious area is reduced. Guidelines for calculating the WQCV, reducing the WQCV, and designing structural controls capable of treating the WQCV are detailed in Chapter 8.

3. Detention – New development and redevelopment shall detain for the minor and major storm event up to the point that the stormwater system downstream can accommodate. In most cases, a site will be controlling the post-development peak discharge rate to the predevelopment rate for the 10- and 100-year event. Most redeveloping areas in the urban core will not be required to detain anything above the WQCV. Guidelines for calculating required detention and designing detention facilities are detailed in Chapter 5 or in Chapter 8, if combining detention with WQCV controls.

4. Stormwater system – The downstream system from each site must be able to safely pass flows from the 5- or 10-year and 100-year event. A downstream hydrologic analysis must be performed to determine if there are any additional impacts in terms of peak flow increase or downstream flooding while meeting minimum standards #2 and #3. This analysis must be performed at the discharge points of the site and, at a minimum, at the next two downstream structures.

5. Floodplains – Development and redevelopment is restricted in both FEMA-floodplains and other tributary streams as determined by the City Engineer. Developments near streams may be required to generate floodplains for their site and meet the requirements detailed in Chapter 6.

6. Mudflows – Development and redevelopment is restricted in mudflow hazard areas, which include those areas determined by the Stormwater Master Plan and other areas as determined by the

City Engineer – might include slopes on site of greater than 15%, slopes down fan of mud flow hazard areas, and sites where mud flows have occurred previously.

7. Grading and drainage designs should be considered early in the design process as they can have a significant impact on the design of the site. Conceptual plans are required to show investigation and plans for all of the above standards. A pre-application meeting with the Development Engineer and approval of a sufficiency review is required before a Building Application Permit can be submitted. Concessions will not be made at the end of the permit review process for sites that fail to incorporate grading and drainage requirements into the initial design.

Principles

To assist in meeting the standards above, it is recommended that a project follow the principles below (adapted from City and County of Denver Water Quality Management Plan [2004]) when developing or redeveloping a site. All site designs should implement a combination of approaches collectively known as *stormwater better site design practices* to the fullest extent possible. Through the use of these practices and techniques, the impacts of urbanization on the natural hydrology of the site and water quality can be significantly reduced. The goal is to reduce the amount of stormwater runoff and pollutants that are generated, provide for natural on-site control and treatment of runoff, and optimize the location of stormwater management facilities. Better site design concepts can be viewed as both water quantity and water quality management tools and can reduce the size and cost of required structural stormwater controls.

Principle 1: Consider stormwater quality needs early in the design process.
Left to the end of site development, stormwater quality facilities will often be “shoe-horned” into the site, resulting in forced, constrained approaches. When included in the initial planning for a project, opportunities to integrate stormwater quality facilities into a site can be fully realized. Stormwater quality and flood control requirements are just as fundamental to good site design as other elements such as building layout, grading, parking, and streets. ***Dealing with stormwater quality after major site plan decisions have been made is too late.***

Principle 2: Use the entire site when planning for stormwater quality treatment.
Often, stormwater quality and flood detention are dealt with only at the low corner of the site and ignored on the remainder of the project. The focus is on draining runoff quickly through inlets and storm sewers to the detention facility. In this “end-of-pipe” approach, all the runoff volume is concentrated at one point and designers often find it difficult to fit the required detention into the space provided. This can lead to drainage plans with expensive, proprietary underground treatment devices, or deep, walled-in basins that detract from a site and are difficult to maintain. Spreading runoff over a larger portion of the site reduces the need for these undesirable alternatives.

Principle 3: Avoid unnecessary impervious area.
Impervious area (parking, roofs, drives, etc.) is an important factor influencing urban runoff and water quality issues. Many impervious surfaces are necessary as a part of urban and sub-urban development (roofs over buildings, to provide shelter; roads for vehicles, for example). Not all impervious areas in typical developments are necessary, however. For example, in residential areas an extra-wide driveway that is used only infrequently could be considered “unnecessary” impervious area, especially if street parking is available nearby for infrequent additional parking. To reduce the impacts of urban runoff on the environment, each site plan should be carefully evaluated to eliminate unnecessary impervious surfaces. Potential ways to reduce unnecessary impervious surfaces include minimizing parking to the extent practical, narrower roadways and driveways, and the use of permeable pavement systems to lower effective imperviousness where a hard but pervious surface is desired.

Principle 4: Reduce runoff rates and volumes to more closely match natural conditions.
Before development, for frequent small events most of the rain that falls on the ground soaks into the soil or is captured by vegetation; very little rainfall runs off and flows downstream. However, after development, rain that falls on roofs and pavement mostly runs off (this is a “runoff event”). Whereas one runoff event per year may be typical prior to development, significantly more runoff events per year

typically occur after urbanization (Urbonas et al. 1989). Peak flows and volumes of runoff are greater after urbanization than before development.

One of the most effective stormwater quality BMPs—potentially more effective than constructing a detention basin to treat the runoff—is **reducing urban runoff volumes to more closely match natural conditions.** The following techniques can be used to achieve this goal:

> <u>Place stormwater in contact with the landscape and soil</u>. Instead of routing storm runoff from impervious areas to inlets to storm sewers to offsite pipes or concrete channels, an approach is recommended that places runoff in contact with vegetated or landscaped areas to slow down the stormwater and promote infiltration. Porous pavement areas also serve to reduce runoff and encourage infiltration. This practice is also known as Minimizing Directly Connected Impervious Area (MDCIA) and can reduce the effective imperviousness of the site.
>
> <u>Select treatment areas that promote greater infiltration</u>. Bioretention, sand-filter detention and other infiltration-based BMPs promote greater volume reduction than extended detention basins, since runoff tends to be absorbed into the filter media or infiltrate into underlying soils. As such, they are more efficient for reducing runoff volume and typically can be sized for less overall treatment volume than extended detention facilities.

By employing these techniques, projects can reduce the increase in runoff and related stream degradation and pollutant loading that comes with conventional development. In addition, some of these techniques will reduce the required WQCV and may help to create a more attractive site. **Aspen strongly encourages implementation of these runoff reduction techniques on all new projects to the maximum extent practicable.**

Principle 5: Integrate stormwater quality management and flood control.
In cases where an extended detention basin, wetland basin, sand filter basin, or underground treatment system is used to address stormwater quality, these BMPs can be modified to include flood control detention in addition to the WQCV. This will generally increase the overall size of the basin. In these situations, all the runoff from a site, from small and large storms alike, is routed to the combined detention basin. Site BMPs, like bioretention, are intended to promote a stormwater quality function, and are not normally designed to provide flood control detention as well. In these cases, all runoff is directed to the WQCV facility and larger events spill out over the surface or through an inlet and storm sewer to a separate flood control detention basin.

Principle 6: Develop stormwater quality facilities that enhance the site, the community, and the environment.
Stormwater quality areas can add interest and diversity to a site. Gardens, plazas, rooftops, and even parking lots can become amenities and provide visual interest while performing stormwater quality functions and reinforcing urban design goals for the neighborhood and community. The integration of BMPs and associated landforms, walls, landscape, and materials can reflect the standards and patterns of a neighborhood and help to create lively, safe, and pedestrian-oriented districts.

The quality and appearance of stormwater quality facilities should reflect the surrounding land use type, the immediate context, and the proximity of the site to important civic spaces. Aesthetics will be a more critical factor in highly visible urban commercial and office areas than at a heavy industrial site. The standard of design and construction should maintain and enhance property values without compromising function. In some cases, this means locating a facility to preserve or enhance natural resources.

Principle 7: Use a treatment train approach.
Considerable research has demonstrated that the most effective stormwater management is achieved through a “treatment train” approach with BMPs in series. Different BMPs use different processes to remove pollutants from stormwater. For example, an underground baffle vault might be effective at settling out coarse solids, but for removal of finer solids or other pollutants, a BMP using filtration might be

necessary. Similarly, a BMP using filtration may clog quickly and become ineffective if pretreatment to remove coarse sediments is not provided before runoff enters the filter surface.

Principle 8: Design sustainable facilities that can be safely maintained.
Stormwater quality facilities must be properly and consistently maintained to function effectively and ensure long-term viability. Regular maintenance is also important for public acceptance of these facilities. Typical maintenance operations to consider in designing facilities include:

- Mowing, trimming, and weed control
- Pruning of shrub and tree limbs
- Trash and debris cleanup, especially at grates and flow control structures
- Sediment removal
- Removal, replacement, and revegetation of porous landscape detention media
- Vacuuming/replacement of porous pavement and porous pavement detention media
- Structural repair

Keeping in mind these and other potential maintenance practices, it is also necessary to fully consider how and with what equipment BMPs will be maintained into the future. Facility design should provide for these operations ensuring adequate access with a minimum of disturbance, disruption, and cost. Removal of trash, debris, and sediment on a regular basis should be considered in the maintenance plan.

Principle 9: Design and maintain facilities with public safety in mind.
The highest priority of licensed professional engineers and public officials is to protect public health, safety, and welfare. Stormwater quality facilities must be designed and maintained in a manner that does not pose health or safety hazards to the public. For the purpose of this discussion, public safety issues are largely related to public access. Some examples of designing safely include gradually sloping banks or pond edges or locating steep slopes away from pedestrian areas,

III. Planning and Design

While much of this Manual focuses on sizing and design criteria for stormwater management, it is equally important to consider planning and site design. The following bullets provide an overview of design considerations for addressing stormwater quality and flood control requirements on a site.

- Create attractive facilities that add value to the site. While most designers focus on providing a functional stormwater management system for a site, they should also configure and detail the stormwater system to create an aesthetically pleasing facility. Preserving natural features and areas and effective integration of landscape elements and the stormwater system can enhance a project and the community.

- Develop an initial site design.

  - Identify a rough layout of lots, buildings, streets, parking, and landscape areas with a general idea of proposed site grades.

  - Estimate approximate areas associated with roofs, streets, walks, parking lots, and landscaping or open space.

- Consider the full range of BMP alternatives. The stormwater facilities shown in the Land Use-based BMP Selection Guidance (Section 8.3.2) provide examples of appropriate BMPs for a variety of land uses.

  - Consider the full range of alternative approaches for addressing drainage and stormwater quality for the site, including techniques to reduce runoff and distribute BMPs throughout the site.

  - Test the influence of several alternatives on the overall character and layout of the site, weigh pros and cons of each, and progress towards an optimum approach.

  - Consider long-term or life-cycle costs in the selection of alternative BMPs. These can be assessed by consulting references that discuss life-cycle costs of BMPs (Heaney et al. 2002; Watershed Management Institute 1997; Stormtech et al. 2003; Olson et al. 2009.), or by developing opinions of probable cost for the construction and maintenance of specific BMP alternatives for the site.

  - When selecting and designing BMPs that provide for infiltration (i.e., grass buffers and swales, porous pavement detention, porous landscape detention, and sand-filter detention), the designer needs to carefully consider geotechnical and foundation issues and the ability of the property owner to understand and properly maintain these facilities.

- Pursue a functional distribution of landscape areas. Keep detention basins shallow and provide some space for tree and shrub plantings.

  - Initially, provide an area about 10 to 15 percent of the size of the impervious area for stormwater quality treatment. This area may be reduced in later stages of design. For some types of development (i.e. Ultra urban, lot-line-to-lot-line) this may not be feasible.

  - Bioretention (porous landscape detention) areas should be more numerous, and distributed throughout the site. In general, it is prudent to locate porous landscape detention in close proximity to the impervious area being served.

  - For extremely constrained sites, an option may be to locate a BMP in the right-of-way. This option will be considered by the City on a case-by-case basis, and if water quality treatment within the right-of-way is allowed, it must also provide some degree of treatment for adjacent public spaces.

- Consider surface conveyance as an alternative to pipes.

  - Consider how runoff will be conveyed to stormwater quality facilities. Conveying flows on the surface is the best method for getting runoff to porous landscape and porous pavement detention because it allows the facilities to be shallow in depth and provides a defined surface flow route for extra flow unlike a pipe. If flow can be conveyed on the surface in grass swales or in strips of porous pavement, additional stormwater quality benefits will accrue and the required water quality capture volume will be reduced.

  - If runoff must be conveyed under the surface in a pipe, area inlets within a landscaped area are preferred over street or curb inlets, since this gives runoff a chance to sheet flow through vegetation and infiltrate prior to entering the storm sewer. In many locations along streets, area inlets may not be feasible; however, in residential areas where swales of bioretention areas are considered, area inlets may be appropriate.

- Integrate flood control detention. Multiple approaches exist for addressing flood control detention that dove-tail with stormwater quality management.

  - Locate flood control detention in landscape areas and in parking lots.

  - Retaining walls that fully enclose a landscape detention area are unacceptable as they create a deep basin without adequate access.

IV. References

Center for Watershed Protection. *Stormwater BMP Design Supplement for Cold Climates*. United States Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds and Region 5. December 1997.

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Chapter 1 – Policy and Permit Requirements

1.1 Purpose

The purpose of this chapter is to instruct the user on the procedure and documents needed for a complete and acceptable development review submittal to the City of Aspen Engineering Department with regard to stormwater management. **Section 1.2.2 and 1.3** discusses the roles of each of the various City departments involved in the approval process. **Section 1.3** defines the information that shall be needed for a complete application.

1.2 Administration

1.2.1 Jurisdiction

Pursuant to Sec. 28.02.020. of the City of Aspen Municipal Code (hereafter referred to as City Code or Code), drainage plans shall comply with criteria set forth in the City of Aspen Urban Runoff Management Plan. In Sec. 13.04.030 of the Code, the City exercises regulatory and supervisory jurisdiction for water quality within the incorporated limits of the City and over all streams and sources contributing to municipal water supplies for a distance of five (5) miles above the points from which municipal water supplies are diverted. In addition, pursuant to Sec. 26.104.010, the ordinances, regulations and policies of the City shall supersede any conflicting law or regulation of the state within the territorial limits and other jurisdiction of the City.

1.2.2 Responsible Organizations

Administration of and decision-making authority for stormwater management activities is the responsibility of the City of Aspen Engineering Department. The Building Division and the Planning Division of the Community Development Department have other decision-making responsibilities for development activities that may affect stormwater management. In some cases, the City Council, the Historic Preservation Commission, and the Planning and Zoning Committee have the ability to make decisions that can affect stormwater management, such as hearing appeals and approving development applications. For other department's responsibilities, refer to Sec. 2.02 and Sec. 26.208 through 26.222 of the City Code.

1.2.3 Adoption, Amendments and Revisions

These policies and criteria may be amended as new technology is developed or if experience gained in the use of this document indicates a need for revision. The City Engineering Department will monitor the performance and effectiveness of these technical criteria and will recommend amendments and revisions as needed. Minor revisions, such as corrections, clarifications or submittal requirements, will require the approval of the City Engineer. Major revisions, such as policy changes or technical criteria changes, will require approval of the City Council.

1.2.4 Overview of Requirements

Unless specifically exempted, no development, disturbance of land or land use, or construction shall be undertaken without first having been reviewed, approved and issued a permit compliant with the requirements of this document. Unless specifically exempted, no building shall be erected, moved or structurally altered without a building permit issued pursuant to the Aspen Land Use Code. This manual provides detailed guidelines on development and building permits that require engineering review. However, for complete requirements, see the Aspen Land Use Code.

All development and redevelopment projects in the City of Aspen that will:

- **increase the amount of impervious area on a site** (this includes adding hard surface patios, increasing the footprint of the house, etc.)**,**
- **disturb more than 200 square feet of land on the site** (this includes grading, even if a structure or hard surface is not added, as well as "scrape and replace" of impervious area)**,**
- **demolish more than 50% of the interior** (based on the entire square footage of rooms where floors, ceilings, or walls are exposed over the square footage of the structure); **or**
- **add or repair snowmelt,**

are required to obtain an engineering review as part of the building permit or landscape and grading permit application review process.

The City has established a de minimis threshold for stormwater management. Generally, projects can be classified as minor or major based on the amount of impervious area added or total area disturbed by the project[1], as well as impervious areas that are "scraped and replaced." See Table 1.1 below for general requirements. Submittal requirements vary for each project classification, as explained in the appropriate sections of 1.3 and in the checklists of Appendix A.

Smaller, less complex projects that in general disturb less than 1000 square feet of area are often referred to as "minor". At a minimum the engineering review for a Minor Project requires a construction mitigation plan (CMP), demonstration that the work will occur within the property boundaries of the site, documentation that there will be no adverse impact to drainage on the site or downstream of the site, description of the existing and proposed drainage, and description of the plan to address water quality requirements**.** However, in most cases projects are more complex, disturbing more than 1000 square feet of area, and are often considered more "major" due to the potential impacts. For Major Projects, the engineering review could require, as determined by the Development Engineer, completion of a sufficiency checklist, attendance at a Pre-Application Meeting with the Development Engineer, preparation of a compliant City of Aspen survey, and development of a Grading and Drainage Plan and Report, a Construction Management Plan, a Soils Report, and, in certain circumstances, an Excavation Stabilization Plan.

Table 1.1 General Requirements for Minor and Major Projects

Project Type*	Area added OR disturbed	Project Classification	General Requirements
Disturbing less than 200 sq ft	< 200 square feet	--------	No requirements
Landscaping or grading only, and No hardscape, and no change to drainage pattern	200 – 1000 square feet	**---------**	No requirements
Landscaping or grading only that might include hardscape or change in grade or drainage pattern, small additions, small scrape and replace	200 – 1000 square feet	**Minor**	• WQCV or drain to green space for the impervious (hardscape) area • CMP
Refinishing a driveway only (retaining or decreasing impervious area square footage)	Limited to the exact footprint of the existing driveway	**Minor**	• CMP if greater than 1000 square feet • WQCV or drain to green space for the impervious (hardscape) area
Interior work only	< 50% demolished	**Minor**	CMP if greater than 400 square feet of work
Interior work only, Pre-project lot coverage of 0-50%	> 75% demolished (< 75% is still a minor)	**Major**	• CMP • WQCV for the entire area • Conveyance of major flows • Detention to the historic undeveloped rate or FIL for the entire area, unless discharging directly to the City's stormwater system depicted in Figure 1.1. • Requires Professional Engineer

Interior work only, Pre-project lot coverage of 50-100%	> 50% demolished	**Major**	• CMP • WQCV for the entire area • Conveyance of major flows • Detention to the historic undeveloped rate or FIL for the entire area, unless discharging directly to the City's stormwater system depicted in Figure 1.1. • Requires Professional Engineer
Landscaping, grading, installing or disturbing hardscapes, additions to structures, etc.	> 1000 square feet and < 25% of the entire site	**Major**	• CMP • WQCV for the new impervious area • Conveyance of major flows • Detention to the historic undeveloped rate or FIL for the disturbed or added area, unless discharging directly to the City's stormwater system depicted in Figure 1.1. • Requires Professional Engineer
Landscaping, grading, installing or disturbing hardscapes, additions to structures, scrape and replace, interior remodel combined with exterior work, etc.	> 1000 square feet and > 25% of the entire site	**Major**	• CMP • WQCV for the entire area • Conveyance of major flows • Detention to the historic undeveloped rate or FIL for the entire area, unless discharging directly to the City's stormwater system depicted in Figure 1.1. • Requires Professional Engineer

Notes:

1 Special Circumstances: *Any* work, regardless of amount or size, performed on historic properties, in environmentally sensitive areas, geologic hazard areas, in jurisdictional or non-jurisdictional floodplains, or work that impacts trees may be required to submit information for permit review and may be required to provide a more detailed drainage analysis and design than suggested in the table above.

2 The de minimis threshold for minor projects applies only to a single addition on a given piece of property. If cumulative additions on a property over a three-year period after the CO is issued increase the impervious area by more than 1000 square feet, "major" project requirements and evaluations will apply to all impervious areas that are in addition to the "baseline" imperviousness determined from the 2008 aerial photography.

3 Pre-project lot coverage is determined by dividing the total hardscape footprint on the lot (house, driveway, patios, sidewalks, etc.) by the total lot area. Interior demolition is measured by the square footage of the room renovated/modified divided by the total square footage of the structure.

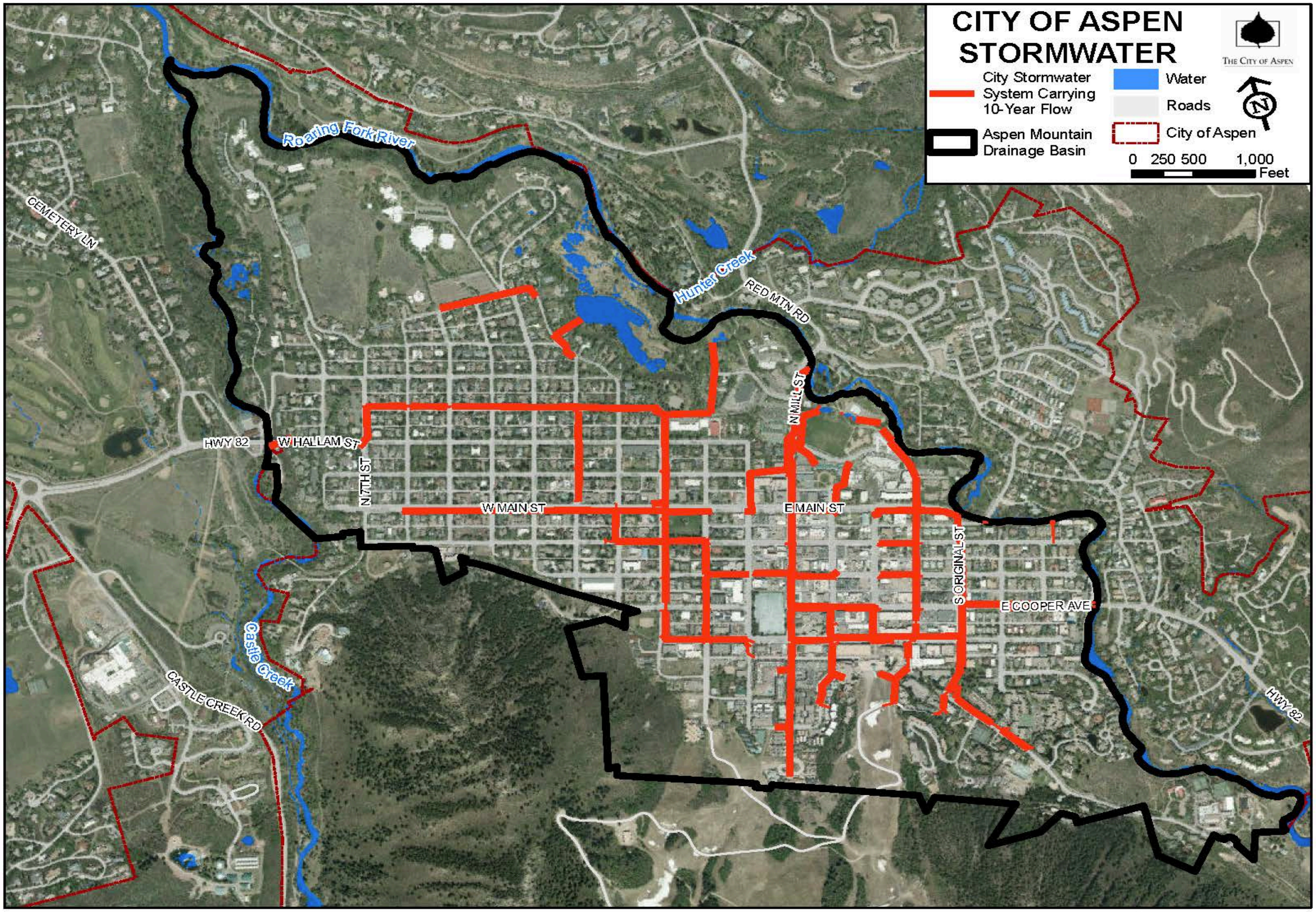


Figure 1.1 – City of Aspen Stormwater System Carrying the 10-year Flow

Stormwater infrastructure can be divided into two areas – hard (or gray) and green. Hard stormwater infrastructure, such as streets, curbs and gutters, alleys, inlets, and pipes, do not provide any water quality benefits (i.e. they do not remove pollutants from stormwater runoff). "Green" infrastructure, such as grass-lined or vegetated swales, does provide water quality benefit by infiltrating some runoff and filtrating pollutants from the remaining runoff. Therefore, those projects that drain to hard infrastructure must insure that water quality improvements are being made by calculating the water quality capture volume (WQCV).

In some instances for minor projects the Engineering Department will allow "water quality improvements" rather than a calculation and design for the WQCV. "Water quality improvements" describe actions taken to reduce runoff and improve infiltration of runoff, such as draining impervious areas to landscaped areas or using pervious pavers. Installing "water quality improvements" is intended to require less design and calculations than installing measures to contain the water quality capture volume (WQCV). The WQCV is a calculated volume based on the amount of impervious area and must be treated using one of the approved best management practices included in Chapter 8. More information regarding water quality improvements and guidelines for calculating and treating the WQCV can be found in Chapter 8 of this Manual.

1.2.5 Review and Acceptance

The City shall review all drainage submittals for general compliance with this document. An acceptance by the City does not relieve the owner, engineer, or designer from the responsibility of ensuring that the design, calculations, plans, specifications, construction, and record drawings are in compliance with these criteria as stated in the owner's and engineer's certifications.

The City may, but is not required to, refer submittals to other agencies that have an interest or responsibility for drainage and/or water quality issues. Other review agencies may include local or State agencies, such as the Colorado Water Conservation Board or the Colorado Geologic Survey, responsible for floodplain and water quality, slope stability, mudflow analysis, geology, water rights and other stormwater related issues.

1.2.6 Interpretation

In the interpretation and application of these criteria, the provisions shall be regarded as the minimum requirements for the protection of the environment and public health, safety, comfort, morals, convenience, prosperity, and welfare of the residents of the City. These criteria shall therefore be regarded as remedial and shall be construed to further the underlying purposes of this document.

Whenever a provision of these criteria and any other provision in any law, ordinance, resolution, rule or regulation of any kind, contains any requirement(s) covering any of the same subject matter, the requirements that are more restrictive or impose higher standards shall govern.

These Criteria shall not abrogate or annul any easements, permits, drainage reports or construction drawings, recorded, issued, or accepted by the City prior to the effective date of this document.

1.2.7 Variances

Requests for variances from the standards, policies or submittal requirements of this document shall be submitted in writing with appropriate documentation and justification to the City Engineer. Variance requests must, at a minimum, contain the following information:

- Criteria from which the applicant seeks a variance.
- Justification for not complying with the criteria.
- Alternate criteria or standard that is proposed to comply with the intent of the criteria.
- Supporting documentation, including necessary calculations, etc.

- Potential adverse impacts of the proposed variance and alternate criteria on downstream water bodies and public and private property.
- An analysis of the variance request may need to be signed and stamped by a Professional Engineer licensed in the state of Colorado, depending on the variance request.

Upon receipt of a complete application for a variance, the City Engineer shall prepare a statement, based on the ability of the proposed project to meet the standards and goals of the City's stormwater management criteria, recommending approval or disapproval or requesting modifications of the proposed variance.

1.2.8 Appeals

Any appeal from an order, requirement, decision, or determination of the City Engineer made pursuant to this Urban Runoff Management Plan shall be taken within fifteen (15) days following the date of such order, requirement, decision, or determination by the filing of a written notice of appeal with the Administrative Hearing Officer. The notice of appeal shall state in detail the action appealed from, the grounds for the appeal, and the relief sought. The Administrative Hearing Officer shall, within thirty (30) days following the filing of the notice of appeal, review the record of the action taken by the City Engineer, and provide a decision to the Applicant in writing. The Administrative Hearing Officer may reverse or affirm wholly or partly the order, requirement, decision or determination appealed from and shall enter such order as it deems appropriate under the circumstance.

1.2.9 Inspections, Enforcement and Penalties

Any violation of these regulations shall be punishable by a penalty as described in Sec. 1.04.080 of the Aspen City Code.

A City Construction Mitigation Officer (CMO) and/or Stormwater Inspector is assigned to each construction project and he or she will complete regular site visits to determine whether a project is following the requirements of the City and the Construction Management Plan including erosion prevention and sediment control and stormwater management. The Construction Mitigation Officer and/or Stormwater Inspector will keep inspection reports. All reports are public documents and will be kept in the City Engineering Department. The City will enforce construction mitigation corrections generally as follows:

1. The first corrective action is a verbal warning and explanation of the violation with a timeframe for completion.
2. The second corrective action is a written warning or correction notice with timeframe for compliance.
3. Third and final notice is a "Stop Work Order" (red tag). If a stop work order is issued, no more work can be completed until the violation is corrected.

However, depending on the severity or threat to public or environmental safety, the City make issue a Stop Work Order directly, without first issuing corrective actions or notices. Failure to correct violations and/or any threat to public or environmental safety could subject the owner, contractor, or both to a fine of $1,000 a day as determined by the municipal court.

1.3 Engineering Review Process and Requirements

All subdivisions, re-subdivisions, planned unit developments, or other development, building, or grading (excluding PUD amendments and administrative re-subdivisions) within the City of Aspen jurisdiction must submit designs in accordance with the requirements of this manual and the City of Aspen Engineering Design Standards. **Major drainage plans and reports, surveys, construction drawings and specifications, and as-built information shall follow the submittal standards in the Engineering Design Standards and/or Appendix A of this Manual.** An electronic copy and two hardcopies must be submitted to the City. The City will attempt to review the reports and plans and provide written review comments and/or approval within thirty (30) working days of the submittal.

The City will make every effort to effect a complete review and comment within the review period. However, the City cannot approve reports or plans by default. In addition, the City cannot guarantee the time for review. All submitted reports must be clearly and cleanly reproduced. Photostatic copies of charts, tables, nomographs, calculations, or any other referenced material must be legible. Washed out, blurred, or unreadable portions of the report are unacceptable and could warrant resubmittal of the report. Incomplete or absent information may result in the report being rejected for review.

Construction shall not commence on any improvements proposed or required until required documentation has been received and approved by the Development Engineer. Incomplete permits will not be accepted.

The process for development and redevelopment depends on the type of review as follows:

Type of Review	Requirements
Development Review Commission (DRC)	Eng. Dept. approval of conceptual site plan DRC approval of conceptual site plan
Plat	Eng. Dept. approval of final site plan
Building Permit	Pre-Application Meeting with Eng. Dept. Development Eng. signature on Sufficiency Checklist Building Permit Application Building Permit Approval Floodplain Development Permit (if in floodplain) No Rise Certification (if in floodplain)
Landscape and Grading Permit	Pre-Application Meeting with Eng. Dept. Development Eng. signature on Sufficiency Checklist Landscape and Grading Permit Application Landscape and Grading Permit Approval
Certificate of Occupancy Certificate of Completion Final Inspection	As-Builts Maintenance Plan and Agreement Pass Final Inspection Elevation Certificate (if in floodplain)

For process guidance, go to the City's Business Navigator webpage at www.aspenpitkin.com/Business-Navigator/. For guidance documents, applications, and checklists (including those referenced and/or contained within this manual), go to the Business Navigator Resource Center at **www.aspenpitkin.com/Business-Navigator/Resource-Center.**

1.3.1 Landscape and Grading Permits

Any activity that modifies the visible features of an area of land or the features planted on that land, but does not include activity on or within a structure, might be required to obtain a Landscape and Grading Permit. The Landscape and Grading Permit triggers and Permit requirements are located in Appendix A. Landscape and Grading Permits are not intended for landscaping projects that will only modify plant selection or ground cover (not including hard surfaces). Landscape and Grading Permits *are* intended for projects that might alter or impact drainage, such as grading; utility installations or improvements (outside of the right-of-way); deck or patio reconfigurations; pool installations; etc.

1.3.2 Building Permit Application Pre-submittal

Building Permits are required for any activity proposed that will modify an existing structure, elements within that structure, or create a new structure (including structures such as bridges or retaining walls). It is advised that prior to applying for any building permit, applicants contact the Community Development Department and discuss the project with a planner. A pre-submittal consultation can minimize unforeseen land use issues or conditions of approval that could delay the issuance of a building permit. In addition, prior to applying for a building permit, applicants must ensure that all land use requirements have been satisfied. Once land use requirements have been satisfied, applicants must obtain referral department forms from the Parks Department, Aspen Consolidated Sanitation District, Water Department, and Engineering Department, and satisfy the requirements of these referral departments.

1.3.3 Development Review Committee or Land Use Plan Submittals

Some development projects are required to go through a Land Use Review or to submit to the Development Review Commission (DRC) prior to submission for Building Permit Application. This determination is made during the pre-submittal meeting with the Community Development Department. Prior to the Land Use or DRC review process, applicants must submit a conceptual grading and drainage site plan to the Engineering Department for approval. For complete requirements, see the conceptual review submittal checklist in **Appendix A** and the guidance provided in Section 1.3 of the Engineering Design Standards

1.3.4 Sufficiency Review

All applications for Building Permit that require an engineering review must first complete a sufficiency review and Pre-Application meeting with the Development Engineer. Completion of the Sufficiency Checklist (located in **Appendix A**) is required prior to the Pre-Application Meeting. The checklist verifies that all of the documents required for the Building Permit Application have been assembled and are prepared for submission. The sufficiency checklist will be reviewed with Development Engineer during the Pre-Application Meeting.

1.3.5 Pre-Application Meeting

The Pre-Application Meeting shall be scheduled by the applicant with the Development Engineer. During the Pre-Application Meeting, the applicant and the Development Engineer will review all documents assembled for the Sufficiency Review. The Development Engineer's signature is required on the Sufficiency Checklist before a building permit application can be accepted for review.

1.3.6 Building Permit Application Content and Referrals

Requirements for building permit applications vary by department and type of development; for complete requirements go to the Business Navigator website at www.aspenpitkin.com/Business-Navigator or contact a Permit Coordinator at 970-920-5090..

Upon receiving a completed Building Permit Application, the Chief Building Official will refer copies of the application to the Community Development Department and to other appropriate City staff and departments, such as Sanitation, Parks, Water, etc., for review and comments. These referrals include the Engineering Department. All building permit applicants to receive an engineering department review must have a signed Sufficiency Checklist at time of application submittal to ensure that all relevant materials are included in the building permit application. Each department will review the application for compliance.

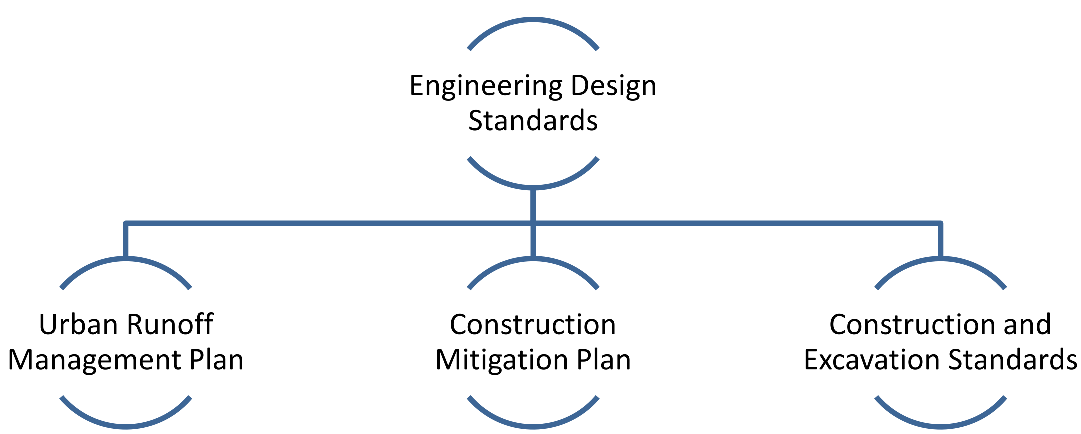
1.3.7 Engineering Department Requirements

The Engineering Department Sufficiency Checklist requires that applicants identify the amount of work to be done for the project and the category this work fits into: minor or major.

- Minor projects must complete the minor grading and drainage plan and report checklist and any other information deemed necessary by the Engineering Department.
- Major projects must include a compliant survey, a major site grading and drainage plan and report, a soils report, and a construction management plan.

Other items that might be required with the any building permit application include an excavation and stabilization plan, public improvements site plan, floodplain permit, and/or a mudflow analysis. In addition, requirements for parking and driveways, and utility meters and pedestals will also be checked at this stage. Each of these requirements is described in greater detail below, though the guidance for some of these additional requirements is not contained in this Manual.

Reference guidance documents are indicated where necessary and include the Engineering Design Standards, Construction Management Plan Requirements Manual, and Construction and Excavation Standards. Checklists are included in **Appendix A of this document or in Appendix A of the Excavation Design Standards or at the Business Navigator Resource Center webpage at** www.aspenpitkin.com/Business-Navigator/Resource-Center.



1.3.8 Grading and Drainage Plan and Report

The purpose of the Grading and Drainage Plan and Report is to identify and refine conceptual solutions to the drainage changes that may occur onsite and offsite as a result of the development.

Preparation of *plan documents* shall follow the standards and guidance found in Chapter 1 of the Engineering Design Standards. For major projects, all *reports* shall be typed on 8½" by 11" paper and bound. Reports should contain enough information to describe the existing site, proposed work, explanation of steps taken to reduce impervious area and implement low impact development strategies, pre- and post-drainage patterns, sizing calculations for stormwater management facilities, how chosen facilities should operate and be maintained. The site plan, drawings, figures, plats, and tables shall be included in the plan set and bound with the report or included in a pocket attached to the report in 24"x36" size. The report shall include a cover letter presenting the preliminary design for review and shall be prepared by or supervised by a civil engineer licensed in Colorado. The report shall contain a certification sheet as follows:

> "I hereby affirm that this report and the accompanying plans for the <u>(type or phase design)</u> of <u>(Name of Development)</u> was prepared by me (or under my direct supervision) for the owners thereof in accordance with the provisions of the City of Aspen Urban Runoff Management Plan and approved variances and exceptions listed thereto. I understand that it is the policy of the City of Aspen that the City of Aspen does not and will not assume liability for drainage facilities designed by others."

_______________________________________ License No. ____________________

Licensed Professional Engineer, State of Colorado (Affix Seal)

Modified requirements and checklist have been developed for minor projects. A narrative description (report) of the project must be included as well as a sketched site plan.

A listing of the items required in the report and plan for minor and major projects can be found in **Appendix A.**

1.3.9 Survey Requirements

As part of a complete building permit application for major projects, applicants must submit two copies of a compliant City of Aspen survey, performed within one year of the date of application for the building permit, per minimum American Land Title Association standards. The applicant must certify the survey represents current site conditions. An applicant may be exempt from the survey requirement if application proposes to increase floor area by less than 15 percent and does not propose to change the building footprint. The survey must include topography at one-foot contour levels, certified by a registered land surveyor. The survey must also include all items identified in the City of Aspen Survey Checklist (see **Appendix A of Engineering Design Standards**).). Guidelines for surveying have not been included in this Manual, but can be found in Chapter 2 of the Engineering Design Standards. Soils Report Requirements (EDS references URMP)

A Soils Report is required for all development projects that disturb more than 1000 square feet of soil disturbance. A soils report is required to assist/support the drainage plan and report. The Soils Report shall include the items listed in the Soils Report Requirements checklist (see **Appendix A**).

1.3.10 Construction Management Plan

Construction projects that exceed 1,000 square feet of soil disturbance or 400 square feet of building demolition, improvement, or renovation (interior and/or exterior) must submit a construction management plan in accordance with the requirements found in the Construction Management Plan Requirements Manual and in the City of Aspen Municipal Code (Code), Title 8. The Construction Management Plan is a combination of diagrams, documents, drawings, and specifications that clearly define the steps that will be taken to demonstrate how the impacts of the construction project to the community will be managed and minimized.

1.3.11 Excavation Stabilization Requirements

An Excavation Stabilization Plan is required if either of the following is true:

- **Nearby Structures and Travel Ways:** both (1) the depth of excavation will be deeper than five feet AND (2) the proposed foundation walls (including light wells) are within a horizontal distance less than the vertical depth of the excavation of any existing travel way, structure, or property line. For this purpose, a travel way is defined as any sidewalk, walkway, driveway, parking area, or street.

- **Nearby Trees:** If excavation will occur within the drip line of a tree that is deemed significant by the City Parks Department. To determine if a tree is considered significant, contact the Parks and Open Space Coordinator of the City Parks Department at 429-2035.

The Excavation Stabilization Plan must adhere to the requirements and guidelines detailed in the Engineering Design Standards. Public Improvement Requirements

In accordance with the City's Sidewalk, Curb and Gutter Master Plan, property owners are required to install and maintain sidewalk, curb and gutter along the street frontage adjacent to their properties. Properties within certain areas of the City are not required to install sidewalk, curb and gutter. These locations are shown on the "Sidewalk Free Zones" and the "No Curb and Gutter Zones" maps in the Engineering Design Standards.

Sidewalk, curb and gutter does not need to be installed as part of the project if (i) the property is outside of the City's sidewalk, curb and gutter zones, and (ii) the cost of installing sidewalk, curb and gutter exceeds 50 percent of the project cost excluding the cost of the sidewalk, curb and gutter. For example, the project would not need to install sidewalk, curb and gutter if the project cost is $20,000 and the cost to install sidewalk, curb and gutter is greater than $10,000.

Where sidewalk, curb and gutter are required, applicants must provide the information listed in the Public Improvements Requirement checklist found in **Appendix A of the Engineering Design Standards**. Guidelines for public improvements are located in Sections 4.3 – 4.8 of the Engineering Design Standards.

1.3.12 Floodplain Requirements

Before construction or development may begin within any area of special flood hazard within the jurisdiction of the City, a Floodplain Development Permit (in **Appendix D**) shall be obtained from the Development Engineer. Special flood hazard areas are identified on the FEMA report entitled, "Flood Insurance Study for Pitkin County, Colorado and Incorporated Areas," dated October 19, 2004. Development within areas of special flood hazard must adhere to the standards in Sec. 8.50.050 of the City code. Further information on floodplain analysis can be found in **Chapter 6** of the Manual.

1.3.13 Mudflow Analysis

Mudflow analysis requirements may be applicable to all development and redevelopment within the City of Aspen jurisdiction and that is developing slopes greater than 15%, that lie within the mudflow plain, or as deemed necessary by the City Engineer. For development projects in a mudflow hazard area that will modify existing grades, create additional obstructions (such as buildings, roads, etc.), or change the orientation of obstructions, the applicant must conduct analyses to demonstrate that the proposed development will not adversely affect nearby properties. In addition, development activities within the mudflow hazard area must be designed to withstand the hydrostatic and shear forces of the mudflow event. Further information on mudflow analysis can be found in **Chapter 7** of the Manual.

1.4 Engineering Inspections and Final Approvals

A City Construction Mitigation Officer (CMO) and/or Stormwater Inspector is assigned to each construction project and he or she will complete regular site visits to determine whether a project is following the requirements of the City and the Construction Management Plan including erosion prevention and sediment control and stormwater management.

Prior to issuance of a Certificate of Occupancy (CO), major projects must submit and receive approval of an As-Built Survey (**Appendix A**). The As-Built must be completed and stamped by a Colorado Professional Land Surveyor and include the Grading and Drainage Certificate, which is a statement (see **Appendix A** for exact statement) located on the As-Builts and signed by a Colorado Professional Engineer (preferably the engineer that completed the design), certifying that stormwater quality and quantity control measures were located on site as shown on approved design plans. If any changes are made to the design of drainage during the construction and installation process, a Change Order must be submitted and approved by the Development Engineer prior to issuance of a CO.

The owner of each stormwater management control and/or structural stormwater BMP installed pursuant to the requirements of this manual or the Aspen City Code shall sign a Maintenance Agreement (as provided in **Appendix A**) which references a Maintenance Plan andstates that the owner will maintain and operate said stormwater management and/or BMP facility so as to preserve and continue its function in controlling stormwater quality and quantity at the degree or amount of function for which the structural BMP was designed.

In addition to the As-Builts and Maintenance Agreement and Plan, major projects will need a final inspection by the Stormwater Inspector to verify conformance with the As-Built drawings and to verify final stabilization. In cases where the site has connected into the City's stormwater system via a pipe, a video of the connection must be submitted that shows a clean conveyance without damage or unacceptable conditions.

1.5 Requirements By Drainage Basin

The boundaries of the City of Aspen fall within four major drainage basins – Aspen Mountain, Smuggler/Hunter, Castle Creek, and Maroon Creek (Figure 1.2). These basins and the general requirements for design within these basins are provided below.

The Aspen Mountain Drainage Basin is bounded by the Roaring Fork River (River) on the north, the top of Aspen Mountain on the south, an unnamed tributary to the east and the ridgeline of Shadow Mountain basically following 8th Street to the west. Surface runoff in this basin generally flows to the north and outfalls into the Roaring Fork River. This basin includes major conveyances off of Aspen Mountain, including Copper, Spar, Vallejo, and Pioneer Gulches, as well as major conveyances through the City's urban core including Main, Original, Mill, and Garmisch Streets. There are four major outfalls into the River from this basin – one on the eastern edge of Rio Grande Park that carries flood flows from the eastern portion of the basin, one in the middle of Rio Grande Park just downstream of the old bridge that carries water quality flows from the eastern and middle portions of the basin, one just upstream of the Mill Street bridge that carries the flood flow of Mill Street and the middle portion of the basin, and one at the Jenny Adair wetlands, which carries the majority of the flows from the western portion of the basin.

A master plan was completed for this basin in 2001 and updated in 2014 – The Aspen Mountain Surface Drainage Master Plan, available at the Engineering Department's webpage and office. The City's stormwater system in this basin has the capacity to carry the 10-year storm event within pipes. Therefore, **development and redevelopment within this basin that is capable of discharging to the City's system without impacting neighboring properties can do so without providing detention beyond the water quality capture volume (WQCV).** There is a significant threat for mudflow from the slopes of Aspen Mountain. Therefore, **properties located within 200 feet of its base and within other portions near the base as identified in Chapter 7 will be required to study and mitigate for mud flow impacts.**

The Smuggler/Hunter Drainage Basin is bounded by Hunter Creek to the north, the Roaring Fork River to the west, , the top of Smuggler Mountain to the east, and by the southern boundary of the watershed area contributing to Stillwater Drive on the south. Surface runoff in this basin generally flows through the developed portions in the lower basin towards the River. A small portion of this basin drains toward Hunter Creek, which quickly empties into the Roaring Fork River. There are three major outfalls into the River from this basin – one on Neale Avenue near the No Problem Joe Bridge and Herron Park that carries flow the Smuggler Trailer Park, King and Queen Streets down along Neale Avenue, one west of Spring Street that carries flow from the southeastern portion of Centennial Condos along South Avenue and down east Francis Street, and one just upstream of the Mill Street Bridge that carries flow from the northern portion of Centennial Condos, through Fox Crossings, and along Gibson Avenue,.

A master plan will be completed for this basin in 2015 – The Smuggler/Hunter Surface Drainage Master Plan – and will be available at the Engineering Department's webpage and office. The City's stormwater system in this basin is currently sporadic and not as robust as it is in the Aspen Mountain Basin. Until more is known about the capacity of the system, **the water quality capture volume and detention for the minor and major storm are required for sites developing in this basin**. For properties in this basin that can convey the minor and major events to the City's system without impacting neighboring properties, **the fee-in-lieu of detention is an option.**

The Castle Creek Drainage Basin is bounded by the Roaring Fork River to the north, Shadow Mountain and 8th Street to the east, and Castle Creek Road, the eastern edge of the golf course, and Red Butte to the west. While the majority of development along Cemetery Lane drains directly into the Roaring Fork and not into Castle Creek, this area is included in this basin for master planning purposes. There is no formal City stormwater drainage system in this area. Therefore **all development must meet the requirements for water quality and detention in this basin. Development that can discharge directly into the river without impacting neighboring properties will not have to provide detention above the water quality capture volume. Fee-in-lieu of detention is not an option within this basin.**

The Maroon Creek Drainage Basin is bounded by the ridge west of Castle Creek Road, through the golf course and up along the ridge of Red Butte on the east, the Roaring Fork River to the north, Deer Hill up through the Maroon Creek Club and Tiehack to the west, and the southern boundary of the watershed to the south. This basin includes several regional stormwater systems including Highlands, Maroon Creek Club, Five Trees, and Burlingame. **Development within these regional systems must provide the water quality capture volume and meet the requirements for the regional stormwater conveyance and detention plan for the area (see drainage reports associated with appropriate subdivisions).** There is no formal City stormwater drainage system in this basin. Therefore, **developments that do not have a regional system, must meet water quality and detention requirements for the area based on this manual. Development that can discharge directly into the river without impacting neighboring properties will not have to provide detention above the water quality capture volume.. Fee-in-lieu of detention is not an option within this basin.**

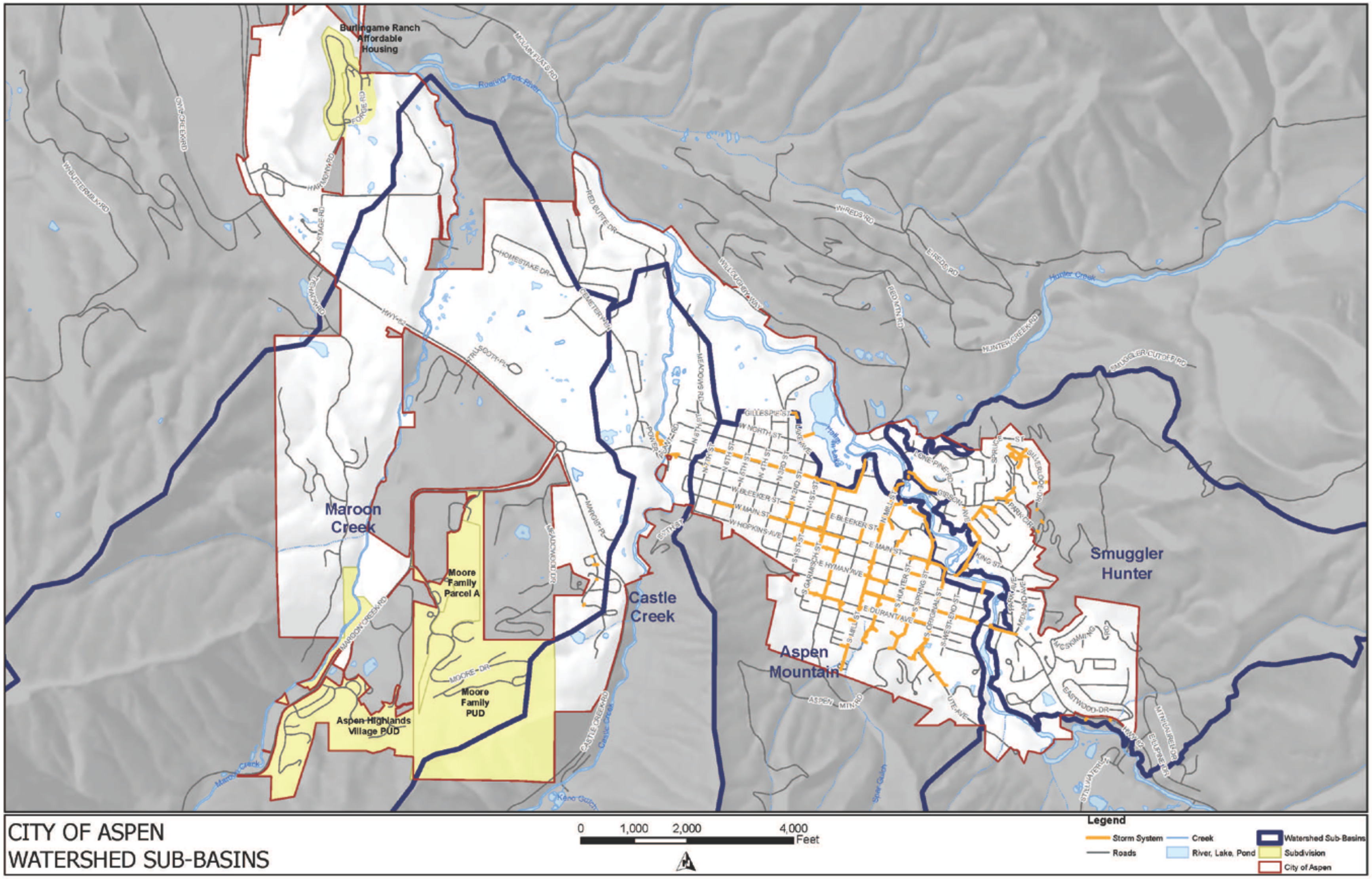


Figure 1.2 City of Aspen Drainage Basins

Chapter 2 – Rainfall

2.1 Purpose

This chapter presents the rainfall and snowfall design information needed for storm and snowmelt runoff analyses in the City of Aspen. Major subjects include:

- precipitation statistics for Aspen,
- IDF (intensity-duration-frequency) relationships for flood predictions from small watersheds,
- temporal rainfall distributions for flood flow simulation through large watersheds,
- snowmelt calculation methods, and
- the derivation of Water Quality Capture Volume (WQCV).

One of the most significant impacts of urbanization and development is the increase in peak flow rates, runoff volumes, and frequency of runoff from impervious areas. This increase in runoff can lead to severe stream erosion, habitat disruption, and increased pollutant loading in receiving waters. The increase in runoff from development is especially pronounced when drainage systems are designed to quickly 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 is reflected accurately by the hydrologic methods discussed herein.

With proper planning, the increased runoff volumes, rates, and pollutant loads can be managed and controlled in ways that mimic natural hydrology, reducing the impacts to the watershed. **The stormwater management policies of the City of Aspen strongly encourage methods to reduce runoff and increase infiltration to attenuate peak flood discharges and improve stormwater quality.** As a result, many of the drainage facilities are designed for watersheds smaller than 100 acres with a time to peak discharge of less than 30 minutes. This requires the use of rainfall patterns that are shorter than two-hour duration in the design of facilities. In this Chapter, the 2-, 5-, 10-, 25-, 50-, and 100-year 2-hr rainfall distribution curves are derived for the Aspen area based on the one-hr precipitation depth. However, **only the 5-, 10-, and 100-year storms are needed for drainage design at this time**. The information source for design storms presented in this Chapter is the Precipitation-Frequency Atlas of the United States, Midwestern States, NOAA Atlas 14, Volume 8 (NOAA 2013).

The continuous daily rainfall and snowfall data recorded at Aspen Weather Observation operated by the Water Department, City of Aspen was analyzed from 2006 to 2008 to derive the localized hydrologic parameters. The 29-year daily climate data collected at Station 050372 from 1980 through 2008 was used to derive the WQCV for the Aspen area (Station 050372, Western Regional Climate Center.)

The methodology used to generate the rainfall data for a project will depend on the size of the drainage basin being studied. The Rational Method for determining runoff, explained in Chapter 3, is widely accepted as providing a sufficient level of detail for generating runoff from relatively small basins and should be used for drainage basins with an area less than 90 acres. The Rational Method uses rainfall data in the form of intensity-duration (time)-frequency curves, discussed in Section 2.3.

Since the assumptions used in the Rational Method become less valid over larger areas, larger basins require a more rigorous analysis to generate runoff data. CUHP or SWMM designs, explained in Chapter 3, must be used for drainage basins with an area greater than 90 acres. CUHP and SWMM uses rainfall data in the form of depth ratios or depths, discussed in Section 2.4.

2.2 Overview

The climate in Aspen offers mild weather with low humidity and year-round sunshine. Summer weather in Aspen starts around June or July where temperatures reach 80°F during the day, although temperatures are much cooler during the night. The occasional summer shower can occur at any time, sometimes turning into thunderstorms. Autumn in Aspen is usually dry and warm and during September daytime temperatures can reach 70°F, but night temperatures can drop to freezing. Aspen is renowned for its warm winter sun. Winter daytime temperatures typically range from 20 to 40°F in the City and from 10 to 30°F on the mountain. Once the sun goes down, the temperature drops dramatically. **Table 2.1** presents monthly statistics for temperature, precipitation, snowfall, and snow depth in the Aspen area.

Table 2.1 Monthly Statistics for Temperature and Precipitation in Aspen

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	35	39	45	52	63	72	78	76	69	58	43	35	55.5
Average Min. Temperature (F)	9.1	12	20	26	35	41	47	46	39	30	19	9.7	27.7
Average Total Precipitation (in.)	1.7	2.1	2.7	2.5	2.1	1.4	1.8	1.6	2.1	2	2.6	1.9	24.37
Average Total Snowfall (in.)	25	27	28	20	7.8	1	0	0	1	11	28	25	173.8
Average Snow Depth (in.)	21	28	27	12	1	0	0	0	0	1	6	14	

(Source: Station 050372 at Aspen 1 SW, Colorado)

2.3 Rainfall Depth, Duration, Frequency, and Intensity

The rainfall intensity-duration-frequency (IDF) curve is a statistical formula to describe the relationship among the local rainfall characteristics and return periods. **The IDF curve is used in the Rational Method for peak runoff predictions of basins smaller than 90 acres.** Based on the NOAA Atlas Volume 3, the IDF curve for the City of Aspen can be derived according to the locality and elevation. The City of Aspen is located at approximately 39°11′32″N and 106°49′28″W, at an elevation of approximately 8,100 feet.

Based on depth and duration data (Appendix B, Table 1), rainfall intensities can be calculated for various frequencies. Rainfall intensity data, which form the basis of the Intensity-Duration-Frequency (IDF) curves in **Figure 2.1** are provided in **Table 2.2**.

Table 2.2 Rainfall Intensity-Duration-Frequency in Aspen, Colorado

Return Period	Rainfall Intensity in inch/hr for Various Periods of Duration								
	5-min	*10-min*	*15-min*	*30-min*	***1-hr (P1)***	*2-hr*	*3-hr*	*6-hr*	*24-hr*
2-yr	2.06	1.51	1.23	0.77	0.47	0.28	0.21	0.13	0.06
5-yr	2.98	2.17	1.77	1.09	**0.64**	0.36	0.26	0.16	0.07
10-yr	3.72	2.72	2.22	1.35	**0.77**	0.43	0.30	0.18	0.08
25-yr	4.75	3.47	2.82	1.71	0.95	0.53	0.36	0.21	0.09
50-yr	5.53	4.05	3.30	1.98	1.09	0.60	0.41	0.24	0.11
100-yr	6.32	4.63	3.76	2.24	**1.23**	0.67	0.45	0.26	0.12

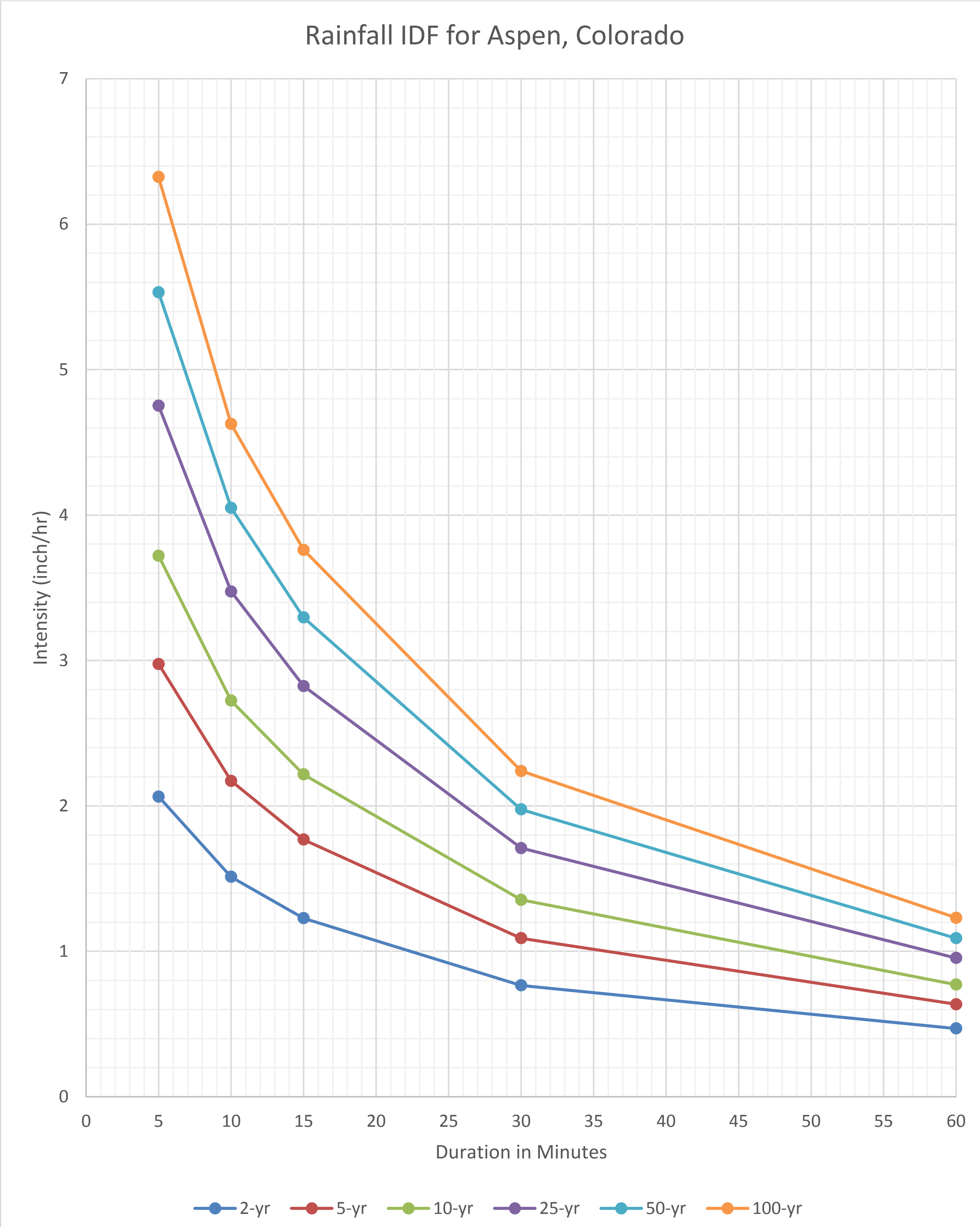
Using the data in **Table 2.2 (**derived from NOAA Atlas 14 Volume 8)**,** the following equation was derived that can be used to determine intensities not shown in the IDF table or curve:

$$I = \frac{88.8P_1}{(10+T_d)^{1.052}}$$ **(Equation 2-1)**

Where, I = rainfall intensity (inch/hr),
P_1 = 1-hr rainfall depth (inches), and
T_d = duration or time of concentration (minutes).

This equation can be used in conjunction with the Rational Method in Chapter 3 of this Manual by setting T_d equal to the time of concentration of the watershed.

The coefficients within Equation 2-1 are applicable to UDFCD spreadsheets. UDFCD spreadsheet Runoff Analysis-UD-Rational v1.02a determines the time of concentration and peak runoff for a given drainage basin. The spreadsheet Detention Design - UD-Detention v2.34 utilizes various methods to determine required detention volume. The analysis is based off user input parameters for given drainage basin characteristics. The spreadsheets can be found at http://www.udfcd.org/downloads/down_software.htm.



Note: Accuracy is more reliable at 5 minute increments.

Figure 2.1 IDF Curves for Aspen, Colorado

2.4 Design Rainfall Distribution

For larger drainage areas (over 90 acres) or for sizing of facilities where a hydrograph must be analyzed, such as a detention pond, a temporal distribution must be assigned to a precipitation event for calculation of runoff. Characteristics of a temporal distribution include duration and distribution (depth at a certain time) of rainfall.

Very intense rainfall patterns resulting from convective storms or frontal stimulated convective storms typically drive flooding in small urban catchments like Aspen. These types of storms often have their most intense periods over duration of one or two hours or less, and they produce brief periods of high rainfall intensities. Analysis of the summer storms recorded at the Aspen rain gage revealed that an overwhelming majority of intense rainstorms produced their greatest intensities in the first hour of the storm. Based on this analysis, a 2-hour design storm with the "leading edge" of intensity in the first hour is recommended for watersheds less than or equal to 10 square miles in the Aspen area[1].

Depth ratios (or percentages) are input parameters for CUHP models. For this manual, another step was taken to derive distribution *depths* (these can also be input for CUHP models) for the 1-hr event in Aspen. Appendix B, Table 2 shows the incremental depths and Appendix B, Table 3 shows the cumulative depths. For areas outside of the City of Aspen, the depth ratios (percentages) in Appendix B, Table 4 should be used in CUHP to derive depths for those areas.

[1] The temporal distribution of rainfall must be adjusted for application to large watersheds (> 10 square miles). Since development projects in Aspen are typically ≤10 square miles, discussion of adjustment procedures for watersheds > 10 square miles is not included in this Manual. In cases where large watersheds are to be analyzed (i.e. the Roaring Fork River, Castle Creek or Maroon Creek) see the rainfall chapter of the UDFCD Urban Storm Drainage Criteria Manual for detailed discussion of adjustments (UDFCD 2001).

Table 2.3 Two-Hour Incremental Rainfall Depths for Aspen

Incremental Design Rainfall Distributions for Aspen Colorado						
2-yr, 1 hour precipitation = 0.47 5-yr, 1 hour precipitation = 0.64 10-yr, 1 hour precipitation = 0.77 25-yr, 1 hour precipitation = 0.95 50-yr, 1 hour precipitation = 1.09 100-yr, 1 hour precipitation = 1.23						
Time *minutes*	2-yr *(in)*	5-yr *(in)*	10-yr *(in)*	25-yr *(in)*	50-yr *(in)*	100-yr *(in)*
0	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.02	0.01	0.01	0.01
10	0.02	0.02	0.03	0.03	0.04	0.04
15	0.04	0.06	0.06	0.05	0.05	0.06
20	0.08	0.10	0.12	0.08	0.09	0.10
25	0.12	0.16	0.19	0.14	0.16	0.17
30	0.07	0.08	0.09	0.24	0.27	0.31
35	0.03	0.04	0.04	0.11	0.13	0.17
40	0.02	0.03	0.03	0.08	0.09	0.10
45	0.01	0.02	0.03	0.05	0.05	0.08
50	0.01	0.02	0.02	0.05	0.05	0.06
55	0.01	0.02	0.02	0.03	0.03	0.05
60	0.01	0.02	0.02	0.03	0.03	0.05
65	0.01	0.02	0.02	0.03	0.03	0.05
70	0.01	0.02	0.02	0.02	0.03	0.02
75	0.01	0.02	0.02	0.02	0.03	0.02
80	0.01	0.01	0.02	0.02	0.02	0.01
85	0.01	0.01	0.02	0.02	0.02	0.01
90	0.01	0.01	0.01	0.01	0.02	0.01
95	0.01	0.01	0.01	0.01	0.02	0.01
100	0.01	0.01	0.01	0.01	0.02	0.01
105	0.01	0.01	0.01	0.01	0.02	0.01
110	0.00	0.01	0.01	0.01	0.02	0.01
115	0.00	0.01	0.01	0.01	0.02	0.01
120	0.00	0.01	0.01	0.01	0.02	0.01

Table 2.4 Two-Hour Cumulative Rainfall Depths for Aspen

Cumulative Design Rainfall Distributions for Aspen Colorado						
2-yr, 1 hour precipitation = 0.47 5-yr, 1 hour precipitation = 0.64 10-yr, 1 hour precipitation = 0.77 25-yr, 1 hour precipitation = 0.95 50-yr, 1 hour precipitation = 1.09 100-yr, 1 hour precipitation = 1.23						
Time *minutes*	2-yr *(in)*	5-yr *(in)*	10-yr *(in)*	25-yr *(in)*	50-yr *(in)*	100-yr *(in)*
0	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.02	0.01	0.01	0.01
10	0.03	0.04	0.04	0.05	0.05	0.05
15	0.07	0.09	0.11	0.09	0.11	0.11
20	0.14	0.19	0.22	0.17	0.19	0.20
25	0.26	0.35	0.42	0.31	0.36	0.38
30	0.33	0.43	0.51	0.55	0.63	0.68
35	0.36	0.47	0.55	0.66	0.76	0.86
40	0.38	0.50	0.58	0.74	0.85	0.95
45	0.39	0.52	0.61	0.79	0.90	1.03
50	0.41	0.54	0.64	0.83	0.96	1.09
55	0.42	0.56	0.66	0.86	0.99	1.14
60	0.44	0.58	0.69	0.89	1.03	1.19
65	0.45	0.60	0.71	0.93	1.06	1.24
70	0.45	0.62	0.74	0.95	1.09	1.26
75	0.46	0.64	0.76	0.97	1.11	1.29
80	0.47	0.65	0.79	0.99	1.13	1.30
85	0.48	0.67	0.80	1.01	1.15	1.32
90	0.49	0.68	0.82	1.02	1.17	1.33
95	0.50	0.69	0.83	1.03	1.18	1.35
100	0.51	0.70	0.85	1.05	1.20	1.36
105	0.52	0.71	0.86	1.06	1.21	1.38
110	0.52	0.72	0.88	1.07	1.23	1.39
115	0.53	0.73	0.89	1.08	1.24	1.41
120	0.53	0.74	0.90	1.10	1.26	1.42

2.5 Snowmelt

The annual snowfall in the Aspen area can be as high as 150 to 200 inches. Snowmelt and refreezing can lead to many drainage problems in the winter and spring, including frost heave, freezing sewers, ice in street gutters, and inlet clogging. Therefore, **evaluation of snowmelt events can be helpful in selection of alternatives for snow management, determining snow storage, and is critical for determining capacities of stormwater quality controls**. However, snowmelt evaluations are not necessary at this time for development design in Aspen.

In some instances, it can be helpful to evaluate snowmelt with and without rainfall. Evaluation of snowmelt runoff depends on the snow-to-water ratio for fresh snow and the snow compact ratio for piled snow.

2.5.1 Snow Compact and Snow-to-Water Ratios

Once the snow is on the ground, it will settle under its own weight (largely due to differential evaporation) until its density is approximately 30% of water. Increases in density above this initial compression occur primarily by melting and refreezing, caused by temperatures above freezing or by direct solar radiation. The snow removal study for Berthoud Pass over Highway 40 reported that the compact ratio for piled snow is 43% (Guo 1999). Under different compact conditions, ten (10) inches of fresh snow can contain 0.10 to 4.0 inches of water, depending on crystal structure, wind speed, temperature, and other factors The Surface Drainage Master Plan for the City of Aspen suggests that **the snow-to-water ratio is set to be eleven (11) inches of fresh snow equivalent to one (1) inch of water** (Master Plan 2001).

2.5.2 Snowmelt Runoff Depth

For engineering practice, the energy budget equation is simplified to assume that daily snowmelt is proportional to the difference between the representative daily temperature and a base temperature *(*Viessman et. al. 1997).

$$P_s = K_s(T_m - 32)$$ **(Equation 2-2)**

Where,

P_s = snowmelt depth (inches of water),

K_s = degree-day snowmelt coefficient (inch/day-^{o}F) = 0.011 inch/day-^{o}F, and

T_m = maximum daily temperature (^{o}F).

To determine an appropriate value for Ks, analysis was conducted to calibrate Eq. 2-2 using the 3-year daily snow data recorded at the City of Aspen (Aspen Weather Observation, 2006 to 2008). The best-fitted value for Ks was found to be 0.011 inch/day-oF when using the daily maximum temperature.

2.6 Hydrology for Stormwater Quality

In 1972, the Federal Clean Water Act established the National Pollutant Discharge Elimination System (NPDES) program. Since 2000, the EPA has expanded the NPDES program to cover stormwater discharges. Since 1994, the City of Aspen has conducted sporadic water quality tests in the Roaring Fork River and increased enforcement of any illegal dumping into the river (Roaring Fork River Report 2008). Chapter 8 of this manual further explains how to prevent stormwater pollutants from reaching receiving waters in the City of Aspen.

There are a number of different types of precipitation/runoff events that have the potential to affect stormwater quality in Aspen. Typical types of events include:

- Summer rainfall/runoff event—consists of runoff, primarily from impervious surfaces during rainfall events that occur from May to October.
- Mid-winter snowmelt—Aspen can experience significant diurnal temperature fluctuations, even in winter, with temperatures far below freezing at night, warming to above the freezing point during the day. These events can be problematic from both flooding and water quality perspectives when inlets are obstructed by snow and ice or when little infiltration is possible due to frozen or saturated ground conditions. Water quality best management practices (BMPs) only function and provide treatment at a fraction of their full capability during winter.
- Spring runoff—generally beginning in April and progressing into May and June. The annual melting of the snowpack accumulated over the winter can produce large peak flows, especially given the significant snow-covered ski area south of the City, and snow stored in town along streets and in snow storage areas.
- Rain on snow—These events are more commonly evaluated for flooding potential rather than for water quality purposes; however, there are important water quality considerations for these events. When rain on snow occurs, performance of BMPs may be compromised if there is snow stockpiled in BMPs and/or because of saturated or frozen ground conditions.

In practice, the settlement process in a storage basin is the most economic and effective means to improve stormwater quality. Therefore the City has determined a volume of water that must be held in order to settle out pollutants. The water quality capture volume (WQCV) is defined as the detention storage volume to capture 80% of annual runoff volumes generated from the tributary catchment (ASCE WEF 1998). WQCV varies with respect to catchment imperviousness and rainfall patterns (Guo and Urbonas 2002). In preparation of this manual, the Western Climate Center provided the continuous daily snow-rainfall data recorded at the City of Aspen. The WQCV for the Aspen area was derived based on the analysis of more than 10,000 precipitation (rain and snow) events from January 1980 through December 2008.

The WQCV for Aspen ranges from 0.05 watershed inches (approximately 180 ft^3/acre) for a catchment with imperviousness of 20 percent up to 0.26 watershed inches (approximately 950 ft^3/acre) for imperviousness of 100 percent. The complete design chart illustrating the WQCV as a function of catchment imperviousness is provided in Chapter 8 - Water Quality.

2.7 References

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Chapter 3 – Runoff

3.1 Overview

The surface in a watershed is composed of pervious or impervious areas. The pervious surface is the area where water can readily infiltrate into the ground. The impervious surface is the area that produces direct runoff as soon as it rains. As urbanization occurs, impervious area increases. As a result, the total amount of runoff volume increases as well. In urban hydrology, the percentage of impervious area is the most sensitive parameter to the runoff generation.

Estimates of runoff flow rates and volumes for selected levels of protection provide the basis for the design of drainage facilities for the management of flood discharges and water quality in a drainage system. **This chapter provides criteria for design peaks and volumes and methods to calculate urban runoff generated in the Aspen area**. Methods described in this chapter include:

- the Rational Method applicable to watersheds less than 90 acres,
- the Colorado Urban Hydrograph Procedure (CUHP) developed for larger watersheds, and
- Storm Water Management Model (SWMM) Version 5 applicable to snowmelt runoff predictions or urban watersheds with on-site low impact treatments.

When the CUHP and SWMM models are used in tandem, they are referred to as CUHP/SWMM in this chapter.

3.2 Hydrologic Loss

Not all raindrops fall to the ground – some fall on vegetation and some is lost to evaporation. In addition, not all rainfall runs off – some is infiltrated in the soil and some is puddled and stored. The major hydrologic losses considered in the rainfall and runoff modeling techniques include *soil infiltration and depression loss.*

3.2.1 Soil Infiltration Loss

The penetration of water into the soil surface is called infiltration. Soil type is the most important factor in determining the infiltration rate. When the soil has a large percentage of well-graded fines, the infiltration rate is low. In some cases of extremely tight soil, there may be, from a practical standpoint, essentially no infiltration. The *Natural Resources Conservation Service* (NRCS or SCS) has classified soils into four hydrologic types as (SCS 1983):

Type A Soil—Soils having high infiltration rates such as sand and gravel.
Type B Soil—Soils having moderate infiltration rates such as loamy soils.
Type C and D Soil—Soils having very slow infiltration such as clay soils.

Figure 3.1 depicts the hydrologic soil group (HSG) locations in Aspen. If the HSG is not known, but the soil type is, please refer to Appendix B, Table 3.2, which lists common soils found in the Aspen area. Note that it is rare to find HSG Type A soils in the Aspen area.

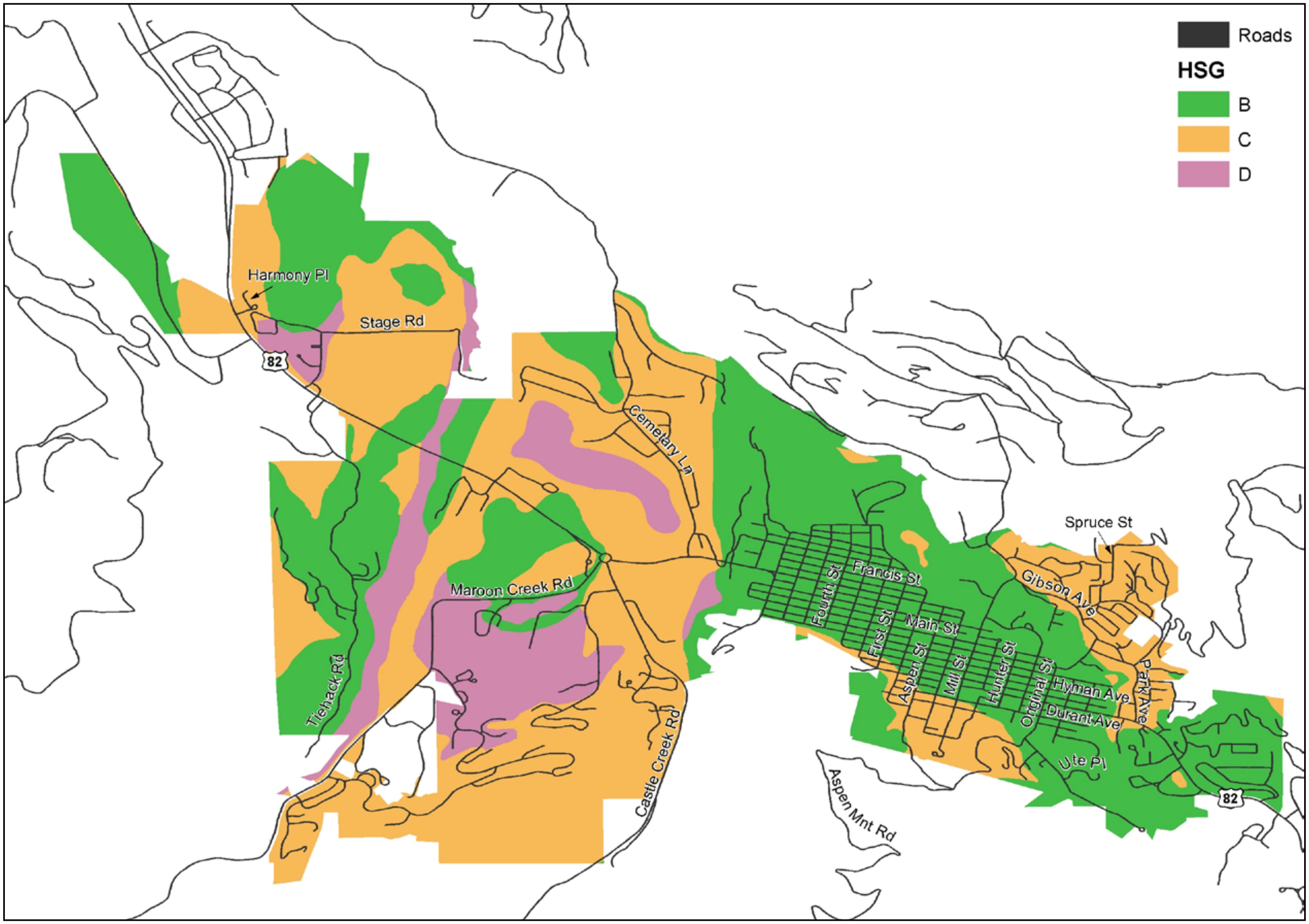

Figure 3.1 Natural Resource Conservation Service (NRCS) Soil Map for Aspen

An infiltration rate reflects the ability of the soil medium to absorb water. This parameter is usually given in inch per hour or millimeter per hour. Infiltration rates are described by a decay function with a high rate at the beginning of the event when the soil is dry, and a low rate when the soil becomes saturated.

Table 3.1 is recommended for design infiltration rates for use in CUHP and SWMM modeling, but is not needed in the Rational Method. When the watershed has several different types of soils, the representative infiltration rate can be determined as the area-weighted value.

Table 3.1 Infiltration Rates for Different Soil Groups (UDFCD 2001)

Soil Type	Initial Rate Inch/hr	Final Rate Inch/hr	Decay Coefficient 1/sec for CUHP	Decay Coefficient 1/hr for SWMM
A	5.0	1.0	0.0007	2.52
B	4.5	0.6	0.0018	6.48
C	3.0	0.5	0.0018	6.48
D	3.0	0.5	0.0018	6.48

3.2.2 Depression Loss

Depression losses account for the amount of water trapped in lowland areas, puddles, and potholes without running off. Depression loss is expressed as the lump sum of the entrapped water volume in inch per watershed. **Table 3.2** is a summary of the recommended depression capacity for use in CUHP/SWMM modeling. Depression losses are not needed for the Rational Method.

Table 3.2 Depression Losses for Various Land Uses (UDFCD 2001)

Land Cover	Range (inches)	Design Value (inches)
Large Paved Area	0.05-0.15	0.10
Flat Roofs	0.10 -0.30	0.10
Sloped Roofs	0.05-0.10	0.05
Lawn Grass	0.20- 0.50	0.03
Wooded Area	0.20- 0.60	0.40
Open Fields	0.20-0.60	0.40
Sandy Area		0.02
Loams		0.15
Clay		0.10

3.3 Selection of Runoff Prediction Methods

The **first step** in determining the flows at a design point is to obtain the representative topographic map of the tributary watershed and to **define the boundaries of all the relevant drainage basins**. Basins to be defined include all basins tributary to the area of study and sub-basins within the study area. Field checks and possibly field surveys must be completed before the preliminary stage of drainage planning. Flow diversions and irrigation canals must be also be investigated because they can transfer stormwater across the watershed boundaries.

All hydrologic methods have application limitations. The **second step, selection of runoff prediction method**, depends on design needs and watershed size. **For determining peak flows from watershed areas less than 90 acres, the Rational Method should be used.**

In large watersheds (>90 acres) the rainfall-runoff process is more complicated because hydrologic losses vary more and should not be simplified as they are in the Rational Method. Therefore, **for large watersheds hydrographs are needed and can be computed using CUHP** (Colorado Urban Hydrograph Procedure, recommended by UDFCD) **or SWMM** (Storm Water Management Model, recommended by the EPA). SWMM can also be used to determine snowmelt runoff hydrographs.

For examples, the Rational Method is sufficient for culvert sizing to pass the design peak flow from a watershed less than 90 acres. CUHP is required for detention basin designs because the procedure involves hydrograph routing. And SWMM can be used to study the alternatives for snow removal and redistribution along the street in the downtown area of the City of Aspen.

3.4 Rational Method

The Rational Method is a simplified hydrologic method developed for peak flow prediction in basins <90 acres only. It is applicable to street inlet sizing, sewer drain design, and single lot developments in the Aspen area. The Rational Method states (Kuichling, 1889):

Peak Flow **=** $Q_P = CIA$ **(Equation 3-1)**

Runoff Volume = $V_R = \frac{C}{12} P\,A$ **(Equation 3-2)**

Rainfall Depth **=** $P = \frac{T_d}{60} I$ **(Equation 3-3)**

in which,

Q_p = peak flow (peak runoff) in cubic feet per second (cfs),

I = rainfall intensity in inch/hour,

A = drainage area in acres,

C = runoff coefficient,

V_R = runoff volume in acre-ft,

P = rainfall depth in inches, and

T_d = rainfall duration (or time of concentration, Tc) in minutes.

The flow (Qp) must be calculated at each design point, starting at the upstream end of the watershed and proceeding downstream. Each watershed must be analyzed for the minor and major storm events. In most cases the minor event is the 10-year storm and the major event is the 100-year storm (see Chapter 5 – Detention for more details).

As indicated in Equation 3.1, the basic input parameters for the Rational Method include *watershed area*, *runoff coefficient*, and *design rainfall intensity***.** The rainfall intensity-duration–frequency (IDF) formula is applied to determine rainfall intensity (I). The rainfall IDF formula for the Aspen area can be found in Chapter 2 – Rainfall and is not covered in a subsection below.

The general procedure for Rational Method calculations for a single basin is described below with accompanying sections of this manual in *italics*.

1. Delineate the basin boundary. Measure its area. *Section 3.3.1*

2. Identify the soil type(s). *Figure 3.1*

3. Determine the runoff coefficient, C. *Section 3.4.2*

4. Define the flow path from the upper-most portion of the basin to the design point. This flow path should be divided into reaches of similar flow type (e.g., overland flow, shallow swale flow, gutter flow, etc.). The length and slope of each reach should be measured. *Section 3.4.3*

5. Determine the time of concentration, Tc, for the catchment. *Section 3.4.3*

6. Find the rainfall intensity, I, for the design storm using the calculated Tc and the rainfall intensity-duration-frequency curve. *Chapter 2, Section 2.3*

7. Calculate the peak flow rate from the watershed. *Equation 3-1*

8. When calculating 1-hour design storm volumes, $t_c=t_d=60$ minutes. *Equation 3-2.*

3.4.1 Watershed Area

The watershed drainage boundary lines are determined by grading and slopes - the pavement slopes, locations of downspouts and inlets, paved and unpaved yards, grading of lawns, and many other features found on the urban landscape. The tributary area to a design point can be outlined on the topographic map using Geographic Information System (GIS), or AutoCAD-based methods. The area may also 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 coarse to distinguish the direction of flow. An urban watershed is often developed for multiple purposes. Therefore, it can be divided into smaller sub-areas based on the land uses and types of soils.

3.4.2 Runoff Coefficients and Percent Imperviousness for Land Uses

For convenience, the runoff coefficient, *C*, is derived to represent the ratio of runoff to rainfall volumes during the event. The determination of *C* mainly depends on the soil type, watershed imperviousness and storm event frequency.

The surface of a watershed is composed of pervious or impervious areas. As urbanization occurs, hard (impervious) surfaces increase, decreasing the amount of precipitation that infiltrates and increasing the amount that runs off. Impervious areas, A_i, in the tributary area can be determined based on the site plan, including roofs, sidewalks, drives, etc. The overall imperviousness of the drainage basin is calculated by dividing the impervious area in the drainage basin by the total area of the drainage basin.

Gravel parking areas, storage areas, and access drives as proposed on site improvement plans, should be analyzed as impervious surface. This is due to a history of gravel areas being compacted or paved over time by property owners and the resulting adverse impacts on the stormwater management facilities and adjacent properties.

As stated earlier, drainage basins can be divided into smaller sub-areas based on the land uses and types of soils. For mixed land uses, the area-weighted method is recommended to derive the representative runoff coefficient for the entire watershed.

For determination of *C,* identify the hydrologic soil group of soils within the basin and the imperviousness of the basin. Use the tables from UDFCD Urban Storm Drainage Criteria Manual Volume 1 copied below to determine the runoff coefficient for the appropriate storm event.

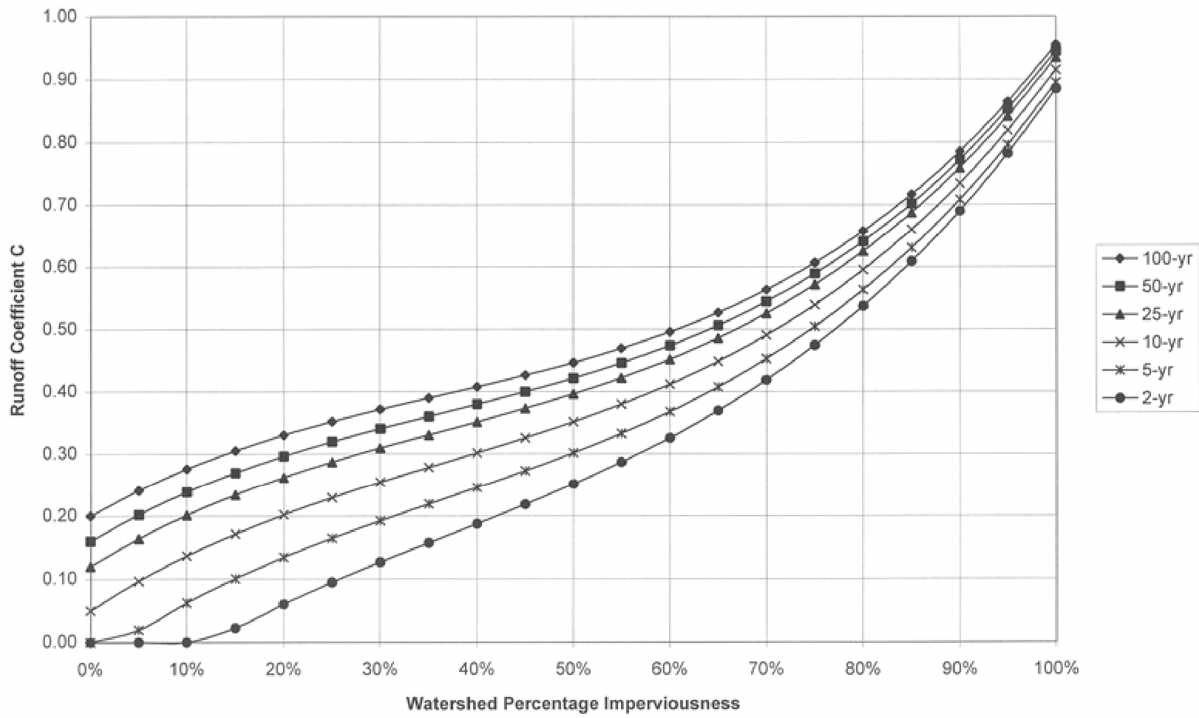

Figure 3.2 – Runoff Coefficients for NRCS Hydrologic Soil Group A

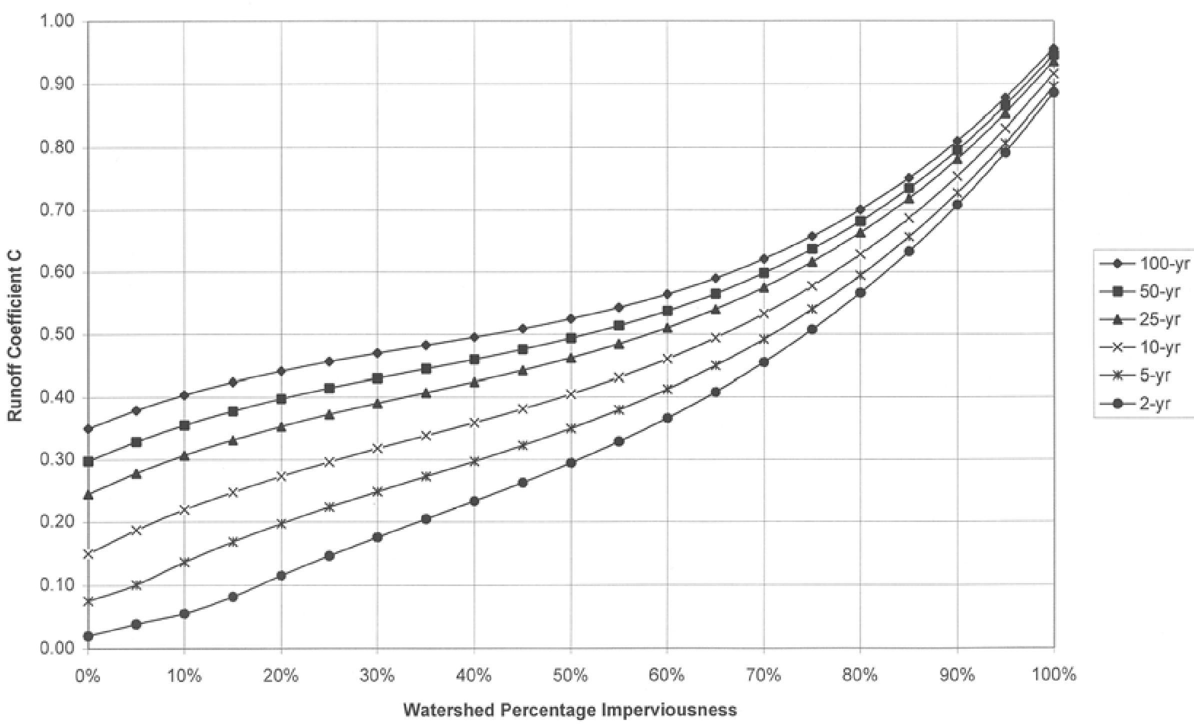

Figure 3.3 – Runoff Coefficients for NRCS Hydrologic Soil Group B

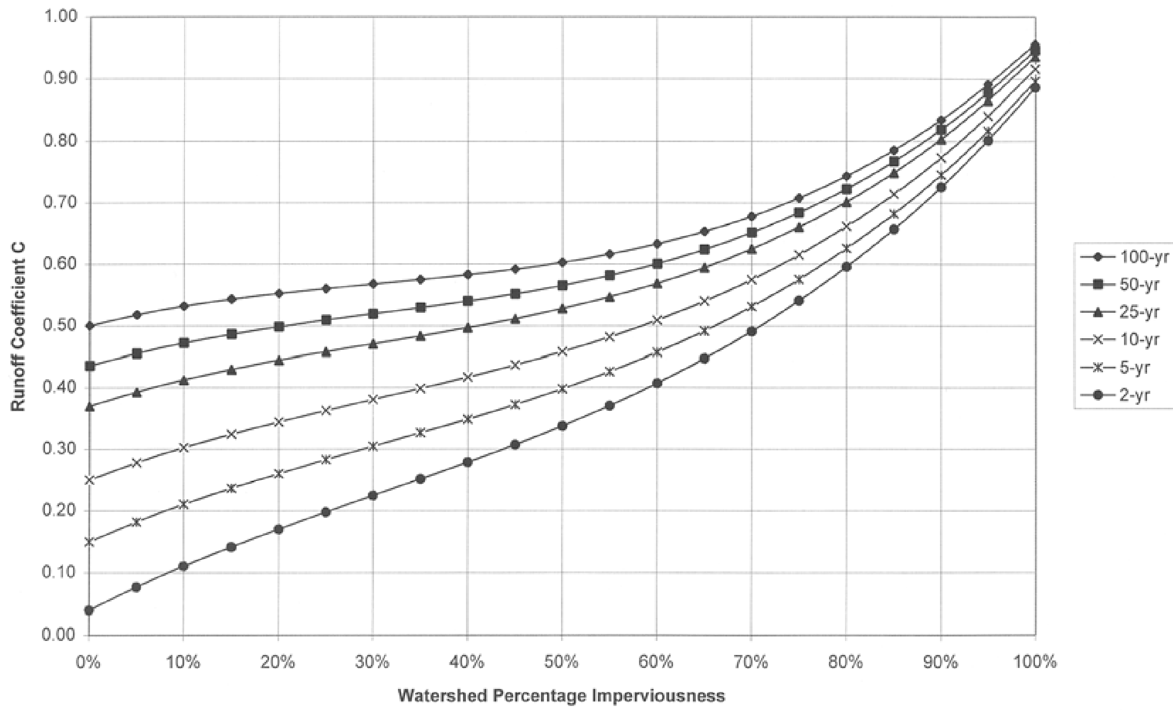

Figure 3.4 – Runoff Coefficients for NRCS Hydrologic Soil Groups C and D

3.4.3 Time of Concentration

The design rainfall duration used in the Rational Method is set to be the flow time required for runoff to flow through the longest waterway (starting at the most hydraulically distant point) within the watershed. This flow time is termed *the time of concentration* of the watershed. The longest waterway starts from the most upstream boundary of the watershed to the outlet or design point. A waterway can be divided into reaches: the *overland flow reach*, and any number of *channel flow reaches*. The time of concentration of the watershed is the cumulative flow times through the reaches.

3.4.3.1 Overland Flow Time

The water velocity of overland flow is a function of watershed slope and waterway roughness. There are many empirical formulas developed for estimating the overland flow time. For an urban setting, the Airport formula is recommended for the calculation of overland flow time as (McCuen et al 1984):

$$T_o = \frac{0.395(1.1 - C_5)\sqrt{L_o}}{S_o^{0.33}} \qquad \textbf{(Equation 3-4)}$$

in which,

T_o = overland flow time in minutes,

L_o = overland flow length in feet,

S_o = overland slope in ft/ft, and

C_5 = 5-year runoff coefficient.

The maximum length for overland flow is up to 300 feet in a developed area and 500 feet in a rural area. Development is symbolized by street curbs, gutters and inlets. Under a rural condition, stormwater flows through natural depressions, turf strips and grass swales that significantly slow down the flow. As a result, the overland flow time in a rural area is longer.

3.4.3.2 Channel Flow Time

Channel flow time (or concentrated flow time) is the travel time in any defined form such as swales, gutters, channels, or the storm sewer. Channel flow time should be calculated separately for each reach that demonstrates different hydraulic properties such as slopes or material lining. The *SCS upland method* was developed to estimate the flow time through shallow swale flows. It is based on flow velocity through a swale.

$$T_f = \frac{L_f}{60V_f} \quad \textbf{where} \quad V_f = K\sqrt{S_f} \quad \textbf{or} \quad T_f = \frac{L_f}{60 * K\sqrt{S_f}} \qquad \textbf{(Equation 3-5)}$$

in which,

T_f = flow time in minutes,

L_f = flow length in feet,

V_f = flow velocity in feet/second,

S_f = reach slope in ft/ft, and

K = conveyance coefficient as described in **Table 3.3** (Guo 2006).

Table 3.3 Conveyance Coefficients for SCS Upland Method

Linings for Conveyance	Conveyance Coefficient
Meadow (rough bushes)	2.5
Tillage (crop fields, mountain vegetation)	4.5
Lawn (turf strip, gravel pavement)	7.0
Bare Soils (unlined ditches)	10.0
Grass Lined Swale (grass ditches)	15.0
Paved Water Way (street gutters)	20.0

3.4.3.3 Time of Concentration

The **computed time of concentration, T_c,** is the sum of the overland and channel flow times.

$$T_c = T_o + T_f \qquad \textbf{(Equation 3-6)}$$

The computed time of concentration is sensitive to the overland flow length. To be conservative, the time of concentration to be used in design in the City of Aspen is set to be the smaller between the computed and regional times of concentration. The **regional formula for time of concentration** is (UDFCD 2001, CCHCDDM 1999):

$$T_R = 10 + \frac{L}{180} \qquad \textbf{(Equation 3.7)}$$

in which T_R = regional time of concentration in minutes, and L = total waterway length in feet.

In no case should a Tc be less than 5 minutes in the City of Aspen. If the computed or regional time of concentration calculations indicate a lesser time, use 5 minutes instead.

For a small urban lot in the City of Aspen, the time of concentration is mainly dominated by the overland flow. For convenience, **Figure 3.5** is the plot to estimate the overland flow time using Equation 3-6 with C_5 =0.88 for paved flow path. Note that the minimum time of concentration for use in Aspen is 5 minutes.

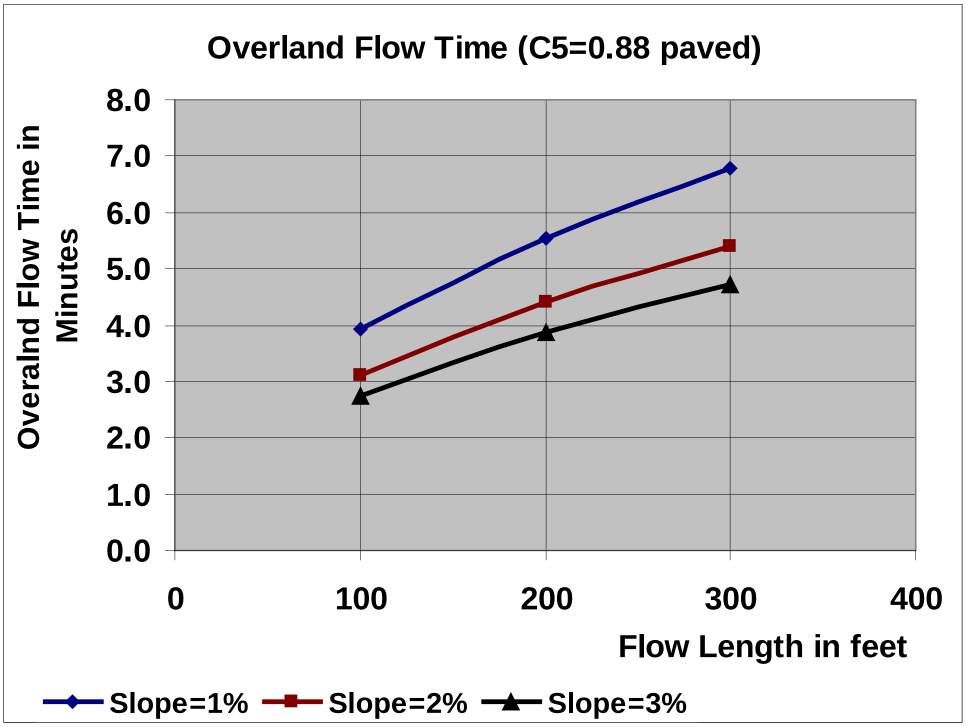

Figure 3.5 Approximate Overland Flow Times for Small Lots

3.4.4 Example Using Rational Method

A city block located in the City of Aspen is being redeveloped. The lot size is 350 ft by 500 ft. The land use proposed for this lot consists is 20% commercial at street corners and 80% of the lot is proposed to be single family residences. The ground elevations at four corners of this lot are marked in **Figure 3.6**. The project needs to determine the 10-year peak discharge released to the inlet.

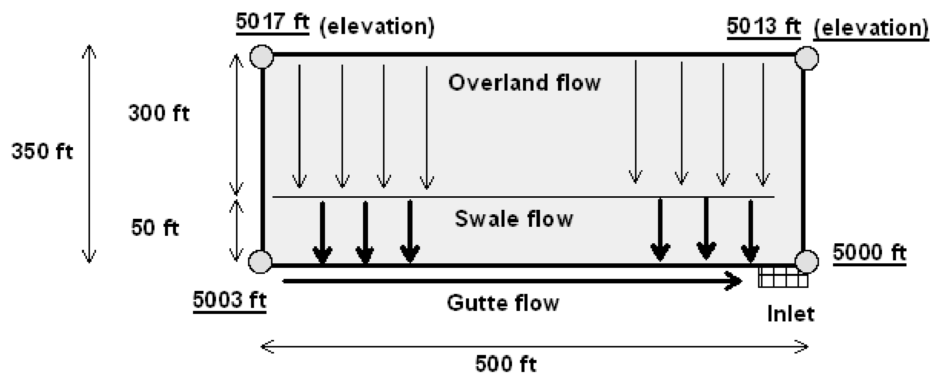

Figure 3.6 Example Watershed for Peak Flow Calculation

Solution:

Using hydrologic soil group B and an imperviousness of 70%, the runoff coefficient for this subdivision is:

$C_{10} = 0.54$

In order to calculate the overland flow time, the required 5-yr runoff coefficient is computed as:

$C_5 = 0.49$

The slope for the overland flow is calculated as:

$$S_o = \frac{5017 - 5003}{350} = 0.04$$

The overland flow time is calculated for the urban maximum allowable length of 300 ft using C_5=0.49 as:

$$T_o = \frac{0.393(1.1 - 0.49)\sqrt{300}}{0.04^{0.33}} = 12.0 \text{ minutes}$$

Before the overland flow reaches the street gutter in this example, the flow time through the additional waterway length of 50 feet is calculated using, Equation 3-8, the SCS upland method with K = 20 because of the paved surface.

$$T_1 = \frac{50}{60 \times 20\sqrt{0.04}} = 0.21 \text{ minutes}$$

The slope for the flow line along the street gutter is calculated as:

$$S_2 = \frac{5003 - 5000}{500} = 0.006$$

The gutter flow time is calculated as:

$$T_2 = \frac{500}{60 \times 20\sqrt{0.006}} = 5.38 \text{ minutes}$$

The computed time of concentration is the sum of the flow times as:

$$T_c = 12.0 + 0.21 + 5.38 = 17.6 \text{ minutes}$$

As a check, the regional flow time through this subdivision is:

$$T_R = \frac{350 + 500}{180} + 10 = 14.7 \text{ minutes}$$

Because 14.7 minutes is greater than the minimum 5 minutes, the accepted time of concentration for the project is:

$$T_d = 14.7 \text{ minutes}$$

From **Chapter 2 Rainfall** of this manual, the 10-yr one-hr precipitation depth is P_1= 0.77 inches for the Aspen area. The 10-yr rainfall intensity, I_{10}, and peak runoff, Q_{10}, are calculated using Equations 2-1 and 3-1 respectively, as:

$$I_{10} = \frac{88.8 \times 0.77}{(10+14.7)^{1.052}} = 2.34\ inch/hr$$

$$Q_{10} = 0.54 \times 2.34 \times (350 \times 500)/\ 43560 = 5.08\ cfs$$

3.4.5 Design Flow for Multiple Sub-Areas

Hydrologic homogeneity is one of the basic assumptions for small watershed hydrology. If the land uses or soil types in a watershed vary from one area to another, then it is necessary to divide the watershed into sub-areas. Each sub-area should have its own outlet that is termed "node" or "design point". All nodes shall then be connected together by swales, street gutters, sewers, or roadside ditches that are often referred to as "link". A node-link schematic represents the flow connectivity through the watershed.

The flow process through multiple subareas starts from the most upstream subarea to accumulate the flow time through the drainage network. At the n-th node on the waterway, the accumulated contributing area is:

$$(A_e)_n = C_n A_n + \sum_{i=1}^{i=n-1} C_i A_i \qquad \textbf{(Equation 3.8)}$$

The accumulated travel time through the drainage network is:

$$(T_c)_n = (T_c)_{n-1} + \frac{L_n}{60V_n} \qquad \textbf{(Equation 3.9)}$$

in which,

A_e = effective contributing area in acres,

T_c = accumulated time of concentration in minutes through the waterway system,

L = waterway length in feet,

V = flow velocity in feet/sec ,

i = i-th node upstream of the design point, and

n = n-th node at the design point.

When several links come to a node, the design rainfall duration or time of concentration at the node is the longest flow time among all incoming links. Knowing the contributing area and flow time, the peak discharge can be predicted by the Rational Method.

Example: Calculating Design Flow Through Multiple Subareas
As illustrated in **Figure 3.7**, the watershed is divided into three subareas. The sewer system is designed to pass the 10-year peak flow. The watershed parameters for these three subareas are summarized in **Table 3.4**. Determine the 10-year peak discharge at Point B.

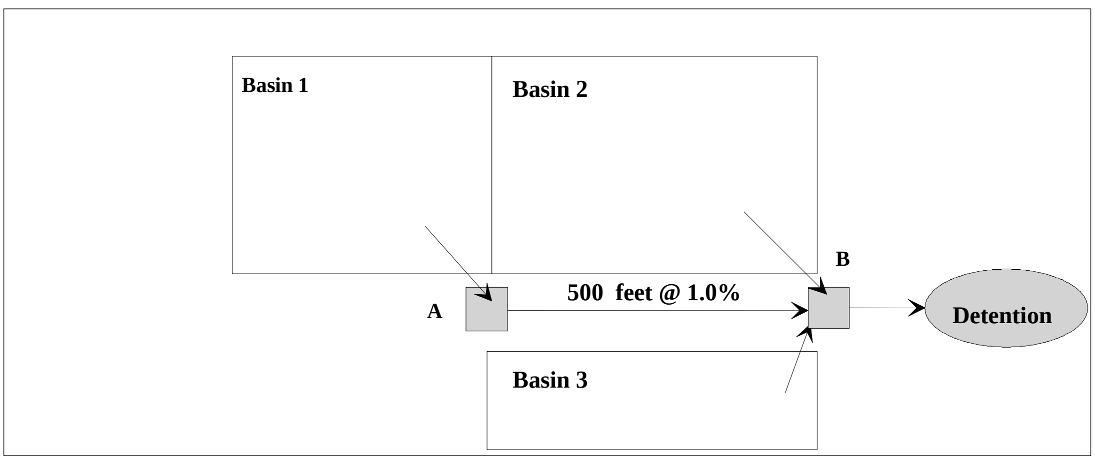

Figure 3.7 Layout for Multiple Subareas

Table 3.4 Parameters for Multiple Subareas

Subarea	Area (acres)	C	Tc (min)
1	2	0.55	15
2	5	0.65	22
3	1.5	0.81	12

Figure 3.7 indicates that there are three flow paths to reach Point B. Their flow times are:

From Basin 2: T_2 = 22 minutes
From Basin 3: T_3 = 12 minutes
From Basin 1: The flow time shall count for the time of concentration of Basin 1, and the flow time from Point A to B through the street.

According to the SCS upland method, the conveyance parameter for the paved gutter flow is 20.0 on a slope of 0.01. Using Equation 3-5, the flow time from Subarea 1 to Point B is the sum of the time of concentration of Subarea 1 plus the flow time through the 500-ft gutter as:

$$T_1 = 15 + \frac{500}{60 \times 20\sqrt{0.01}} = 19.17 \text{ minutes}$$

At Point B, the design rainfall duration (time of concentration) is the longest one among three incoming flow paths as:

$T_d = \max(T_1, T_2, T_3) = \max(19.17, 22, 12) = 22$ minutes.

The 10-year design rainfall intensity for this case is computed using Equation 2-1 as:

$$I_{10} = \frac{88.8 \times 0.77}{(10+22)^{1.052}} = 1.78\ inch/hr$$

$I = \frac{29 \times 1.2}{(10+22)^{0.789}} = 2.26$ inch/hr

According to Equation 3-18, the effective area, CA product, at Point B is calculated as:

$A_e = 0.81 \times 1.50 + (0.55 \times 2.0 + 0.65 \times 5.0) = 5.7$ *acres*

As a result, the 10-year peak discharge is calculated using Equation 3-1 as:

$Q = 2.26 \times 5.7 = 12.6$

Q= 1.78 x 5.7 = 10.17 cfs

3.4.6 Excel-based Computer Model – RATIONAL

RATIONAL is an excel-based computer model developed for the procedure described in this manual. The program, RATIONAL, is available from the website of the City of Aspen. RATIONAL is featured with the capabilities of computing the average runoff coefficient using the area-weighted method, time of concentration for multiple reaches, design rainfall intensity and peak flow using the Rational Method (Guo, Urbonas, MacKenzie, and Lloyd 2007).

3.5 CUHP for Rainfall-Runoff Simulation

3.5.1 Background

The Colorado Urban Hydrograph Procedure (CUHP) is a synthetic unit hydrograph method that was developed and calibrated by the rainfall-runoff data collected from the Denver and Boulder metropolitan areas in Colorado. CUHP has been supported and accepted as the official flood prediction method by the UDFCD in Denver Colorado. CUHP2005 is an excel-based computer program that provides numerical automation using CUHP to generate hydrographs at design points. These computed hydrographs can be saved into a text file that can be imported into EPA SWMM Version 5 (SWMM5) for channel and reservoir routing. Both CUHP2005 and SWMM5 computer models have been widely accepted and applied to stormwater simulation studies in the State of Colorado. On-line documentation is available for both models as follows:

- **hthttp://www.udfcd.org/downloads/down_disclaimer.htm**

http://www2.epa.gov/water-research/storm-water-management-model-swmm These models are free and can be downloaded at the web addresses above. Because both of these models are well documented with complete user manuals, this chapter will only focus on model inputs for applications in the City of Aspen rather than the equations and numerical methods used in the models.

3.5.2 CUHP Input Parameters

CUHP is an empirical procedure to predict runoff hydrographs using the synthetic unit hydrograph method (Snyder 1938, Sherman 1932). A CUHP2005 computer model is composed of rainfall data, sub-area hydrologic parameters, and options for various printout format, and user-defined practices. Details are discussed as follows:

3.5.2.1 Design Rainfall

CUHP requires the input of a design rainfall distribution expressed as incremental rainfall depths in inches with a pre-selected time interval such as 1, 5, 10, or 15 minutes. All the 2-hr design rainfall curves discussed in Chapter 2 – Rainfall can be generated by CUHP2005 using the one-hr rainfall depth. Of course, the user has the option to enter an observed rainfall distribution with duration up to 6 hours or 72 time steps with a time interval of 5 minutes. For most urban studies, the rainfall duration for the unit hydrograph should be 5 minutes. However, such duration may be increased to 10 or 15 minutes for larger watersheds or decreased to one (1) minute for smaller watersheds.

3.5.2.2 Watershed Input Parameters

CUHP can accept as many watersheds in one computer run as the user wishes. A large watershed should be divided into smaller watersheds between 100 to 150 acres in size. As a rule of thumb, the watershed length to width ratio shall not exceed 4:1. For each watershed, the following input data needs to be entered:

Horton's Infiltration Rates (see **Table 3.1**)

Pervious and Impervious Depression in inches (see **Table 3.2**)

Watershed area (square miles)— the tributary area is used to generate runoff hydrograph.

Length of Waterway (miles)—the length of waterway should be the longest flow path from the most upstream boundary to the outlet point. It shall be measured by following the waterway meandering pattern.

Length to Centroid (miles)—the centroid of a watershed is the geometric center that can be measured based on the area's shape and size. Projecting the area-centroid laterally onto the waterway locates the waterway centroid. From the waterway centroid to the outlet gives the length to centroid.

Percent Impervious (%)—the portion of the watershed's surface area that is impervious or paved. Percent impervious is expressed as a percent value between 0 and 100.

Waterway Slope in ft/ft -- Waterway slope is an important and sensitive factor when calculating the time parameters used in CUHP. A waterway shall be divided into several reaches, according to the uniformity of the invert slope that is calculated as:

$$S_i = \frac{H_i}{L_i} \qquad \textbf{(Equation CUHP-1)}$$

in which S_i = slope for i-th reach, H_i = vertical drop in elevation, and L_i = length of reach. Equation CUHP-1 shall be applied to all reaches in order to produce the length-weighted slope as:

$$S_0 = \left[\frac{1}{L}\sum_{i=1}^{i=n}\left(L_i S_i^{\ 0.24}\right)\right]^{4.17} \qquad \textbf{(Equation CUHP-2)}$$

in which S_o = waterway representative slope in ft/ft, and L = total length of waterway. Equation CUHP-2 is operated with topographic maps that do not reveal the drops and lining roughness through the waterway. As recommended in **Figure 3.8**, when the measured slope is steeper than 4%, it is subject to a correction. For instance, 5.7% shall be entered into CUHP for the measured slope of 8%, according to **Figure 3.8**.

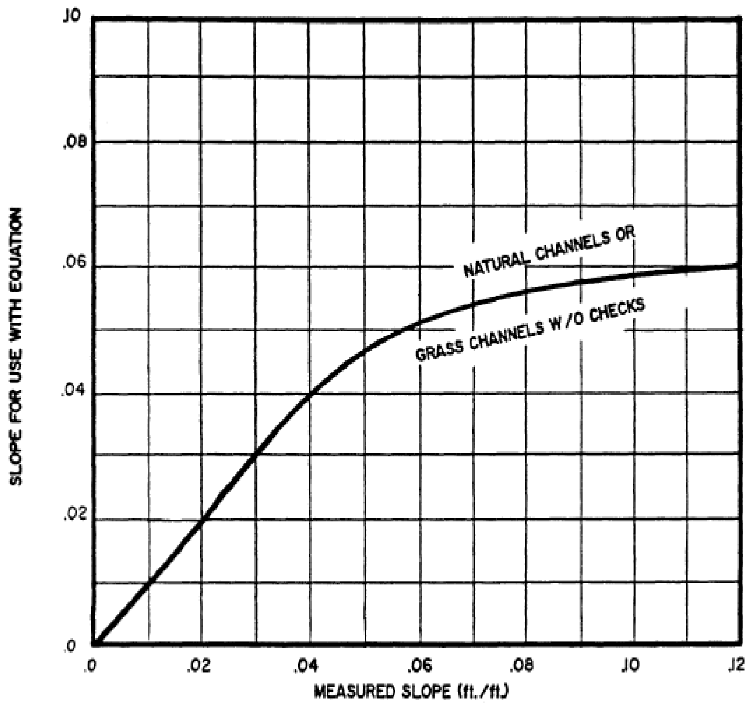

Figure 3.8 Corrections on Measured Waterway Slope

3.5.2.3 User Option to Reshape Unit Graph

The program, CUHP2005, computes the time to peak coefficient, C_t , and peak parameter, C_p, according to the watershed area and imperviousness percentage. However, the user has an option of overriding the computed values for these parameters. The shape of the unit hydrograph also relies on proportioning the widths at 50% and 75% of the unit hydrograph peak. The proportioning is based on 0.35 of the time-width at 50% of peak being ahead of the time to peak and 0.45 of the time-width at 75% of peak being ahead of the time to peak. If the user has derived unit hydrographs from other sources, CUHP allows the user to reshape the unit hydrograph according to the user-defined time-widths.

3.5.2.4 User Option to Define Cascading Flows for Low Impact Layout

The CUHP2005 computer model recognizes the effects of cascading flows in which the unconnected impervious areas drains onto porous area for additional infiltration effects. With the concept of cascading flow, a typical urban watershed, as shown in **Figure 3.9** may have four separate surface runoff components as:

1. Impervious area directly connected to the drainage system (DCIA).
2. Impervious area that drains onto or across pervious surfaces (UIA).
3. The pervious area receiving runoff from impervious portions (RPA).
4. The separate pervious area (SPA) not receiving runoff from impervious surfaces.

For modeling convenience, two design variables are defined as:

$$D = \frac{DCIA}{IA}$$ **(Equation CUHP-3)**

$$R = \frac{RPA}{PA}$$ **(Equation CUHP-4)**

IA = total impervious area, DCIA = directly (hydraulically) connected impervious area, D= fraction of the total impervious area directly connected to the drainage system, RPA = receiving pervious area, PA = total pervious area, R = fraction of pervious area receiving disconnected impervious runoff, SPA = separate pervious area, and UIA = unconnected impervious area.

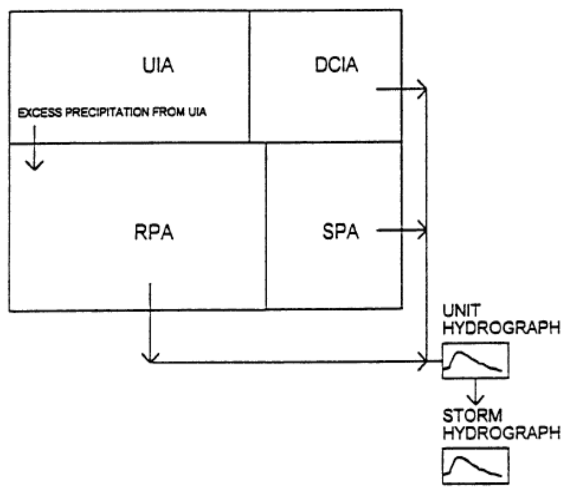

Figure 3.9 Illustration of Cascading Flow Layout

The following watershed parameters are also optional inputs and are available to the user to account for the effects of directly connected/disconnected impervious areas:

- DCIA (directly connected impervious area) is the input variable that specifies the on-site drainage pattern. Option 1 represents the Standard Management Practice (SMP) in which the impervious and pervious areas are independently, separately drained onto the street. Option 2 represents the Best Management Practice (BMP) in which the impervious area drains onto porous area before the street.

- D is the variable to define the fraction of the total impervious area directly connected to the drainage system. It ranges from 0.01 to 1.0.

- R is the variable to define the fraction of total pervious area receiving runoff from the disconnected impervious areas. It ranges from 0.01 to 1.0.

Although CUHP provides the default values for R and D used in SMP and BMP, the user has the option of replacing the default with the user-defined values.

3.5.3 File Management

CUHP2005 provides three options to structure the printout in a spreadsheet format, including summary for watersheds, unit hydrographs, and storm hydrographs respectively. CUHP2005 is a hydrograph generator that does not have any hydrologic routing capability. The user has options to save all the predicted hydrographs in a text file and then transfer this file into the EPA SWMM5 computer model as an input file for various hydrologic routing features. Details can be found in CUHP2005 user manual.

3.6 EPA SWMM for Rainfall-Snowmelt Runoff Simulation

3.6.1 Background

SWMM was first developed in 1971 and has undergone several major upgrades since then. The current edition, EPA Storm Water Management Model-Version 5 (SWMM5), is a complete re-write of the previous release. Running under Windows, SWMM5 provides an integrated environment for editing study area input data; running hydrologic, hydraulic and water quality simulations; and viewing the results in a variety of formats (Rossman 2005). These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses.

As stated in the user manual, SWMM5 is a dynamic rainfall-runoff simulation model used for single event or long-term simulation of rainfall and snowmelt runoff for both quality and quantity studies. The runoff component of SWMM5 operates on a watershed area that receives precipitation and generates runoff and pollutant loads. The routing portion of SWMM5 transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM5 tracks the quantity and quality of runoff generated within each watershed, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

3.6.2. SWMM Input Parameters

A SWMM5 computer model consists of four basic components: (1) Time Variables, (2) Climatology Parameters, (3) Watershed Parameter, and (4) Network for Hydrologic Routing. SWMM accepts interface files to transfer pre-processed rainfall or runoff data sets into a SWMM computer model to speed up simulations. For instance, the option of Rainfall Interface File is used to load a long term rainfall or snowfall record into the SWMM computer model for simulation studies.

It is important to understand that a CUHP/SWMM in-tandem model does not need Climatology and Watershed Parameters in the SWMM model because the pre-processed CUHP hydrographs can be directly transferred into the SWMM model for Hydrologic Routing. Details of interface files (Option of Inflow) can be found in SWMM User Manual (Rossman, 2005).

3.6.2.1 Time Variable

SWMM follows the clock time to conduct rainfall and runoff analyses. The user must specify the beginning and the end of the storm event and the time steps used for computation and reporting.

3.6.2.2 Climatology (Not needed if CUHP is used.)

Rain Gage is the object for the user to define the design rainfall distribution that can be expressed in incremental volume or intensity for each time step.

Air Temperature is used when simulating snowfall and snowmelt processes during runoff calculations. For rainfall and runoff simulations, temperature data are not required.

Evaporation can occur to standing water on watershed surfaces, for subsurface water in groundwater aquifers, and for water held in storage units such as detention basins. Evaporation rates can be prescribed as constant value, a set of monthly average values as shown in **Table 3.5**, or a user-defined time series of daily values.

Table 3.5 Monthly Evaporation Rates inch/day
(Observed in Chatfield Reservoir, Denver, Colorado)

Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
0.04	0.04	0.06	0.12	0.2	0.28	0.30	0.30	0.25	0.16	0.08	0.04

Wind Speed is an optional climatic variable that is only used for snowmelt calculations. SWMM can use either a set of monthly average wind speeds or wind speed data contained in the same climate file used for daily minimum/maximum temperatures.

Snowmelt Parameters are climatic variables that apply across the entire study area when simulating snowfall and snowmelt. They include: (a) the air temperature, such as 32F^o, at which precipitation falls as snow (b) heat exchange properties of the snow such as antecedent temperature Index (ATI) and negative melt ratio, and (c) surface study area elevation, latitude, and longitude correction. **Figure 3.10** is the summary of the recommended values for snowmelt studies for the Aspen area.

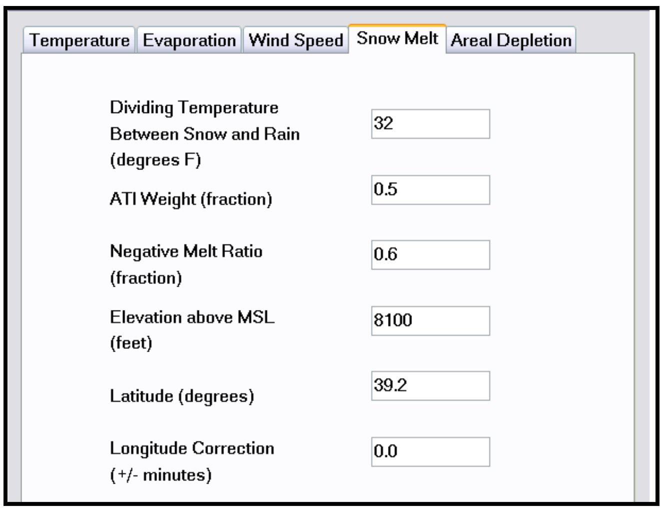

Figure 3.10 Recommended Values for Design Variables used Snowmelt Studies

Areal Depletion refers to the tendency of accumulated snow to melt non-uniformly over the surface of a watershed. As the melting process proceeds, the area covered by snow gets reduced. This behavior is described by an Areal Depletion Curve that plots the fraction of total area that remains snow covered against the ratio of the actual snow depth to the depth at which there is 100% snow cover.

Snow Pack Parameters characterize the buildup, removal, and melting of snow over three types of storage areas within a watershed, including (a) the plowable snow pack area as a user-defined fraction of the total impervious area, (b) the impervious snow pack area covers the remaining impervious area of a watershed, and (c) the pervious snow pack area encompasses the entire pervious area of a watershed.

3.6.2.3 Watershed Input Parameters (Not needed if CUHP is used.)

Based on the land uses and types of soils, a watershed is divided into smaller subareas for stormwater analyses. Among these subareas, the hydrographs are routed and combined along the drainage network. For each subarea, the following input data need to be entered.

Subarea (in acres) is the tributary area used to generate runoff hydrograph and pollutant loadings.

Width of Subarea (in feet) is referred to the collector channel across the KW plane. As a rule of thumb, the width of the KW plane is approximated to be twice the length of the waterway (Guo and Urbonas 2009).

Subarea Slope (in percent) represents the average slope on the KW plane. The transverse slope of the watershed is a good approximation (Guo 1998).

Percent Impervious represents the imperviousness percentage of the subarea between 0 and 100.

Manning's N's for pervious and impervious surfaces are used to calculate flood wave movement. Overland flow is a two-dimensional sheet flow that is significantly affected by the surface resistance. As recommended, the value of 0.25 is used for pervious surface, and 0.025 is for impervious surface.

Pervious and Impervious Depression in inch (see **Table 3.2**)

Percent of Zero-Imperv is the variable that represents the percent of impervious area with no depression storage such as roof area in a subarea. A value of 25% is recommended.

Subarea Routing represents the arrangement of cascading flows on the KW plane. IMPERV means the upper porous area draining onto the lower impervious area. PERV is the option to drain the upper impervious area onto the lower porous area, and OUTLET implies that the pervious and impervious areas are separately drained or no cascading flow at all.

Percent Routed is the variable that quantifies the percent of the upper area draining onto the lower area when cascading inlet option is selected.

Soil Loss Parameters are user-defined infiltrating rates used in Horton's formula (see **Table 3.3**)

Downstream Junction Node is the object to represent the location where the hydrograph generated from a subarea is placed. Between two junction nodes is a channel or a pond. A node (similar to a manhole) is described by its invert elevation and the maximum and initial water depths if the node is surcharged. In case of flooding, the user can specify the ponded area in sq feet atop the junction.

3.6.3 Drainage Network for Hydrologic Routing

Hydrologic routing schemes are numerical methods to transport hydrographs through a channel or a reservoir by solving the equation of continuity. A kinematic wave (KW) routing method ignores the backwater effect while a dynamic wave (DW) routing method takes into consideration the flow acceleration and the storage effects under the backwater profiles. In comparison, DW calculations are sensitive to the time increment. The rule of thumb is to select a short time step such as 1 to 60 seconds for DW calculations and 300 seconds or longer for KW calculations. To be conservative, the KW model is recommended for stormwater planning studies while the DW model can be accepted for on-site stormwater designs and detailed studies.

Hydrologic routing schemes in SWMM5 are classified into conveyance routing, flow diversion, and detention basin routing.

3.6.3.1 Conveyance Flow Routing for Channels and Pipes

In an urban area, flows are collected and conveyed by streets, sewers, roadside ditches, and channels. As illustrated in **Figure 3.9**, these conveyance facilities are modeled as:

Case 1: Street and Sewer Section representing a street with an underground sewer,
Case 2: Culvert and Overtopping Flow representing a crossing culvert underneath a roadway

Case 3: Street and Roadside Ditch representing a street with a swale ditch
Case 4: Overbank Channel representing a composite channel with low and high flow sections.

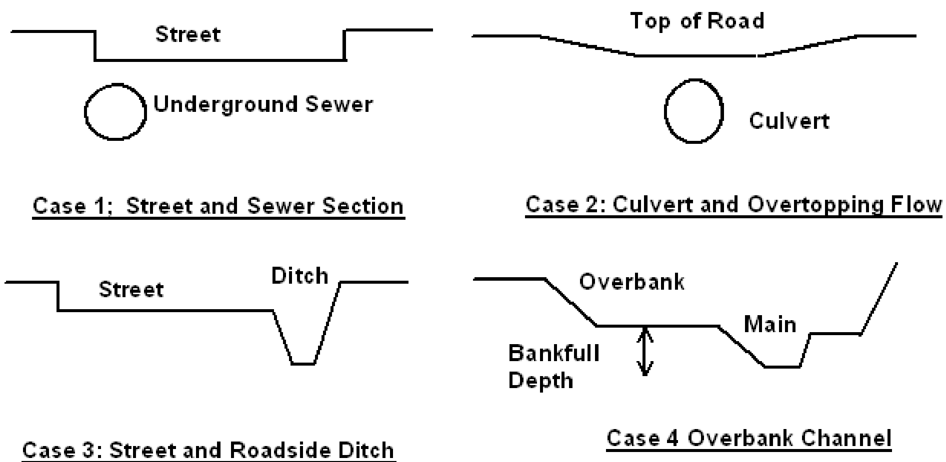

Figure 3.11 Conveyance Facilities in Urban Area

A conveyance facility is described by its upstream and downstream nodes, offset distances from the upstream and downstream node inverts, length, cross sectional geometry, hydraulic parameters, bankfull depth, and minor loss coefficients. Computationally, the KW routing through a composite section begins with the low flow section such as the pipe or roadside ditch. After the low flow section is filled up to its bankfull depth, the excess water begins to spill into the overbank section or street section.

3.6.3.2 Reservoir Flow Routing for Detention Basins

Detention basin is a hydraulic structure designed for flood control. Numerically, a detention system is modeled as a conveyance element with a large storage volume. According to the basin geometry and outlet work, a detention system can be described by its stage-area curve with a set of orifices and weirs for initial planning studies or a stage-outflow curve for the final design.

In practice, roadway embankments and culvert entrance can form storage volumes. It is important to understand that these local, random storage volumes are not reliably maintained for flood control purposes. During a major event, the embankment could be washed away. Therefore, it is suggested that any and all non-institutionalized storage volumes in the watershed be excluded for the flood control studies, but can be included in the computer model when investigating the existing flooding condition such as forensic studies.

3.6.3.3 Flow Diversion Routing

Diversion of storm runoff occurs when storm runoff is transferred across the physical boundary of a watershed. In an urban area, a flow diversion is often caused by street intersections or drainage structures. To model a flow diversion, the relationship of inflow, Q, versus diverted flow, Q_2, must be developed from the configuration of the diversion structure.

Example for Flow Intercepted by Street Inlet
As illustrated in **Figure 3.10**, a 36-inch storm sewer In the City of Aspen is designed to intercept the 10-year peak discharge of 40 cfs from the street inlet. The 100-yr peak discharge at the street inlet is 130 cfs. To model the 100-year event on this street, the street inlet is assumed to be capable of intercepting

the 100-yr flood flow up to 40 cfs. The street flow immediately downstream of the inlet is the difference between the 10- and 100-year runoff flows.

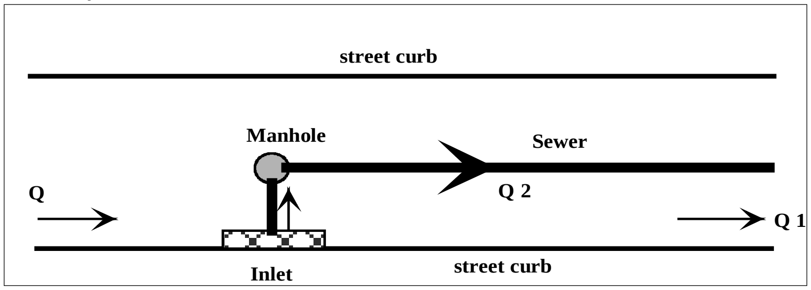

Figure 3.12 Interception of Street Inlet

For this case, the flow diversion table used in the SWMM5 computer model shall follow the inflow rising hydrograph to the 10-year peak discharge and leveled off as shown in **Table 3.6.**

Table 3.6 Flow Diversion at Street Inlet

Q-100 yr (inflow rate) cfs	0	40	41	130
Q-10 yr (diverted flow) cfs	0	40	40	40

3.7 References

CUHP 2005 User Manual (2009), *Colorado Urban Hydrograph Procedure*, Excel-based Computer Model, UDFCD, Denver, June, http://www.udfcd.org

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Chapter 4 – Street Drainage System Design

4.1 Purpose

Urban streets not only carry traffic, but stormwater runoff as well. However, water on a street can create hydroplaning effects, and can severely impact the traffic flow and the safety of travelers. For these reasons, a street drainage system must be properly designed to quickly remove stormwater from the traffic lanes. Street drainage includes both minor and major drainage systems. A minor system consists of street inlets and storm sewers, which can handle minor storm events. During a major storm event, street gutters and roadside ditches operate like wide and shallow channels to carry the flooding water away.

This chapter summarizes the procedures for street drainage system designs, including street hydraulic allowable capacity, street inlet sizing, and storm sewer design and flow analyses. The design methods presented in this chapter are referenced to the Hydraulic Engineering Circulation 22 published by Federal Highway Administration (FHA HEC22) and Chapter 6 in the Urban Stormwater Drainage Criteria Manual, Urban Drainage and Flood Control District, Denver, Colorado (USWDCM 2001, UDFCD).

4.2 Design Storms

As stated above, a street drainage system consists of minor and major systems. While street inlets and sewers are designed to intercept minor storm events, street gutters and roadside swales are, in fact, part of the major drainage system that is capable of passing the storm runoff from major storms. During a major storm event, the excess stormwater will accumulate in and be carried through the street gutters.

Proper street drainage design requires that public safety be maintained and any flooding be managed to minimize flood damage. Wherever the spread or pooling of water on the street exceeds the allowable spread, an inlet must be placed. Street inlets intercept surface runoff and transfer the water into the sewer system. **Table 4.1** presents City of Aspen's requirements established for the level of protection in terms of storm return periods for the minor and major street drainage systems.

4.3 Street Classifications

For purposes of street drainage system design, streets in the City of Aspen are classified into alleys, local, commercial and collector streets and typically match the following descriptions.

An alley is a narrow street that usually runs through the middle of a block giving access to the rear of lots or buildings and is typically not intended for general traffic circulation. Alleys in Aspen are inverted (center is lower than sides) and approximately 20 ft wide. They are typically gravel in the residential areas and paved in the commercial areas.

Local streets in the City of Aspen are designed to provide traffic service for residential areas. They may have stop signs and are characterized by two moving traffic lanes that are 11-ft wide in each direction. The street cross-section is symmetrical to the street crown with a transverse slope across the traffic lanes ranging from 2 to 3.5%, with a maximum allowed 4% across the parking lane which is 8 feet wide. In a rural setting, road side ditches collect the street runoff without curbs and gutters.

Residential/Collector streets in the City of Aspen are designed to provide service to residential areas and to serve the main thoroughfares of the City. An example of a residential/collector street is Cemetery Lane. The cross section of a residential/collector street is similar to a local street, except that there is potentially a parking lane – width is 8 feet for parallel parking or 18 feet for head-in parking at an angle.

Commercial streets in the City of Aspen are designed to provide service to business areas. A commercial street provides two moving traffic lanes of a minimum of 11 feet wide in each direction. The street cross-section is symmetrical to the street crown with a transverse slope varied from 2 to 3.5% across the traffic lanes. Parking lanes are adjacent to the curbs and gutters. There is a landscaping strip 5 feet or wider between sidewalks and parking lanes.

Cross-section drawings of standard street sections can be found in the most recent edition of the City of Aspen Engineering Department's Design and Construction Standards.

4.4 Design Considerations for Street Drainage

Water spread on the street hinders traffic flow and can become hazardous due to water splash and hydroplaning, and certain design considerations must be taken into account in order to meet street drainage objectives**. Table 4.1** lists the design criteria to keep the water spread on the street within the allowable limits during a minor or major storm event. Basically, all street gutters or ditches in the City of Aspen must be able to handle the minor event storm without overtopping the curb(s) or swale(s) and without inundating the sidewalks or crowns of the road. Residential and Commercial streets in the City of Aspen need to maintain at least one-lane width in the middle of the street for each traffic direction free from stormwater to allow for emergency use. Standards for major storm drainage designs are also required. The major storm runoff on the street needs to be assessed to determine the potential for flooding and public safety.

Table 4.1 Minor and Major Street Systems Design Return Periods and Allowable Spread

Drainage System	**Level of Protection (Return Period in years)**			
	Commercial Street	**Residential/Collector Street**	**Local Street**	**Alley**
Minor System	10	10	5	5
Maximum Water Spread during a Minor Event	No curb overtopping. Flow spread must leave at least one lane free from water for both traffic directions	No curb overtopping. Flow spread must leave at least one lane free from water for both traffic directions	Flow may spread to crown of street	The depth of water cannot exceed 12 in. in the low point or cause inundation of adjacent buildings
Major System	100	100	100	100
Maximum Water Depth during a Major Event	The depth of water should not exceed the street crown to allow operation of emergency vehicles. The depth of water over the gutter flow line should not exceed 12 in or cause inundation of adjacent buildings	The depth of water over the gutter flow line should not exceed 12 in. or cause inundation of adjacent buildings	The depth of water over the gutter flow line should not exceed 12 in. or cause inundation of adjacent buildings	The depth of water cannot exceed 12 in. in the low point or cause inundation of adjacent buildings

It is the responsibility of the property owner to protect their property from street drainage and to maintain the street's ability to carry floodwaters. Property owners should establish a vertical grade 6 inches from the top of the curb or 12 inches from the street surface to maintain the appropriate capacities of the streets.

Since it is more economical to continue accumulating gutter flow across a street intersection, not every street corner needs an inlet unless the water spread will be wider than what is allowable. In the City of

Aspen, a cross flow is allowed at a street intersection if it does not create hazards to traffic movement and pedestrians. The dimension of a cross pan is illustrated in **Figure 4.1**.

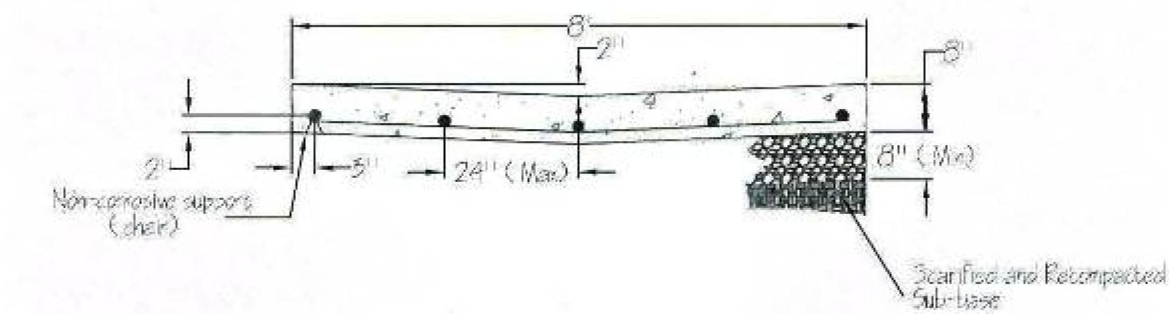

Figure 4.1 Cross Pan

4.5 Street-Side Swale

Swales are designed to collect runoff from streets and transport stormwater to the nearest inlet or major waterway. Most often swales are used in rural areas or on local streets in the City of Aspen because those streets are not equipped with curb and gutter sections. However, curbless streets with swales are encouraged where possible because of the systems' effectiveness in reducing runoff and pollutant loadings. This system allows street runoff a chance to infiltrate into the soils and be filtered by vegetation before reaching hard infrastructure or the City's waterways. More information about the water quality benefits and the design of road side swales can be found in the Water Quality Chapter of this Manual. .
Figure 4.2 illustrates a swale design. Swales with a bottom width of less than 6" shall be modelled as triangular swales and not trapezoidal.

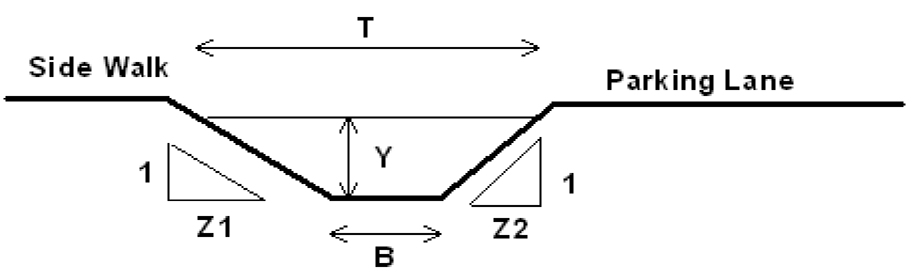

Figure 4.2 Typical Swale Cross-section

To calculate the capacity of a swale refer to the worksheet included in Appendix C or use the following set of equations:

$$T = B + (Z_1 + Z_2)Y$$ **(Equation 4-1)**

$$A = \frac{1}{2}(T + B) * Y$$ **(Equation 4-2)**

$$P = B + y(\sqrt{1 + Z_1^{\ 2}} + \sqrt{1 + Z_2^{\ 2}})$$ **(Equation 4-3)**

$$R = \frac{A}{P}$$ **(Equation 4-4)**

$$Q = \frac{1.489}{N} A \ R^{2/3} \sqrt{S_o}$$ **(Equation 4-5)**

Where Z_1 = left side slope, Z_2 = right side slope, B= bottom width (ft), Q = flow rate (cfs), N = Manning's roughness coefficient, A = flow area (ft2). T= top width (ft), R = hydraulic radius (ft), P = wetted perimeter (ft), and S_o = longitudinal slope (ft/ft).

Considering public safety and maintenance, swales shall be designed with limitations on flow velocity, depth, and cross-slope geometries. The following limitations shall apply to street-side swales:

- Maximum 100-year flow velocity = 7.0 ft/sec to avoid severe erosion
- Maximum 100-yr depth = 2 feet
- Minimum side slope for each side = 4H:1V. to stabilize the banks
- Minimum longitudinal slope = 2% or by including an underdrain system unless creating swale for water quality enhancements (see Chapter 8)

Under no circumstances shall a street-side swale have a longitudinal slope steeper than that of the adjacent street. Use proper linings or grade control checks to satisfy the design criteria.

4.6 Gutter Design

4.6.1 Street Gutter Flow

The street hydraulic capacity for a local or collector street in the City of Aspen is dictated by the allowable water depth in the gutter or the allowable water spread across the traffic lane. In practice, a gutter depression, Ds, of 2 inches is introduced at the street curb in order to increase the gutter conveyance capacity. The dimensions of a curb-gutter unit used in the City of Aspen are illustrated in **Figure 4.3** in which R1" means a radius of 1 inch to define the curve surfaces.

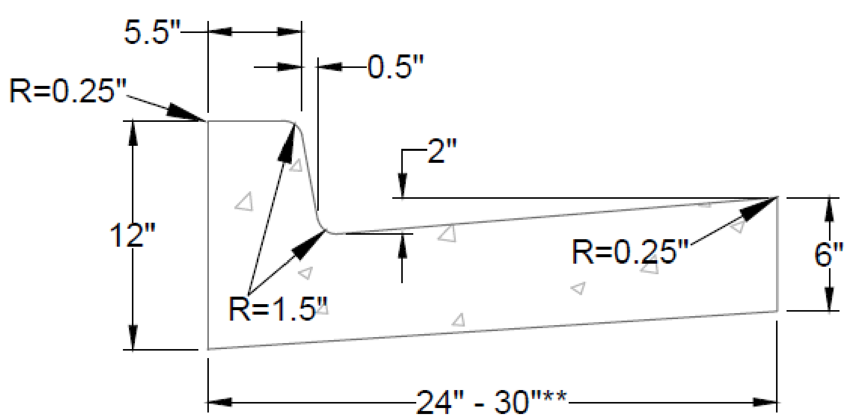

Figure 4.3 Catch Type – Curb and Gutter Unit

Figure 4.4 illustrates a typical street and gutter cross section. Stormwater flow carried in a street gutter can be divided into *gutter flow, Qw, and side flow, Qx.* The gutter flow is the amount of flow carried within the gutter width, *W*, and the side flow is the amount of flow carried by the water spread, T_x, encroaching into the traffic lanes.

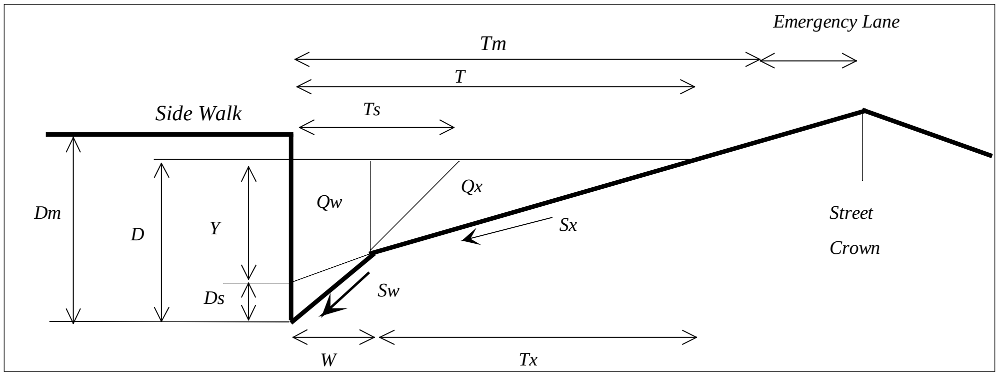

Figure 4.4 Street and Gutter Cross-Section for a Local or Collector Street
(Not Drawn to Scale)

Where

- W = gutter width (2.5 ft for the City of Aspen),
- D_s = gutter depression (2 inches),
- S_x = street transverse slope (2% or 3.5% for the City of Aspen)
- S_w = gutter cross slope
- D = water depth at curb face = Y+Ds (Typically 6")
- T_s = water spread in feet for water depth, D, in the gutter
- Tx = side flow width
- Q_x = side flow in cfs,
- Q_w = gutter flow in cfs,
- n = surface roughness coefficient of 0.016.

In Aspen, the minimum gutter grade shall be 0.75%. The minimum cross-slope on all streets shall be 2.0% and may vary from 2.0% to 3.5%. The street and gutter section having the most restrictive capacity (steepest cross-slope) shall be used for design.

Applying the open channel flow theory to the gutter and side flows yields:

$$Q_x = \frac{0.56}{n} S_x^{1.67} T_x^{2.67} \sqrt{S_o} \qquad \textbf{(Equation 4-6)}$$

$$Q_w = \frac{0.56}{n} S_w^{1.67} [T_s^{2.67} - (T_s - W)^{2.67}] \sqrt{S_o} \qquad \textbf{(Equation 4-7)}$$

The total flow, *Q*, on the street is the sum as:

$$Q = Q_x + Q_w \qquad \textbf{(Equation 4-8)}$$

The flow cross sectional area for a composite street is calculated as:

$$A = \frac{YT + WD_s}{2} \qquad \textbf{(Equation 4-9)}$$

4.6.2 Allowable Street Hydraulic Capacity

Street hydraulic capacity is dictated by the allowable gutter depth or the allowable water spread across the traffic lanes, whichever is smaller. To calculate the water depth at the curb face, D, and the corresponding spread, Ts, see equations in **Appendix B**. The allowable water depths in the street gutter are described in **Table 4.2** for a minor and major event. The allowable water spread is determined with consideration of emergency vehicle needs during a storm event (Agrawal, et al, 1977). In addition to water flow depth and spread, water flowing on a steep street can develop a high speed and imposes a significant impingement force on vehicles and pedestrians. As recommended (USWDCM 2001, UDFCD), the street gutter-full capacity is subject to flow reduction. Using the product of flow velocity and water depth, flow reduction factors are derived for both minor and major storm events for the City of Aspen (Guo 2000). As illustrated in **Figure 4.5**, the steeper the street is, the higher the flow reduction factor must be.

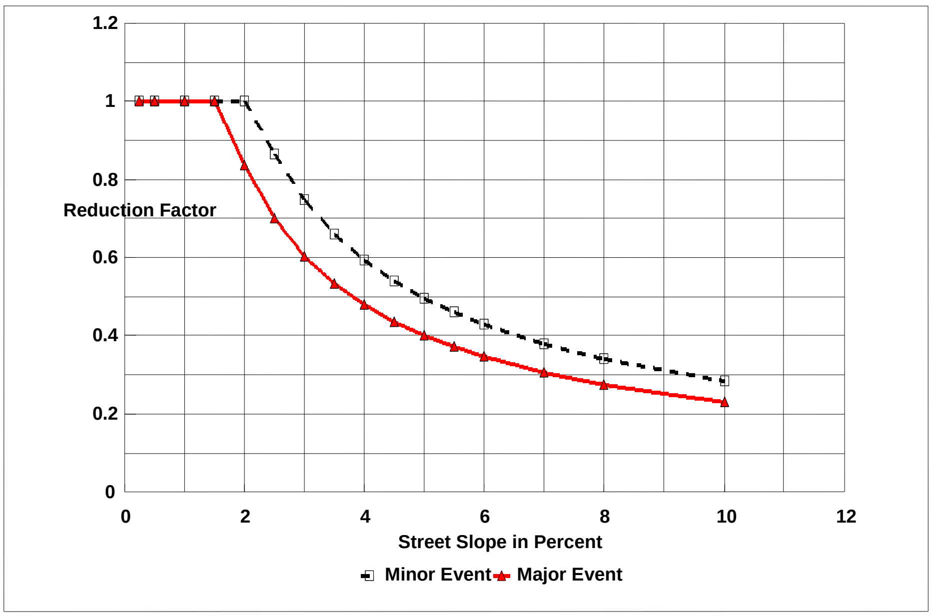

Figure 4.5 Flow Reduction Factors for Street Flow

To calculate the allowable street hydraulic capacity (ASHC), Q_a:

$$Q_a = \min(R \times Q_g, Q_m)$$ **(Equation 4-10)**

In which Q_a = ASHC in cfs, Q_g = gutter full capacity in cfs, R = flow reduction factor, and Q_m = spread-width capacity in cfs.

For derivations of gutter flow equations and calculated example problems see Appendix C.

4.7 Inlet Functions

Stormwater inlets are a vital component of the urban stormwater collection and conveyance system. Inlets collect excess stormwater from the street, transition the flow into storm sewers, and can provide maintenance access to the storm sewer system. They can be made of cast iron or concrete and are installed on the edge of the street adjacent to the street gutter, or in the bottom of a swale. Roadway geometrical features often dictate the location of pavement drainage inlets. The following subsections provide general guidance, specifications to use and reduction factors to use when designing inlets. The professional engineer has a variety of tools (software programs and other methodologies) to determine flows, effective area and etcetera.

4.7.1 Inlets

In general, inlets are placed at all low points (sumps or sags) such as median breaks, intersections, and crosswalks. The spacing between two adjacent inlets is governed by the allowable street hydraulic capacity (ASHC). In other words, the street inlets are so spaced that the design flow on the street is close to, but not exceeding, the ASHC for the minor storm event. There are four major types of inlets: grate, curb opening, combination, and slotted. Example inlets are shown in **Figures 4.6 – 4.8.** In Aspen, Type R inlets are generally not permitted. Type R curb openings or combination inlets must receive approval from the City Engineer.

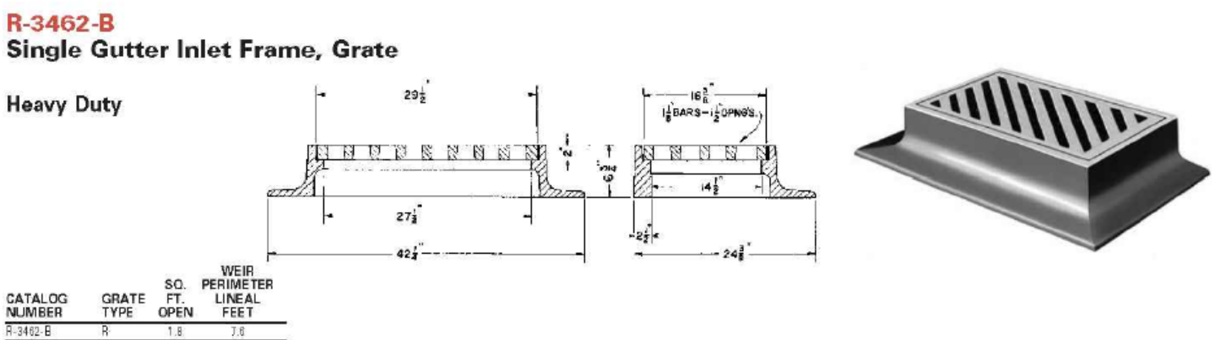

Figure 4.6 Grate Inlet used in City of Aspen

Figure 4.7 Curb Opening Inlet used in City of Aspen

Figure 4.8 Trench Drain (Slotted Inlet) in City of Aspen

4.7.2 General Design Guidelines

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

1. Design and location of inlets shall take into consideration pedestrian and bicycle traffic. All inlet grates shall be pedestrian and bicycle-safe.
2. Maintenance of inlets shall be considered when determining inlet locations. The slope of the street, the potential for debris and ice accumulations, the distance between inlets and/or manholes etc., shall be considered. Maintenance access shall be provided to all inlets.
3. Pedestrian safety in winter months, when snow banks begin to melt, needs to be considered. To prevent standing water in the pedestrian travel way, inlets must be located directly upgradient and downgradient (i.e. flanking inlets) of ADA ramp access to sidewalks
4. To avoid potential damage from large vehicles driving over the curb return, inlets shall not be placed in the curb return radii.

5. 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 accumulation, visibility, expected loading from vehicles, and hydraulic capacity.
6. Consideration should be given to flanking inlets on each side of the low point when the depressed area has no outlet except through the system. The purpose is to provide relief if the inlet at the low point becomes clogged. Consult HEC-22 for additional information regarding this concept.
7. In many cases, inlets are necessary at grade breaks, where street or ditch grades change from steep to relative flat because of the reduced conveyance capacities. In addition, it is common for icing or sediment deposition to occur with nuisance flows in reaches where the grades are relatively mild.
8. Inlets in a sump condition must have a 0.75% grade to the inlet along the flow line. Many times large vertical curves do not provide positive drainage to the inlets that meet this criteria and in those instances, separate flow line profiles shall be provided to prevent bird baths or standing water.
9. Must calculate using clogging factor in 4.7.3.

4.7.3 Inlet Clogging

The proper operation of an inlet is subject to clogging by urban debris, which can vary by location and season. To be conservative, a clogging factor of 50% is recommended for a single grate and 12% for a single curb opening inlet. For an inlet with multiple units, the clogging factor declines as the number of inlet units increases. **Table 4.4** lists the recommended clogging factors for inlets with multiple units.

Table 4.2 Clogging Factors for Inlet Design

Number of Inlet Units	Clogging Factor - Curb-Opening Inlet	Clogging Factor - Grate Inlet
1	0.12	0.50
2	0.08	0.38
3	0.05	0.29
>4	0.04	0.23

The interception capability of an on-grade inlet is proportional to the inlet wetted length, and an in-sump inlet is proportional to the inlet opening area. Therefore, the effective length of an on-grade inlet is calculated as:

$$L_e = (1 - C_g)L \qquad \textbf{(Equation 4-11)}$$

in which L= total wetted length, C_g= clogging factor selected for the number of inlet units, and L_e = effective (unclogged) length. Similarly, the effective opening area of an in-sump inlet is calculated as:

$$A_e = (1 - C_g)A \qquad \textbf{(Equation 4-12)}$$

in which A = total opening area, and A_e = unclogged opening area.

4.7.4 Design Flow on Street

Often an on-grade inlet is designed to capture 70 to 90% of the street flow. The by-pass flow will be carried over to the next downstream inlet. The design flow, Q_s, at an inlet location is the sum of the local flow, Q_p, contributed from the local area and the carry-over flow, Q_{co}, from the immediately upstream inlet.

$$Q_s = Q_p + Q_{co}$$ **(Equation 4-13)**

4.7.5 On-Grade Grate Inlet

Stormwater carried in the street includes the gutter flow that is carried within the gutter width, and the side flow that is spread into the traffic lanes. In general, the gutter flow within the gutter width can be completely intercepted by the inlet. The interception percentage, R_x, of the side flow is estimated as:

$$R_x = \frac{1}{\left(1 + \frac{0.15V^{1.8}}{S_x L_e^{2.3}}\right)}$$ **(Equation 4-14)**

As a result, the total interception capacity, Q_i, for the grate inlet is equal to

$$Q_i = Q_w + R_x Q_x$$ **(Equation 4-15)**

The carry-over flow, Q_{co}, is the difference between Q_s and Q_i as:

$$Q_{co} = Q_s - Q_i$$ **(Equation 4-16)**

4.7.6 In-Sump Grate Inlet

A grate inlet in a sump can operate like a weir under a shallow water depth. Its weir-flow capacity is estimated as:

$$Q_w = C_w P_e Y_s^{1.5}$$ **(Equation 4-17)**

in which Q_w = weir-flow capacity in cfs, C_w = weir coefficient such as 3.0 for feet-second units, Y_s = water depth in ft, and P_e = effective weir length in feet around the inlet grate defined as:

$$P_e = (1 - C_g)P$$ **(Equation 4-18)**

When a grate is submerged and operates like an orifice, its orifice-flow capacity is estimated as:

$$Q_o = C_o A_e \sqrt{2gY_s}$$ **(Equation 4-19)**

$$A_e = (1 - C_g) m W_o L_o$$ **(Equation 4-20)**

in which C_o = orifice coefficient (this coefficient relates the wetted perimeter of the grate, P, to the effective perimeter P_e, that acts as a weir; the recommended value for C_o for most applications is 0.65), g = gravitational acceleration (32.2 ft/sec^2), W_o= grate width in ft, L_o=grate length in ft, and m = area opening ratio on the grate. The transition between weir flow and orifice flow is not clearly understood. Theoretically, the change in the hydraulic performance of a grate occurs at a depth where the weir rating curve intersects the orifice rating curve. In practice, for a specified water depth, the interception capacity of an inlet grate is the smaller of Q_w and Q_o.

4.7.7 On-Grade Curb Opening Inlet

To install a curb opening inlet on a continuous grade, the required curb opening length, L_t, for complete (100%) interception of the design storm runoff, Q_s, on the street is computed by:

$$L_t = 0.60 Q^{0.42} S_o^{\ 0.30} \left(\frac{1}{nS_e} \right)^{0.6}$$ **(Equation 4-21)**

$$S_e = S_x + S_w \frac{Q_w}{Q_s}$$ **(Equation 4-22)**

in which L_t = required length for 100% interception, S_o = street longitudinal slope, n = Manning's roughness of 0.016, and S_e = equivalent transverse street slope. The curb-opening inlet shall have a length less than, but close to, L_t. The interception capacity of a curb-opening inlet is calculated as:

$$Q_i = Q \left[1 - \left(1 - \frac{L_e}{L_t} \right)^{1.80} \right]$$ **(Equation 4-23)**

in which Q_i = inlet capacity, and L_e = effective length of the curb opening inlet.

4.7.8 In-Sump Curb-Opening Inlet

Referring to **Figure 4.9**, a curb-opening inlet in a sump operates like a weir. Its interception capacity is estimated as:

$$Q_w = C_w P_e Y_s^{1.5}$$ **(Equation 4-24)**

$$P_e = (1 - C_g)(L + kW_p) + 2W$$ **(Equation 4-25)**

in which P_e = effective weir length around the depression pan in front of the curb opening inlet, W_p= width of depressed pan, and k = 1.8 for two sides of the pan in **Figure 4.9.** When the water gets deeper, a curb opening inlet operates like an orifice that can be modeled as:

$$Q_o = C_o A_e \sqrt{2g(Y_s - Y_c)}$$ **(Equation 4-26)**

$$A_e = (1 - C_g) HL$$ **(Equation 4-27)**

in which Y_s = water depth, Y_c = center of opening area above the ground, H= height of opening area, L= width of opening area. The center of the curb opening area is the vertical distance above the flow line. It is important that the thickness of the concrete cover be included in the calculation of the depression of the curb opening.

It is not well understood how an in-sump curb opening inlet switches from weir to orifice flow. In practice, for a specified water depth, the interception capacity of an in-sump inlet is dictated by the smaller value of the weir or the orifice flows.

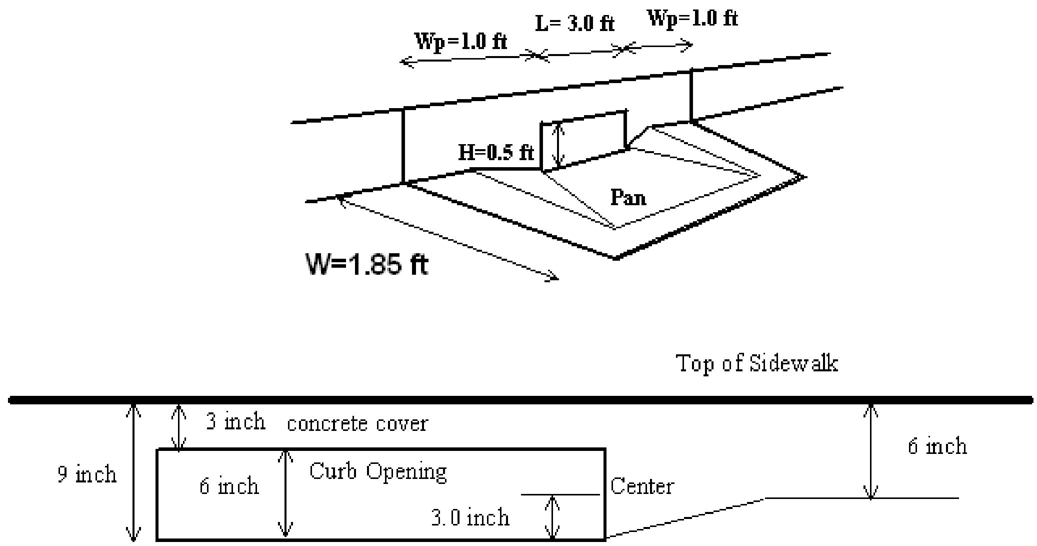

Figure 4.9 Example of Curb Opening Inlet in Sump

4.7.9 Slotted Inlet

A slotted inlet is similar hydraulically to a curb-opening inlet. As a result, design formulas developed for curb-opening inlets are also applicable to slotted drain inlets. In the City of Aspen, trenches are often used as a slotted inlet. The interception capacity of a trench is similar to the slotted inlet while the conveyance capacity of a trench is calculated using the ditch flow formulas, **Equation 4.1** through **4.5**.

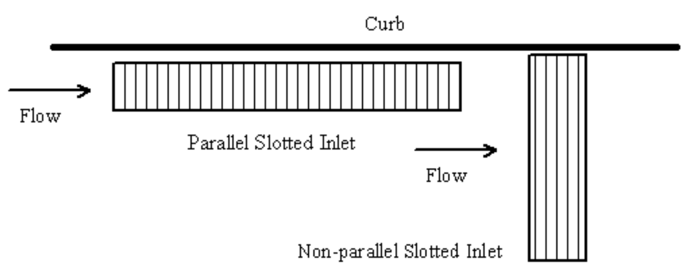

Figure 4.10 Slotted Inlet

4.7.10 Combination Inlet

A combination inlet, shown in **Figure 4.11**, is formed with a curb opening and a grate inlet. During a storm event, if one inlet is clogged, the other can still function. Empirical formulas for sizing an inlet were developed under the assumption that each inlet operates independently, although the interference between the grate inlet and the curb opening inlet in a combination inlet has not been fully investigated yet. The assumption of independent operation implies that the curb-opening inlet is placed immediately downstream of the grate inlet. In other words, the curb-opening inlet receives the carryover flow from the grate inlet. In the case of 100% interception by the grate, the curb opening inlet will intercept no flow at all. In theory, the capacity of a combination inlet is less than the sum of the interception for both inlets. To be conservative, the capacity of a combination inlet is assumed to be the higher value of either the grate or the curb-opening inlet when the water depth is shallow (<6 inches) (Guo, 1996). The assumption that both inlets can work independently may be justified when the water depth is greater than the curb-opening height.

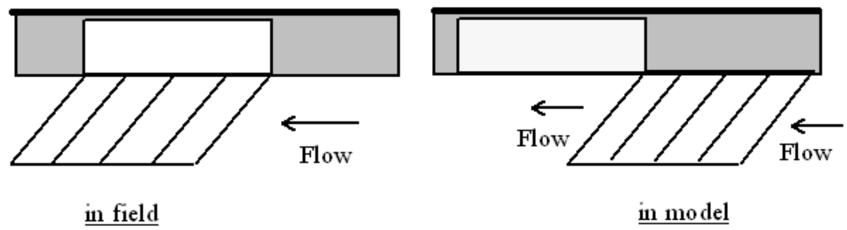

Figure 4.11 Assumptions Regarding Flow Interception by a Combination Inlet

For examples calculating inlet design, see Appendix C.

4.8 Storm Sewers

The storm sewer system is comprised of inlets, pipes, manholes, bends, outlets, and other appurtenances. The stormwater passes through these components and is discharged into a downstream water quality enhancement facility before draining into a natural water body. The plan layout and vertical profile of a storm sewer system are governed by following factors as:

- street alignment for the sewer line
- street inlet placement
- existing utility locations
- sewer system outfall location and tailwater elevation
- drainage master plan for the City of Aspen

4.8.1 Manholes

Manholes are generally made of pre-cast or cast-in-place reinforced concrete. They are typically 4 feet in diameter. Manholes and junctions are used in sewer systems to provide a hydraulically efficient transition at alignment changes along a sewer line. Manholes and junctions are also used to provide access to storm sewers for maintenance purposes. To maintain hydraulic efficiency and adequate maintenance access, a manhole shall be located at any of the following points:

- where the pipe size changes
- where the direction of sewer line changes
- where the invert grades along the sewers change
- where drops are added to the vertical profile
- in conjunction with all laterals
- where the lateral is not easily accessible for maintenance from the inlet
- where the spacing between manholes exceeds 400 feet

4.8.2 Design Procedure and Constraints

The design of a storm sewer system requires basic data in the proposed service area, including topography, drainage boundaries, soil types, and locations of any existing storm sewers, inlets, and manholes. In addition, identification of the type and location of other utilities is necessary. Design of a sewer system begins with the placement of inlets and manholes. The vertical profile for the proposed sewer line can be approximated using the street profile as a reference. Considering a minimum of 7-ft soil cover, the sewer crowns may be set 7 feet or greater below the ground surface. Manhole drops can be introduced to reduce the water flow velocity or to avoid utility conflicts. The sewers are sized from the most upstream manhole to the system exit as the flow rate and flow time are accumulated along the sewer network. At a manhole, the longest flow time among all incoming flow paths shall be used to calculate the design rainfall intensity. The Rational method is recommended to estimate the peak flow at the manhole and the Manning's formula, Equations 4.1 through 4.5, are suitable to size the outgoing sewer from the manhole. The calculated pipe diameter is often not commercially available. As a result, the next larger commercial pipe size shall be adopted. After all sewers are sized by open channel flow under the normal flow condition, the sewer system is further subject to a performance evaluation under a given tailwater at the system exits. The energy and hydraulic grade lines will predict if any manholes in the sewer system are surcharged. If a storm sewer is determined to be surcharged, hydraulic losses are modified to reflect the surcharge condition. Hydraulic Grade Lines shall not be less than 1-ft from the ground surface.

The sewer design can be finalized by continuously adjusting sewer sizes and manhole drops until all the design criteria and constraints are satisfied, including:

- permissible flow velocity in a sewer between 2 and 18 fps for the selected pipe material and slope.
- minimum earth coverage of 7 feet, for the cold climate in the Aspen area,
- minimum sewer diameter of 18 inches for sewer trunks and 15 inches for lateral lines.
- minimum manhole drop of 0.20 foot, and
- maximum manhole spacing of 400 feet.
- storm sewer pipes within the right-of-way shall be Reinforced Concrete Pipe (RCP) with a minimum diameter of 15 inches.

To accommodate back water effects, a sewer shall be sized so that the normal design depth does not exceed 80% of the diameter of a circular pipe or the height of a box sewer. Since the design discharge in a sewer system increases downstream, sewer sizes in a system must increase downstream as well. Decrease in sewer size due to steep invert slope or smooth pipe roughness must be avoided.

4.8.3 Design Flow at Manhole

A manhole is treated as a design point where the system flow from the upstream tributary area is combined with the local flows from the local tributary areas. There are two ways to compute the design flow at a manhole.

Design Flow Using Rational Method

To model the accumulation of flows along the sewer line, all manholes and sewers are converted into nodes and links. Sewer sizing starts from the most upstream manhole. At the n-th node, the local area is combined with the accumulated area in the system as:

$$(A_e)_n = C_n A_n + \sum_{i=1}^{i=n-1} C_i A_i \qquad \textbf{(Equation 4-28)}$$

The accumulated travel time through the sewer line is:

$$(T_c)_n = (T_c)_{n-1} + \frac{L_n}{60V_n} \qquad \textbf{(Equation 4-29)}$$

in which A_e = effective contributing area in acres, T_c = accumulated time of concentration in minutes, L = sewer length in feet, V = sewer flow velocity in fps, i = i-th node upstream of the design point, and n = n-th node at the design point. Set the design rainfall duration equal to T_c to calculate the peak flow using the Rational Method.

Design Flow with Known Local Flow

This approach can be used in the case that the local flow at the manhole is specified by the hydrologic report, or provided as a quantified off-site input to the sewer system. The inherent time of concentration, T_a, for this known local flow, Q_a, can be calculated using the local area, A_a, and runoff coefficient, C_a, as:

$$i = \frac{Q_a}{C_a} = \frac{19P_1}{(10+T_c)^{0.789}}$$ **(Equation 4-30)**

Equation 4-30 will then be incorporated into the accumulation process of flow time through the sewer line for continuous peak flow calculations using the Rational Method.

4.8.4 Sewer Sizing – Circular, Box, and Arch Pipes

Circular Sewer Hydraulics

Equation 4-43 can be applied to determine the minimum diameter, d, required to accommodate a design flow, Q, in a pipe flowing full under gravity (normal) flow conditions using Manning's equation.

$$d = \left(\frac{nQ}{K\sqrt{S_0}} \right)^{\frac{3}{8}}$$ **(Equation 4-31)**

Where Q = design flow in cfs, S_o = conduit invert slope in ft/ft, d = hydraulically required circular diameter in feet (full flow assumed), and K = 0.462 for feet-second units. The calculated pipe size is often not commercially available. As a result, the next larger commercially available pipe size shall be used. This will result in partially-full flow. To determine the depth for partially-full flow (to check against 80% criterion under normal flow conditions), the following procedure can be used:

1. Calculate Q_{full} for the actual pipe diameter using Manning's equation,
2. Calculate the ratio of Q_{design}/Q_{full},
3. Look up d/Dfull value corresponding to Qdesign/Qfull
4. Calculate depth, d = d/Dfull * pipe diameter.

For larger commercially-available pipe, use the nomograph or tabular procedure for evaluating partially full flow conditions.

Arch (Elliptical) Sewer Hydraulics

The limited clearance due to existing underground utilities often sets constraints to the sewer profile. Between two manholes, a flat and wide sewer may fit the narrowed corridor. As a result, an elliptical or arch pipe is sometimes selected as a replacement for a circular pipe. The flow through an elliptical or arch pipe in **Figure 4.12** is dictated by the cross-sectional geometry. For simplicity, an equivalent circular pipe may be used as an approximation in hydraulic computations.

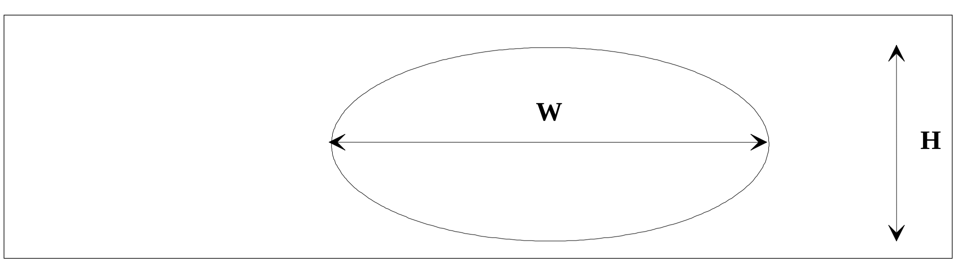

Figure 4.12 Elliptical Sewer

The equivalent diameter is approximated by

$$d = 0.5(H + W) \quad \textbf{(Equation 4-32)}$$

in which H = rise of the arch sewer and W = span of the arch sewer

Box Sewer Hydraulics

When a box sewer is selected, the width of the box sewer must be specified first. The hydraulic calculation is to provide the flow depth. As illustrated in **Figure 4.13**, the hydraulic parameters in a box sewer are related to the flow depth as:

$A = BY$ **(Equation 4-33)**

$P = 2Y+B$ **(Equation 4-34)**

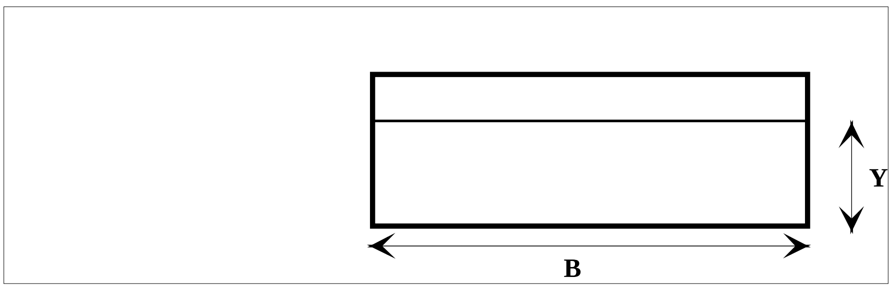

Figure 4.13 Box Sewer

4.8.5 Sewer Energy and Hydraulic Grade Lines

The Energy Grade Line (EGL) represents the energy slope between the two adjacent manholes in a storm sewer system. A manhole may have multiple incoming sewers, but only one outgoing sewer. Each sewer and its upstream manhole form a sewer and manhole unit. The entire storm sewer system can be decomposed into a series of sewer & manhole units. Each unit has to satisfy the energy principle. The computation of energy grade line (EGL) is a repetition of the energy balance process through each sewer and manhole unit.

$$H_1 + \frac{V_1^2}{2g} = H_2 + \frac{V_2^2}{2g} + H_f + H_m \quad \textbf{(Equation 4-35)}$$

Where H = water surface elevation at manhole, V = flow velocity through sewer, H_f = friction loss through the sewer pipe, and H_m = juncture losses at manhole. The subscript “1” represents the upstream manhole and “2” represents the downstream manhole.

Pipe Form Losses

Generally between the pipe inlet and outlet, the flow encounters a variety of configurations and condition changes such as pipe size, branches, bends, junctions, expansions, and contractions. These shape variations and conditions impose losses in addition to those resulting from pipe friction. Form losses are the result of fully developed turbulence and can be generally expressed as follows:

$$H_L = K\frac{V^2}{2g} \quad \textbf{(Equation 4-36)}$$

Where: H_L = head loss (feet)
K = loss coefficient
V = average flow velocity (feet per second)
g = gravitational acceleration (32.2 ft/sec^2)

The following is a discussion of a few of the common types of form losses encountered in storm sewer system design.

1. Expansion Losses

Expansion in a storm sewer conduit will result in a shearing action between the incoming high velocity jet and the surrounding sewer boundary. As a result, much of the kinetic energy is dissipated by eddy currents and turbulence. The loss of head can be expressed as:

$$H_L = K_e \frac{V_1^2}{2g} (1-\frac{A_1}{A_2})^2$$ **(Equation 4-37)**

Where: A = the cross-section area (square feet)
V = the average flow velocity (ft/sec)
K_e = the loss coefficient.
The value of K_e is 1.0 for a sudden expansion and 0.2 for a well-designed expansion transition. Table 803 presents the expansion loss coefficients for various flow conditions.
g = gravitational acceleration (32.2 ft/sec^2)
Subscripts 1 and 2 denote the upstream and downstream sections, respectively.

2. Contraction Losses

The form loss due to contraction is:

$$H_L = K_c \frac{V_2^2}{2g} (1-\frac{A_2}{A_1})^2$$ **(Equation 4-38)**

Where: A = cross-sectional area (square feet)
V = average flow velocity (ft/sec)
K_c = the contraction coefficient.
K_c is equal to 0.5 for a sudden contraction and 0.1 for a well-designed transition. Table 803 presents the contraction loss coefficients for various flow conditions.
g = gravitational acceleration (32.2 ft/sec^2)
Subscripts 1 and 2 denote the upstream and downstream sections, respectively.

3. Bend Losses

The head losses for bends, in excess of that caused by an equivalent length of straight pipe, may be expressed by the equation:

$$H_L = K_b \frac{V^2}{2g}$$ **(Equation 4-39)**

Where: V = average flow velocity (ft/sec)

g = gravitational acceleration (32.2 ft/sec^2)
K_b = the bend coefficient.

The bend coefficient has been found to be a function of (a) the ratio of the radius of curvature of the bend to the width of the conduit, (b) deflection angle of the conduit, (c) geometry of the cross-section of flow, and (d) the Reynolds number and relative roughness. The recommended bend loss coefficients are presented in Table 804 and Figure 804.

4. Junction and Manhole Losses

A junction occurs where one or more storm sewers enter a main storm sewer, usually at manholes. The hydraulic design of a junction is in effect the design of two or more transitions, one for each flow path. Allowances should be made for head loss due to the impact at junctions.

The head loss for a straight-through manhole or at an inlet entering the storm sewer is calculated from Equation 8-1.

The head loss at a junction can be calculated from:

$$H_L = \frac{V_2^2}{2g} - K_j \left(\frac{V_1^2}{2g}\right) \qquad \textbf{(Equation 4-40)}$$

Where: V = average flow velocity (ft/sec)
g = gravitational acceleration (32.2 ft/sec^2)
K_j = loss coefficient.

The coefficients for various junction configurations are presented in Figure 805.

Subscripts 1 and 2 denote the upstream and downstream sections, respectively.

Storm Sewer Outlets

When the storm sewer system discharges into the major drainage system (usually an open channel), additional losses occur at the outlet in the form of expansion losses. For a headwall and no wingwalls, the loss coefficient (K_e) equals 1.0 while for a flared-end section, the loss coefficient is 0.5 or less. Expansion and Contraction coefficients can change with the angle in degrees between sections.

Partially Full Pipe Flow

When a storm sewer is not flowing full, the storm sewer acts like an open channel and the hydraulic properties of the pipe can be calculated using open channel techniques. For convenience, charts for various pipe shapes have been developed for calculating the hydraulic properties. The data presented in these figures assumes that the friction coefficient, Manning's "n" value, does not vary by depth.

The flow in a sewer pipe can be either, or a combination of: open channel flow, surcharged flow, or pressurized flow. When a free surface exists through the pipe length, open channel hydraulics shall be applied to the backwater surface profile computations. The friction loss through the sewer pipe is the cumulative head losses through the specified type of water surface profile. For instance, the sewer pipe carrying a subcritical flow may have an M-1 water surface profile if the downstream manhole is almost surcharged or an M-2 water surface profile if the downstream manhole is not surcharged.

On the other hand, a pipe carrying a supercritical flow may have an S-2 water surface profile if the downstream manhole is not submerged. Otherwise, a hydraulic jump may be expected.

When the downstream sewer crown is submerged to a degree that the entire sewer pipe is under the hydraulic grade line, the head loss for this flowing-full condition is estimated by pressure flow hydraulics.

When the downstream sewer crown is slightly submerged, the downstream end of the sewer pipe is surcharged, but the upstream end of the sewer pipe can remain as open channel flow. The head loss during surcharge flow depends on the flow regime. For a subcritical flow, the head loss is the sum of the friction losses for the flowing-full flow and for the open channel flow. For a supercritical flow, the head loss may involve a hydraulic jump. As a result, the culvert hydraulic principles can be used to calculate both inlet and outlet control conditions; whichever is higher dominates the final results.

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Chapter 5 – Detention

5.1 Overview and Policies

Detention is a practice in which storage is provided to temporarily impound stormwater runoff during an event and to release runoff in a controlled manner. A detention volume is created because inflows to the detention facility exceed the controlled outflow rate, and runoff accumulates in the designated detention area until inflow rates decrease and the outflow empties the storage volume in a controlled manner. The typical purpose of a detention facility is to manage runoff to control the effects of peak runoff rates on downstream conveyances and property. For new development, it is common practice to require detention so that peak flow rates for the proposed development do not exceed pre-development, or existing, peak flow rates for design events. In the context of redevelopment or infill development in urban areas, the goal of detention often is to ensure that runoff from the development site does not exceed the capacity of the existing conveyance system or exacerbate existing flooding problems.

Much of the development in Aspen falls into the categories of redevelopment or infill development. Historically development in the commercial core and surrounding areas did not incorporate flood control detention for the minor and major events. Given Aspen's proximity to the Roaring Fork River and the large undeveloped drainage area in the Roaring Fork River watershed above Aspen, detention is not a practice that provides major flood control benefits for the City of Aspen. In addition, channel scour, which may be more pronounced in the absence of detention, has not been reported as a chronic problem in the vicinity of Aspen. However detention is an important practice for runoff from the City and offsite drainage areas draining through the City to be conveyed to the Roaring Fork River without causing significant damage to properties in town.

The City of Aspen's stormwater management goal is to mimic Aspen's natural hydrology to the maximum extent practicable. By requiring treatment of the water quality capture volume, discussed in **Chapter 8 – Water Quality**, it, in effect, provides infiltration or detention for many very small events (on the order of a 6-month to 1-yr event), approximately 80% of the storms in Aspen. For the remaining 20% of storms, the larger events, a small portion of the runoff will be detained in the water quality treatment areas. The remaining runoff must be conveyed to the river safely and in a manner that doesn't increase the flooding potential of downstream properties.

Given these observations, the City's detention policy is as follows, by area:

1. **Commercial core/downtown and sub-urban areas draining to the stormwater system depicted in Figure 1.1 –** These drainage areas are highly impervious and are served by the City of Aspen stormwater infrastructure. In general, the minor, 10-year, event in this area is handled by storm sewers and the major, 100-year, event is accommodated by a combination of storm sewers and street flow. Additionally, detention (above the WQCV) appears to have minimal effects on the system capacity in this area due to the large basins located upland of the City which are not being detained and contribute a large portion of flow to the system. Because the City's system generally has the capacity to accommodate the existing flow volumes and rates and because detention has minimal effects on system capacity, detention is not required for sites that discharge directly to the City's system in this area (see Figure 1.1). For sites that cannot discharge directly to the City's system, detention to the historic rate is required or a project may have the option to pay a fee-in-lieu of providing the required detention (see Section 2.12.140 of the Municipal Code).

2. **Sub-urban area not analyzed or not served by public storm sewer –** These are areas outside of the downtown area and drain to unanalyzed portions of the City's stormwater system, the Roaring Fork River or its tributaries via local drainage systems. Detention to the historic peak flow rates for the 5- and 100-year events is required for new development and redevelopment activities that disturb or add more than 1,000 square feet of impervious area. If the disturbed or

added impervious area is less than 25% of the total site then only the new area must be so treated. If the disturbed or added impervious area is more than 25% of the total site then the site shall be treated as a new development and the total site shall meet detention requirements to the historic peak flow rates. A project may have the option to pay a fee-in-lieu of providing the required detention (see Section 2.12.140 of the Municipal Code).

3. **Private regional drainage systems** – These are areas, such as subdivisions or Metro districts, in which the detention requirements for the entire planned development have already been met. For these areas, detention (above the WQCV) is only required for runoff not planned/designed for in the accepted/approved drainage plan of the subdivision/district. In cases of increased runoff, detention to the pre-developed rate will be required for the design storm used in the original design.

In instances where the City is aware of existing flooding problems and/or undersized conveyances, the City reserves the right to require minor and/or major event detention for any of the areas described above. Over-detention (i.e. providing detention that decreases developed peak flow rates to less than pre-development conditions) may be required in instances where there are downstream system capacity limitations, although this situation will require site specific evaluation by a registered professional engineer.

The above policies relate to detention only, not requirements for the WQCV. See **Chapter 8 – Water Quality** for WQCV requirements that apply to all development and redevelopment in the City.

If there is a need to design detention facility for both flood mitigation and water quality enhancement, this chapter should be used in conjunction with **Chapter 8 – Water Quality** in this Manual. Following the guidelines in this Manual, multipurpose, attractive detention facilities should be developed that are safe, maintainable and viewed as community assets rather than liabilities.

This chapter provides guidance to design stormwater flood control detention facilities. Topics discussed in this chapter include:

- Evaluation of detention requirements,
- Types of detention facilities,
- Design considerations,
- Determination of allowable release,
- Design procedures,
- Methods for calculating detention volume requirements,
- Initial sizing for detention basin design, and
- Preliminary design and final refinement.

5.2 Evaluation of Detention Requirements

For detention requirements for a development or redevelopment site in Aspen, there are several conditions that generally must be evaluated for the minor and major events, including the following:

1. **Historic** — Historic conditions are defined as the conditions on a site prior to any development activities (i.e. before construction of any *existing or proposed* buildings or infrastructure). Since development first began in Aspen with mining in the late 1800's, there has been significant impervious area added in the City, up to more than a 90% level in the commercial core, with very little flood control detention. Given the nature and density of the development that currently exists in the City in many areas, detention of runoff to historic conditions is not always practical. Therefore, the policy for the City of Aspen is that redevelopment and add-on projects provide detention to match existing conditions. Historic conditions primarily apply to new developments in the City rather than redevelopment project, although it may also serve as a "benchmark" for redevelopment projects that use over-detention to address existing downstream flooding problems.

This "do no more harm than formerly" approach is a pragmatic approach to detention, realizing many of the space-constraints in the City, but it does have limitations on its effectiveness. In some portions of the City storm sewer and/or street capacity are not sufficient to prevent flooding under existing conditions and flooding problems currently exist. The "do no more harm" approach is not expected to alleviate existing flooding in these areas, but it is not expected to make it worse. For areas that have undersized storm sewers, improvements for routine flooding problems are expected to result from City plans to upgrade all storm sewers in the commercial core to 10-year capacity. The City, at its discretion, may require detention beyond that dictated by existing conditions, including over-detention, to address pressing flooding problems within the City. Site specific analysis by a registered engineer will be necessary in these conditions.

2. **Proposed Conditions**— Proposed conditions include both existing and new imperviousness for a project. In all cases evaluation of existing and proposed peak runoff rates shall include off-site drainage areas that drain through the project site. For evaluating proposed conditions, all off-site areas shall be considered fully developed without detention, unless dedicated approved detention facilities are in plan that can reasonably be relied on. It may not be necessary for a development with an on-site detention facility to provide detention for off-site flows, but detention facilities must be designed to safely convey off-site flows while providing the required detention for on-site flows. For most small sites, the Rational Method will be applied to determine existing and proposed flow rates for the minor and major events. The proposed condition time of concentration shall not be greater than the existing condition time of concentration, unless detailed calculations are submitted to justify the proposed increase.

5.3 Types of Detention Basins

The main objective of stormwater detention is to mitigate increased storm runoff volume and reduce the peak flow rates. Detention basins provide temporary storage of stormwater that is released through an outlet at a pre-set release rate. There are two primary types of detention basins that are commonly used:

- Dry detention basins—Dry detention basins are facilities that store water primarily during runoff events. As inflow rates increase the detention basin fills and impounds water as it is released via an outlet at a controlled rate. As inflows subside, the detention basin continues to release the stored water over an extended period of time, eventually draining completely. Dry detention ponds commonly have grassed bottoms, and when designed with appropriate side slopes and layouts may provide multiple functions when dried out including open space, wildlife habitat and in some cases recreational areas. Dry detention ponds may also provide water quality functions - when the water quality capture volume is captured and infiltrated the volume can be "nested" in the minor and major events volumes.

- Bio-retention or sand filter facilities that provide the WQCV can be increased in volume to provide detention for minor and major events. When these two BMPs are utilized the storage may be nested. That is, the WQCV is included within (not in addition to) the volumes captured in the minor or major events.

- Wet detention basins—Wet detention basins, sometimes referred to as retention ponds, differ from dry detention basins in that they include permanent pools that persist during inter-event dry periods. Strictly speaking, "retention" refers to ponds that do not have an outlet but instead hold runoff that is either ultimately evaporated or infiltrated. These types of ponds are not common in Colorado and can carry water rights issues that should be investigated prior to incorporating a wet detention basin into the design. More typically, a wet detention pond (as opposed to a strict "retention" pond) provides detention storage volumes for the minor and major events (and sometimes the WQCV) above the elevation of the permanent pool and releases the surcharge volume via an outlet that regulates flows. Wet detention ponds can be aesthetic amenities, providing a water feature, but there are additional design considerations relative to dry detention ponds. Adequate baseflow to sustain the permanent pool, water rights considerations, management of potential algae, dry weather circulation and mixing, and additional safety considerations are some of the factors that must be considered.

There are a number of other distinctions of types of detention basins that are useful to understand:

- On-site, sub-regional, regional—*On-site* detention ponds typically provide treatment for a single lot or development. They are generally small and privately operated and maintained. They are generally more costly per unit volume of runoff detained than sub-regional or regional facilities because of economies of scale and they typically do not provide multiple functions in addition to peak attenuation due to their small size. *Sub-regional* detention facilities refer to ponds that provide peak attenuation for multiple parcels and are typically larger than on-site facilities. An example of a sub-regional detention facility would be a detention pond in a neighborhood park that provides detention for surrounding residences and businesses. *Regional* detention facilities generally provide treatment for drainage areas in excess of 130 acres (a regionally accepted threshold for differentiating between "local" and "regional drainage"). Regional facilities offer the greatest potential for multiple uses in addition to stormwater detention given their large size. Regional facilities are generally publicly operated and maintained. The Jennie Adair constructed wetlands are an example of a regional water quality facility in Aspen.

- On-line/in-stream, offline/off-stream—On-line or in-stream detention facilities are typically situated along drainageways and provide detention for all upstream contributing areas, on-site and off-site. As a result most on-line facilities are sub-regional or regional facilities. For on-line facilities, it is often necessary to provide on-site water quality treatment to protect the reach of the stream that runs from the site of the individual developments to the regional facility. In addition, given that on-line systems are typically coincident with waterways, wetland permitting is often necessary for construction of such facilities. Off-line or off-stream detention facilities may be adjacent to major drainageways, but usually provide treatment for only a single sub-watershed contributing runoff to the drainageway. Off-line facilities are commonly on-site or sub-regional facilities.

- Above-ground, below-ground—Far and away, the most common types of detention facilities in Colorado and across the country are above-ground facilities. Above-ground facilities have many advantages over underground facilities including easier inspection and maintenance; potential for incorporating multiple functions, including aesthetics, open space, recreation, etc.; ability to drain via gravity versus pumped outfall; lower costs; and other factors. Underground detention is a practice that is disallowed in many municipalities because of historic problems with operation and maintenance and a general "out-of-sight out-of-mind" mentality. Some municipalities that allow underground water quality facilities choose to disallow underground flood control detention—because if an underground water quality facility fails to function, there is potential for impairment of water quality; but if an underground flood control facility fails to function, people may experience flooding and significant damage. Given extremely high real estate values in Aspen, and the need to provide flood control detention for public health, safety and welfare, underground detention is a practice that may be considered by the City and allowed on a case-by-case basis. **It is not a desirable practice, and should be used only as a last resort when the applicant is able to demonstrate that above-ground options are infeasible.** For any underground detention applications, the applicant will be required to develop a rigorous inspection, operations and maintenance plan that must be approved by the City during the design phase.

5.4 Design Considerations

Design of a detention system involves an integration of functional integrity, land value, aesthetics, recreation, and safety that merges the system into the urban setting. From the engineering perspective, the design of a stormwater detention basin shall take the following factors into consideration.

5.4.1 Location

In an urban area there are many potential multi-use areas where detention potentially can be incorporated including parking lots, parks, sport fields, roadside ditches/culvert crossings, and naturally depressed areas on individual lots. In addition to engineering considerations, selection of a basin site depends on land ownership, cost, public safety, and maintenance. It is important to apply the concept of multiple uses so that detention facilities can provide open space, landscape amenities, habitat and other functions. Coordination with a landscape architect and other related professionals during the design of a detention facility can make the difference between a soggy, unattractive “hole in the ground” and a multi-functional feature that is an amenity to a development.

5.4.2 Basic Basin Layout

The basic elements for a detention basin (**Figure 5.1**) include: (1) inlet work at the entrance to collect runoff flows, (2) a *forebay* for sediment settlement, (3) *trickle channels* to pass low flows (not required for wet ponds or wetland basins), (4) a *storage basin* to detain flood water, (5) an *outlet structure* to control the release of water, and (6) a maintenance system.

At the basin entrance, energy dissipaters shall be designed for erosion protection. Inflows first fill up the forebay and then overtop the level spreaders along the top of the forebay and flow into the storage basin. Low flows will be released into the trickle channel that runs through the bottom of the basin to the micro pool in front of the outfall structure. In general, the capacity of a trickle channel is 1.0 to 3.0 % of the 100-year peak discharge, and it shall pass 1/3 to 1/2 of the 2-year event. The longitudinal slope for the trickle channel should be between 0.4 and 1.0 % to assure adequate slope for conveyance of low flows on the mild side and to avoid supercritical flow and/or erosive velocities of the high side. The trickle channel drains into the micro pool for stormwater quality control, or directly releases low flows through the outfall concrete vault. The micropool should be sized in accordance with **Chapter 8 – Water Quality**.

The basin length to width ratio should be between 2:1 (L:W) and 3:1 so that the flood flows can sufficiently expand and diffuse into the water body to enhance the sedimentation process. If this range of length to width ratios is difficult to obtain for a proposed pond, the designer may consider using baffles or berms within the pond to adjust the effective length to width ratio.

Slopes on embankments must be designed to maintain bank stability—for reasons of public safety, maintenance, slope stability and others, slopes on earthen embankments shall not be steeper than 4H:1V and on riprap embankments shall not be steeper than 3H:1V. The geometry of the basin shall be designed for multiple flood events. As shown in **Figure 5.1**, the lower storage volume in a basin is shaped by the 10-year event. The volume from the 10-year water level to the weir crest shall provide additional storage to accommodate the 100-year flood event. The freeboard height is from the weir crest up to the brim-full level of the basin and shall be a minimum of 1.0 foot.

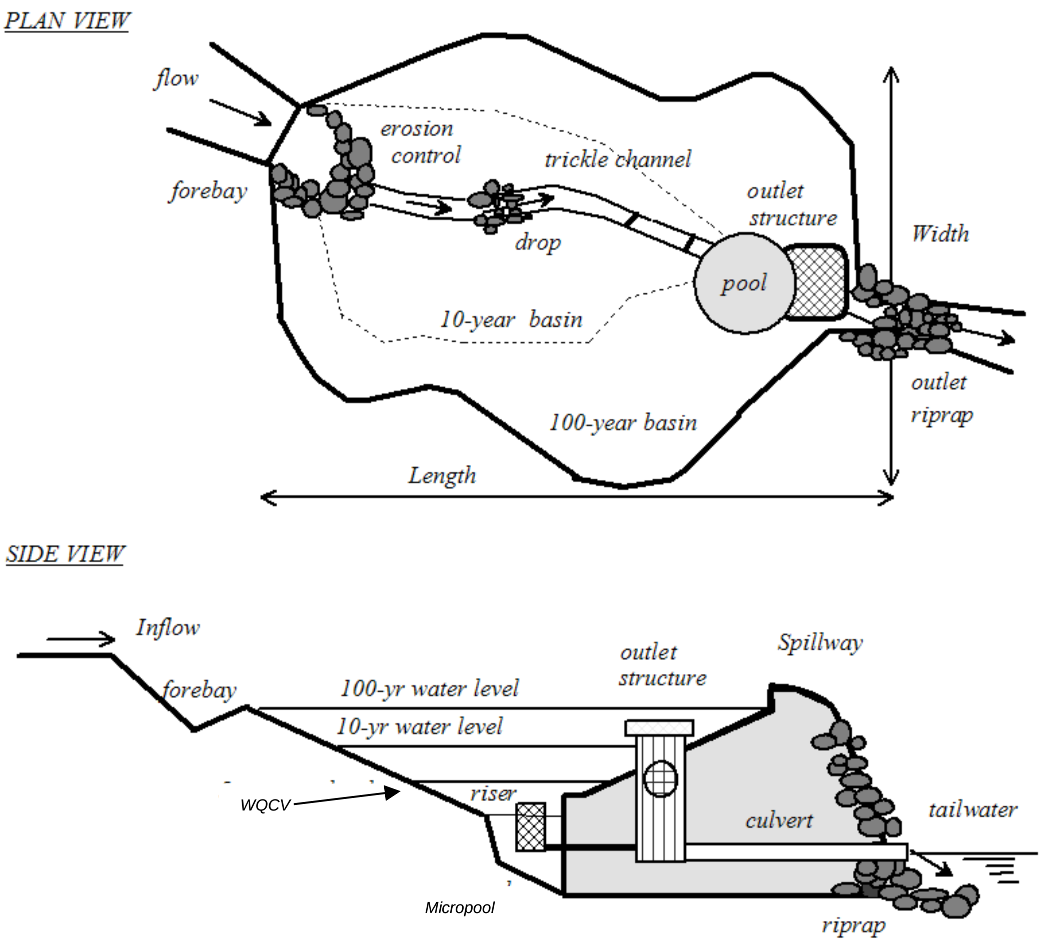

Figure 5.1 General Layout of a Detention Basin for Multiple Storm Events including WQCV

(Note: for sub-urban areas not served by public storm sewer, 5-year event is used for minor event rather than 10-year event as shown)

5.4.3 Inlet and Outlet Works

The inlet and outlet of a detention basin shall be protected from erosion and deposition of sediments. A level spreader is often used at the transition from the forebay to the main body of the pond to disperse the concentrated inflow into uniform sheet flow into the basin. The level spreader may consist of level concrete curbing designed to overflow uniformly form the forebay to the pond or a level concrete ribbon at the edge of the forebay with a gravel filled trench on the upgradient side (low flows initially percolate into the gravel trench—as the gravel trench fills, excess flows spill out uniformly across the concrete ribbon.

Additional information on level spreaders is provided in **Chapter 8—Water Quality**. Riprap rundowns are generally not recommended for pond inflows because of past problems with erosion of rundowns. A forebay, equipped with a level spreader is a preferable alternative.

The outlet works includes a concrete drop box that has orifices and weirs to collect flows into the box, and an outfall conduit to discharge the allowable release. Orifice and weir coefficients must be selected according to operational requirements. A trash rack is critically important with regard to public safety. The surface area of a trash rack should be no less than four (4) times the orifice opening area.

Detention ponds that have an outlet pipe terminating in the gutter of a street, such as through a chase section, present potential ponding and icing problems in the gutter, and create hazards to the traveling public during periods in which the pond is emptying rapidly. Therefore, detention ponds shall be designed to outlet into a storm sewer, drainageway, or other designated drainage system that is reasonably available, as determined by the City. It must be shown that the storm sewer, drainageway, or other designated drainage system where the pond outlets have the capacity to convey the detention pond flows.

The City may allow an outlet to discharge into the gutter in cases where a storm sewer or other drainage system is not reasonably available when the minor storm (5- or 10-year) peak flow for the tributary area is less than 3.5-cubic feet per second, and it must be shown that the street has adequate capacity to convey the excess runoff within the allowable limits. A transition from the outlet pipe 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, and shall be angled toward the downstream slope of the gutter to direct flows downstream instead of perpendicularly into the street. Discharge into the gutter will not be allowed on local streets.

5.4.4 Liners

A storage facility may require an impermeable clay or synthetic liner for a number of reasons. Stormwater detention and retention facilities have the potential to raise the groundwater level in the vicinity of the basin. If the basin is close to structures or other facilities that could be damaged by raising the groundwater level, consideration should be given to lining the basin with an impermeable liner. A liner should be considered in the following circumstances:

1. For detention facilities within ten feet of a building foundation. Even for facilities that are located more than ten feet from a building foundation, a liner may be considered if the facility is upgradient of the foundation, if expansive soils are known to exist, or if there are site specific concerns with the potential for the foundation to be exposed to moisture seeping from the pond. Drainage designers are urged to confer with geotechnical engineers regarding the potential implications of infiltrating stormwater on building foundations.

2. For detention facilities with underlying average seasonal high groundwater within 3 feet of the planned pond bottom or where groundwater levels are determined to be within 3 feet or a nearby building foundation.

3. Areas of existing groundwater or soil contamination.

An impermeable liner may also be warranted in a retention basin where the designer seeks to limit seepage from a permanent pond. Alternatively, there are situations where the designer may seek to encourage seepage of stormwater into the ground. In this situation, a layer of permeable material may be warranted.

5.4.5 Groundwater Impacts and Baseflows

When the detention basin operates as a dry pond, it is necessary to assure that the average time interval between two adjacent storm events allows the basin to dry up. On the contrary, if the detention basin is designed to be a wet pond, care must be taken to assess infiltration to and exfiltration from the local groundwater table. It is necessary to carefully evaluate the water budget between the groundwater and surface water, and associated hydrologic losses to ensure that the pond will remain wet.

An important component of the hydrologic budget for a pond in an urban setting can be baseflows generated from irrigation return flows, snowmelt throughout the spring and early summer and other urban water uses. For detention facilities such as wet ponds and constructed wetland basins, baseflows should be characterized on a seasonal basis and factored into the hydrologic budget for the facility.

5.4.6 Tailwater Effects

The performance of an outlet is controlled by the headwater in the basin and the tailwater in the downstream water receiving system (such as the water surface elevation in the storm sewer, stream or lake). It is important to assess the downstream tailwater conditions when estimating the release capacity from the basin under design.

5.4.7 Maintenance Access

All-weather, stable access to the bottom, inflow, forebay, and outlet works areas shall be provided for maintenance vehicles. Maximum grades should be 10 percent, and a solid driving surface of gravel, rock, concrete, or gravel-stabilized turf should be provided.

5.4.8 Retaining Walls

The use of retaining walls within detention basins is generally discouraged due to the potential increase in long-term maintenance costs and concerns regarding the safety of the general public and maintenance personnel. If retaining walls are proposed, footings shall be located above the WQCV. Wall heights not exceeding 30-inches are preferred, and walls shall not be used on 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 2 (horizontal) to 1 (vertical). 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 and may not be used for parking or as a driveway.

5.4.9 Other Considerations

Operation of a stormwater detention system may also involve many institutional issues, including the infrastructure needed to ensure proper planning, design, construction, operation, and maintenance. A monitoring or regulatory mechanism is required to ensure that the approved design is constructed, operational integrity is implemented, and maintenance is regularly provided.

Other considerations include public safety, facility access, landscaping, and aesthetics. Locating detention basins in areas reserved to meet site landscaping requirements is generally encouraged. Incorporating detention into landscaped areas generally creates detention facilities which are easy to inspect, are relatively easy to maintain, and can enhance the overall aesthetics of a site.

5.5 Design Procedure

The City of Aspen recommends that a detention basin be designed with two levels of release controls (minor [5- or 10-year] and major [100-year] events), in addition to the water quality capture volume (WQCV) control (if WQCV is being provided in detention basin). Although the detention basin is shaped to accommodate the minor and major storms, the operation of a detention basin needs to accommodate events of all kinds, including events that are greater than the 100-year event. **Figure 5.2** outlines the design steps beginning with basin site selection. During the initial design stage, little information is available. Therefore, it is suggested that the basin geometry be approximated by a triangular, rectangular or circular shape, and the basin operation be approximated by the inlet control capacity determined by weir and orifice hydraulics only. Of course, when the project moves to the final design, the preliminary design will be refined with more information. For instance, the tailwater and backwater effects must be considered to refine the basin characteristic curves, and the basin performance must be evaluated using hydrologic routing techniques. The below procedure will be an iterative process until all design criteria and safety concerns are satisfied.

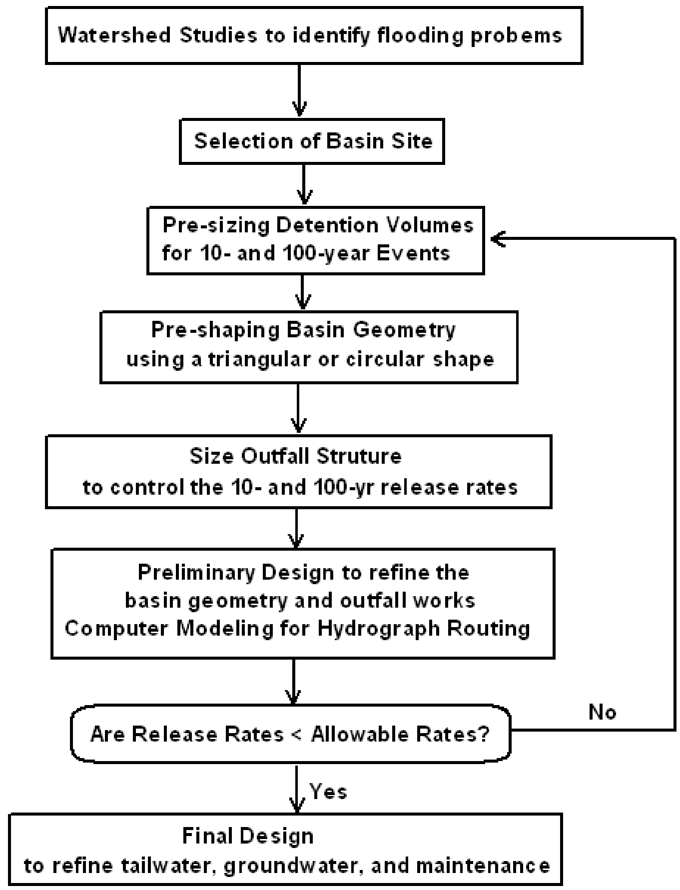

Figure 5.2 Flow Chart for Detention Basin Design

5.6 Initial Design Detention Volumes

5.6.1 Rational Volume Method for Detention Volume (Watershed <90 acres)

The Federal Aviation Administration (FAA) procedure was modified to provide a reasonable estimate of the required storage volume for small on-site detention facilities (FAA 1996, Guo 1999a). This method is a rational-formula based approach that is only applicable to small urban watersheds less than 90 acres. In this approach, the design rainfall duration is unknown. The engineer shall investigate the required detention volumes for a range of rainfall durations, starting from the time of concentration, T_c, until the volume is maximized. The computational steps are as follows:

1. Select a design event, 10 or 100-year.

2. Select rainfall duration, T_d, ≥ T_c. For this method, multiple event durations are chosen until the storage volume is maximized. The design duration should be chosen to be greater than or equal to the time of concentration.

3. Calculate design rainfall intensity using the rainfall Intensity-Duration-Frequency (IDF) curve (**Chapter 2 - Rainfall**) or formula:

$$I = \frac{29P_1}{(10+T_d)^{0.789}}$$ **(Equation 5-1)**

Where I = rainfall intensity in inch/hour, T_d = duration in minutes, and P_1 = one-hour rainfall depth in inches for the design frequency (see **Chapter 2 – Rainfall**).

4. Calculation of inflow volume:

$$V_i = \frac{1}{720} C\ I\ T_d\ A$$ **(Equation 5-2)**

Where V_i = inflow volume in ft^3, C = runoff coefficient, and A = tributary area in ft^2.

5. Calculation of outflow volume, V_o:

$$V_o = 30(1+\frac{T_c}{T_d})Q_a T_d$$ **(Equation 5-3)**

Where V = outflow volume in ft^3, T_c = time of concentration in min, T_d = rainfall duration in min, and Q_a = allowable release rate (peak flow or runoff from the design storm, **Equation 3-1**) in cfs.

6. Volume difference, V_d, is calculated as:

$V_d = V_i - V_o$ for the selected rainfall duration. **(Equation 5-4)**

Repeat Steps 2 thorough 6 for another rainfall duration until the volume difference is maximized. The design detention volume, S, is determined as the maximum storage volume determined from evaluating multiple rainfall durations. This method is sometimes referred to as the "bow string" method because the shape of the curve of storage versus event duration is shaped like a bow—the bow arcs like a parabola with the required storage volume increasing initially as the duration of rainfall increases beyond the time of concentration, eventually reaching a maximum value and then decreasing again as the duration increases beyond the critical design duration. This is illustrated in the example below in **Section 5.6.2.**

It is noted that the design rainfall duration for detention volume sizing is always longer than the time of concentration of the watershed.

5.6.2 Design Example for Rational Volume Method

A commercial development has a total tributary area of 2 acres. Under the post-development imperviousness of 80%, the runoff coefficient for the 100-year event is 0.86 and the time of concentration for the project site is calculated to be 12 minutes. The 100-year 1-hour precipitation depth is 1.69 inches. The allowable release rate is already determined to be 5.0 cfs for the 100-year event. For rainfall duration of 15 minutes, the required detention volume is calculated as:

$$I_d = \frac{29 \times P_1}{(10+T_d)^{0.79}} = \frac{29 \times 1.69}{(10+15)^{0.79}} = 3.87 \text{ inch/hour}$$

$$V_i = \frac{1}{720} C\ I\ T_d\ A = \frac{1}{720} \times 0.86 \times 3.87 \times 15 \times (2 \times 43560) = 6035 \text{ cubic feet}$$

$$V_o = 30(1 + \frac{T_c}{T_d}) Q_a T_d = 30(1 + \frac{12}{15}) \times 5.0 \times 15 = 4050 \text{ cubic ft}$$

$$V_d = V_i - V_o = 6035 - 4050 = 1985 \text{ cubic ft}$$

Repeat this above procedure as shown in **Table 5.1**. The 100-year detention volume for this example is found to be 2180 cubic feet under rainfall duration of 21 minutes. It is imperative to continue these calculations with increasing durations until the storage volume is maximized and begins to decrease. See **Figure 5.3** for a graphical depiction of the "bow string."

Table 5.1 Detention Volume by Rational Volume Method

Inputs				
Area =		2.0	acres	
tc =		12	min	
P1 =		1.69	in	
Release =		5.0	cfs	
C =		0.86		
Calculations				
Duration	Rainfall Intensity	Inflow Volume	Outflow Volume	Storage Volume
(min)	(in/hr)	(ft^3)	(ft^3)	(ft^3)
15	3.87	6035	4050	1985
18	3.54	6623	4500	2123
21	3.26	7130	4950	2180
24	3.03	7576	5400	2176
27	2.84	7973	5850	2123

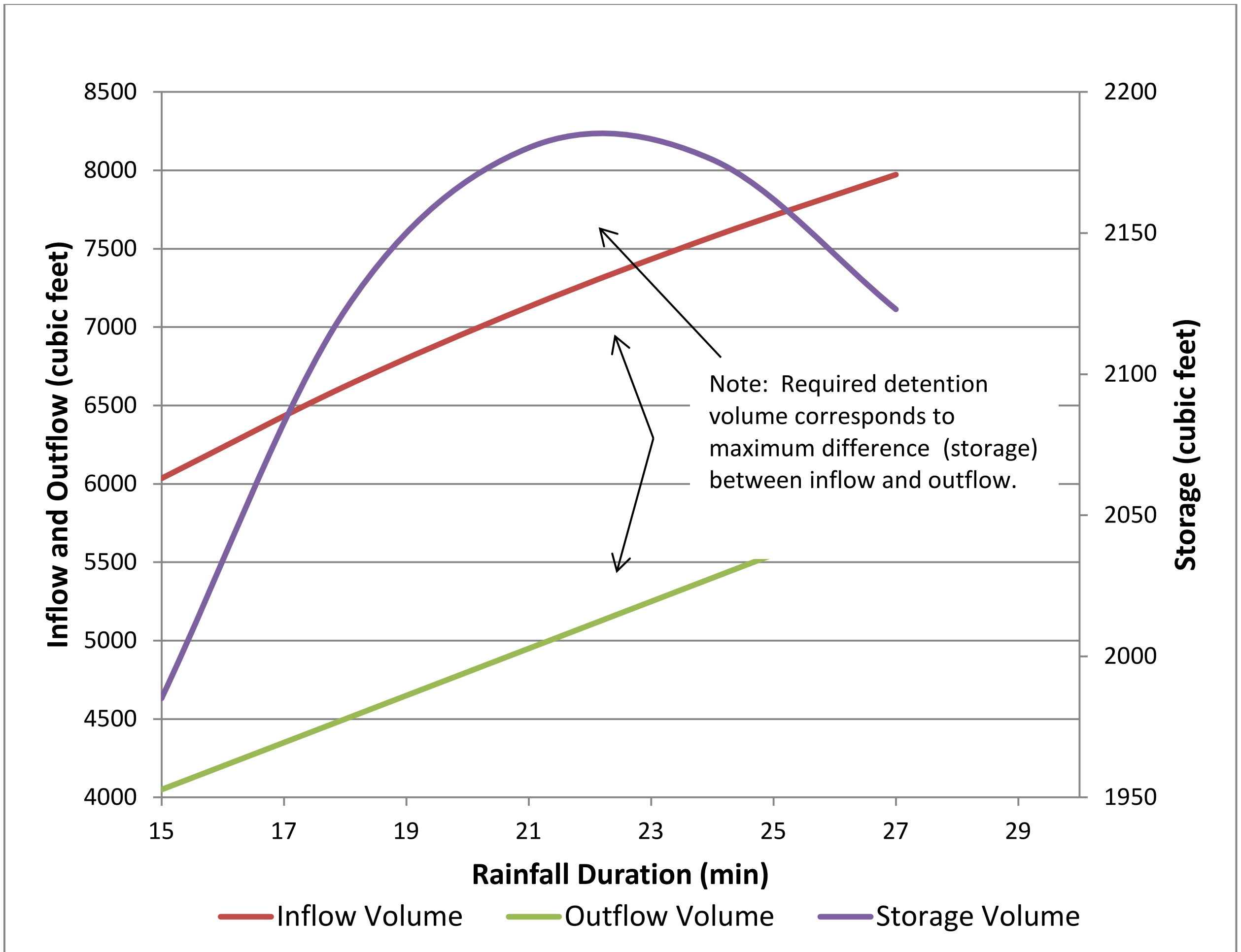

Figure 5.3 Detention Volume Example "Bow String"

5.6.3 Hydrograph Method for Detention Volume

The detention volume can be calculated using the hydrograph method as the difference between the inflow and outflow hydrographs. This method is applicable to all sizes of watershed as long as the inflow hydrograph is readily available. The inflow hydrograph to a detention basin is often generated from the developed watershed condition using CUHP or SWMM computer programs. As illustrated in **Figure 5.4**, the detention volume is the volume difference between the inflow and outflow hydrographs from the beginning of the event to the time when the allowable release occurs on the recession hydrograph. At the planning stage, the outlet hydraulics have not yet been developed. For convenience, the outflow hydrograph is approximated by a triangular shape with its peak flow equal to the allowable release (Malcom 1982, Guo 1999b). As shown in **Figure 5.4**, the outflow rate, O(t), at time t on the linear rising limb is estimated as:

$$O(t) = \frac{Q_a}{T_P} t \quad \text{for } 0 \le t \le T_P \qquad \textbf{(Equation 5-5)}$$

in which,

$O(t)$ = linear outflow rate in cfs,
Q_a = allowable release in cfs,
T_p = time to peak in minutes on outflow hydrograph, and
t = elapsed time in minutes.

If the calculated outflow rate is greater than the inflow rate, the outflow rate should be set equal to the inflow rate.

The detention volume is the sum of the volume difference between the inflow hydrograph and the rising limb of the outflow hydrograph as:

$$S = \sum_{t=0}^{t=T_P} [I(t) - O(t)] \Delta t \times 60 \qquad \textbf{(Equation 5-6)}$$

in which

S = design detention volume in ft^3,
I(t) = inflow rate in cfs at time *t*, and
Δt = time increment such as five (5) or ten (10) minutes.

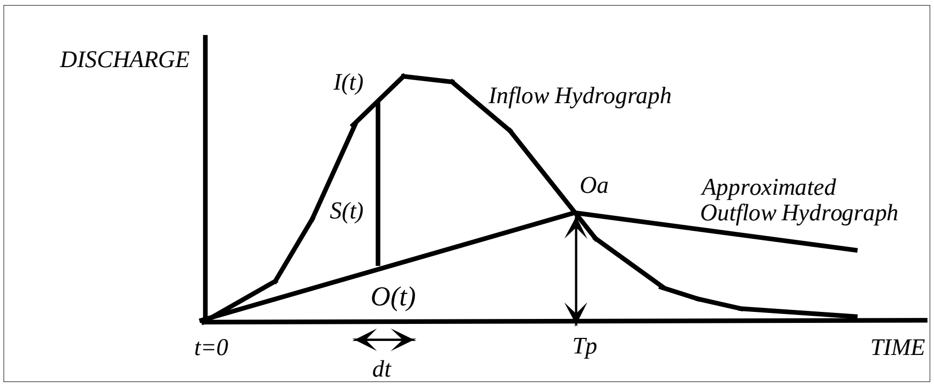

Figure 5.4 Detention Volume by Hydrograph Method

5.6.4 Example for Hydrograph Method for Detention Volume

As shown in **Table 5.2**, the 100-year inflow hydrograph for the 2-acre commercial development was generated by the CUHP05 computer model. The 100-year peak flow is calculated to be 7.9 cfs. The 100-year allowable release from the watershed is set to be 5 cfs at *t* = 30 minutes. Under the assumption of a linear rising outflow hydrograph, the linear outflow can be calculated as follows:

$$O(t) = \frac{5}{30} t$$

Where the calculated outflow is greater than the inflow listed in **Table 5.2**, the outflow is assumed equal to the inflow.

Using five (5) minutes as the time increment, the accumulative storage volume, *S*(*t*) at time *t*, is computed as:

$$S(t) = \sum_{t=0}^{t=30} [I(t) - \frac{5}{30} t] \times (5 \times 60)$$

Incremental volume is calculated as the inflow minus the outflow rate times the time increment (300 seconds) for each time increment.

As shown in **Table 5.2**, the linear outflow column and the cumulative volume column provide the paired volume and outflow values, as the approximate basin's storage-outflow curve. At T_p= 30, the design detention volume is found to be 2130 cubic ft which is similar to the Rational Volume Method in **Section 5.6.2**.

Table 5.2 Preliminary Storage Volume-Outflow Curve by Hydrograph Method

Input				
Inflow hydrograph is given from SWMM				
Maximum outflow rate		5	cfs	
Time of maximum outflow		30	minutes	
Calculations				
Time	100-year Inflow I(t)	Linear Outflow O(t)	Incremental Volume	Cumulative Volume S(t)
(min)	(cfs)	(cfs)	(ft^3)	(ft^3)
0	0.0	0.00	0	0
5	0.0	0.00	0	0
10	0.6	0.60	0	0
15	2.1	2.10	0	0
20	5.0	3.33	500	500
25	7.9	4.17	1120	1620
30	6.7	5.00	510	2130
35	4.5	4.50	0	2130

5.7 Initial Shaping of a Storage Basin

The initial shaping of a storage basin provides a starting point for defining the stage-storage relationship. The stage-storage relationship will be refined during the preliminary and final design phases of the project. The initial shaping can be approximated using a regular geometry such as a triangular basin. For instance, the base area of a triangular basin in **Figure 5.5** is calculated by the base width, *B*, and length, *L*, as:

$$A_1 = 0.5BL \quad \textbf{(Equation 5-7)}$$

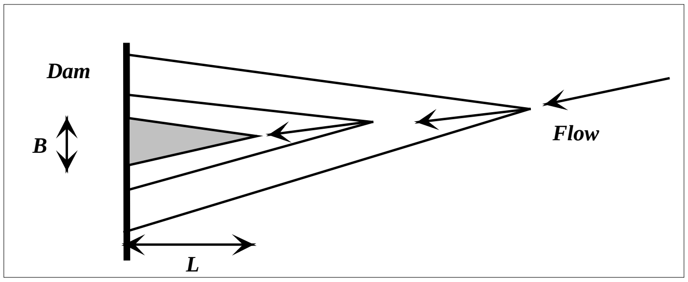

Figure 5.5 Pre-shaping for a Triangular Basin

Assuming that the width and length of the triangular cross section increase uniformly with depth, the top cross area is:

$$A_2 = \frac{1}{2}(B + 2zh)(L + 2zh)$$ **(Equation 5-8)**

Where

A_1 = lower base area,
A_2= upper area,
h = vertical spacing between two sections, and
z = average side slope between these two adjacent layers.

The volume, V, between these two triangular layers is approximated as:

$$V \cong \frac{1}{2}(A_1 + A_2)h$$ **(Equation 5-9)**

The required side slope, no steeper than 4H:1V, between these two adjacent layers can be incorporated into the volume calculation. Using the initial sizing and shaping procedure, the approximate *stage-storage* and *stage-contour area* can then be established. Upon completion of the initial design, the engineer can begin to work on the topography at the basin site to refine the basin geometry. The City encourages designers to collaborate with landscape architects to develop storage facilities that are attractive visually, fit into the fabric of the landscape, and enhance the overall character of the neighboring area.

5.8 Initial Outlet Works

Outlet works are the structures that control the depth of water and release rates from storage facilities. The outlet system for a basin must be designed with a full understanding of the downstream tailwater effects. The performance of the outfall culverts must be evaluated for a range of headwater depths at the entrance, and tailwater depths at the exit. **Figures 5.6 and 5.7** show typical designs that may be used. These designs incorporate the water quality capture volume (WQCV), and include a perforated (or orifice) plate to release the WQCV. The minor storm release is controlled by the size of the orifice at the bottom of the drop box. The trash rack at the top of the drop box shall have a surface area at least four (4) times the orifice opening area. The outfall culvert at the bottom of a second drop box should be sized to convey 120% of the intended design flow so it does not act as a constriction. A minimum of 1-foot of freeboard should be provided above the design water surface elevation.

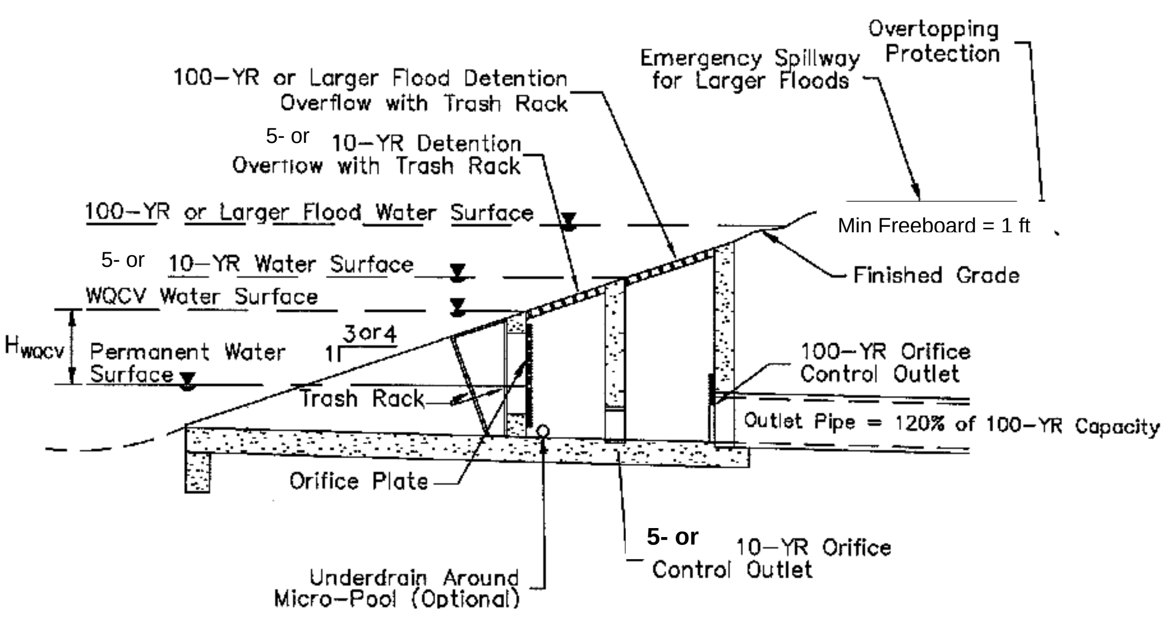

Figure 5.6 Drop Box Outlet with Conduit to Release the 100-year Flow (5- or 10-year Minor Event)

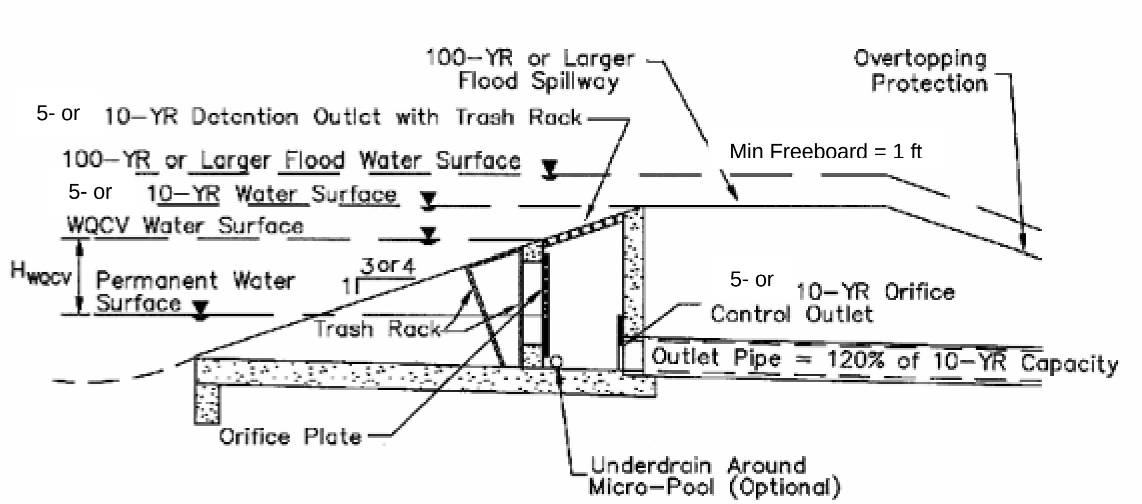

Figure 5.7 Drop Box Outlet with Overtopping Spillway to Release 100-year Flow (5- or 10-year Minor Event)

The hydraulic capacities of the various components of the outlet works (orifices, weirs, pipes) can be determined using standard hydraulic equations (Brown et. al. in 1996, King and Brater in 1976). The discharge pipe of the outlet works functions as a culvert. A rating curve for the entire outlet can be developed by combining the rating curves developed for each of the components of the outlet and then selecting the most restrictive element that controls a given stage for determining the composite total outlet rating curve (Stahre and Urbonas, 1990).

Note that when detention storage volumes are very small, an outlet similar to what is illustrated in **Figures 5.6 and 5.7** may not be practical or necessary. For very small detention volumes, the designer should refer to the guidance provided for bioretention facilities in **Chapter 8 – Water Quality**.

In addition to the outlet designs depicted above, there are a number of variations that may be successfully applied in Aspen. The designer is encouraged to review other criteria manuals including the UDFCD Urban Storm Drainage Criteria Manual and design details from Douglas County and Arapahoe County, Colorado that provide details of self-contained micropools for small sites that may be applicable in Aspen.

5.8.1 Orifices

Multiple orifices may be used to collect water flow into the drop box. The flow capacity of each orifice can be superimposed to develop the total flow. For a single orifice as illustrated in **Figure 5.8**, orifice flow can be determined as:

$$Q_o = C_o A_o \sqrt{2gH_o}$$ **(Equation 5-10)**

in which:

Q_o = orifice flow rate (cfs),
C_o = discharge coefficient,
A_o = opening area of orifice (ft^2),
H_o = effective headwater depth (ft), and

g = gravitational acceleration (32.2 ft/sec^2).

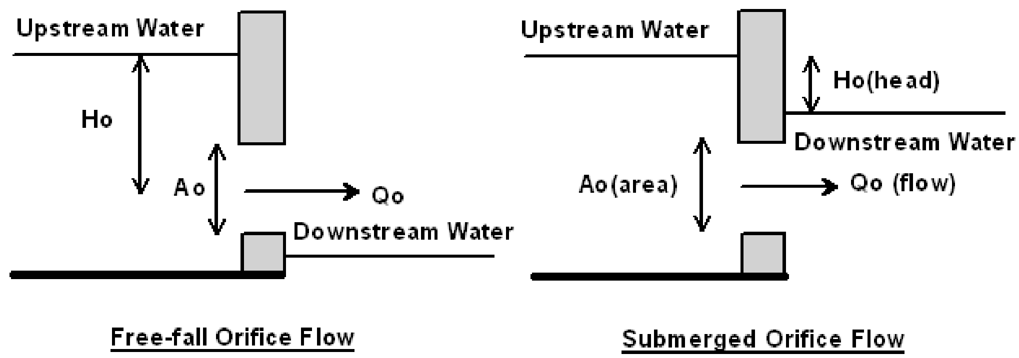

Figure 5.8 Orifice Flow

If the orifice discharges as a free-fall outfall, the effective head is measured from the upstream water surface elevation to the centroid of the orifice opening. If the orifice is submerged, the effective head is the difference in elevation between the upstream and downstream water surfaces. A discharge coefficient of 0.6 is recommended for square-edged, uniform orifice entrance conditions. For ragged-edged orifices, such as those resulting from the use of an acetylene torch to cut orifice openings in corrugated pipe, a value of 0.4 should be used (ASCE and WEF, 1992). Volume 3 of the Denver Urban Storm Drainage Criteria Manual provides additional information on orifice sizing, spacing of multiple orifices, acceptable materials and calculations. The designer should refer to information on Extended Dry Detention Basins in Volume 3 for additional information and guidance.

5.8.2 Weirs

Typical sharp-crested and broad-crested weirs are illustrated in **Figure 5.9**. The general formula for weir flow is described as:

$$Q_w = C_w (L_w - 0.1NH_w) H_w^{1.5} \qquad \textbf{(Equation 5-11)}$$

$$C_w = 3.27 + 0.4\frac{H_w}{H_c} \qquad \textbf{(Equation 5-12)}$$

in which

Q_w = weir flow (cfs),
Cw = weir coefficient,
L_w = horizontal weir length (ft),
N = number of end contraction,
H_c = height of weir crest (ft), and
H_w = headwater depth above the weir crest (ft).

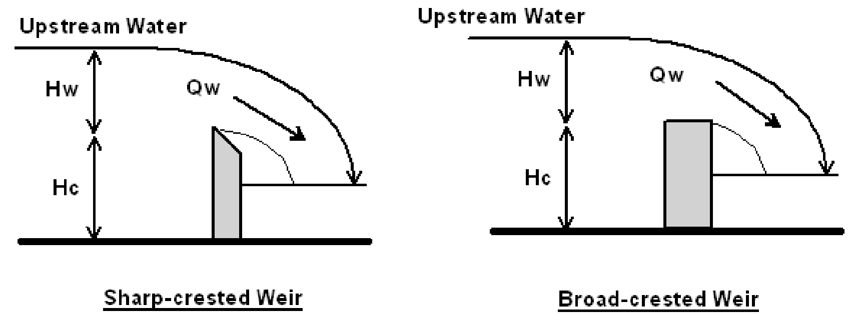

Figure 5.9 Sharp and Broad-crested Weirs

In practice, N = 0, 1, or 2, depending on the weir geometry. Without details of the weir layout, it is acceptable to assume that N = 0. **Equation 5-11** is also applicable to broad-crested orifices when N = 0 and C_w = 3.0. The discharge through a V-notch weir is shown in **Figure 5.10**. The stage-flow relationship for a V-notch weir is a function of the central angle and headwater depth as:

$$Q_V = 1.38\tan(\frac{\theta}{2})H_v^{2.5}$$ **(Equation 5-13)**

in which

Q_v = discharge (cfs),
θ = angle of V-notch in degrees, *and*
H_v = headwater depth above the apex of the V-notch (ft).

A trapezoidal weir can be formed by a rectangular weir and two half-notch weirs. The flow through a trapezoidal weir is estimated as the sum of these two individual weirs.

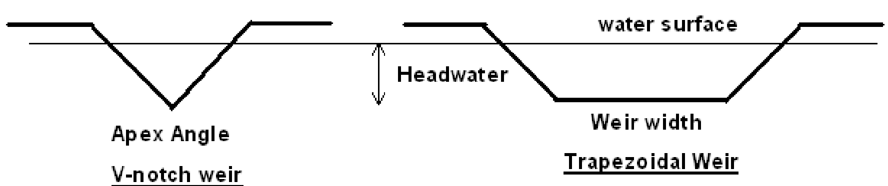

Figure 5.10 V-notch Weir and Trapezoidal Weir

5.8.3 Culverts

Water enters the concrete drop box in **Figure 5.11** from the orifices and weirs. The outfall pipes are usually short enough, 200 to 300 feet, to act like a culvert. Outflow culverts should have a minimum diameter of 15 inches. The operation of the culvert is affected by the tailwater depth. When the culvert is under a full flow condition, the energy balance between Sections 1 and 2 is written as:

$$H = Y + LS_o = (K_e + K_x + K_b + K_n)\frac{V_c^2}{2g} + \frac{V_c^2}{2g}$$ **(Equation 5-14)**

$$K_n = 184.1\frac{N^2 L}{D^{\frac{4}{3}}}$$ for a circular pipe **(Equation 5-15)**

$$K_n = 29.0\frac{N^2 L}{R^{\frac{4}{3}}}$$ for a non-circular pipe **(Equation 5-16)**

in which

- H = water surface elevation at the entrance in ft,
- Y = headwater depth in ft at the entrance,
- L = length of the pipe in ft,
- S_o = pipe slope in ft/ft,
- D = diameter or height of barrel,
- K_e = entrance loss coefficient (0.2 to 0.5),
- K_x = exit loss coefficient (0.5 to 1.0),
- K_b = bend loss coefficient as shown in **Table 5.3,**
- K_n = friction coefficient,
- V_c = flow velocity,
- N = Manning's roughness coefficient (0.015 for concrete pipe),
- d = tailwater depth, and
- R = hydraulic radius.

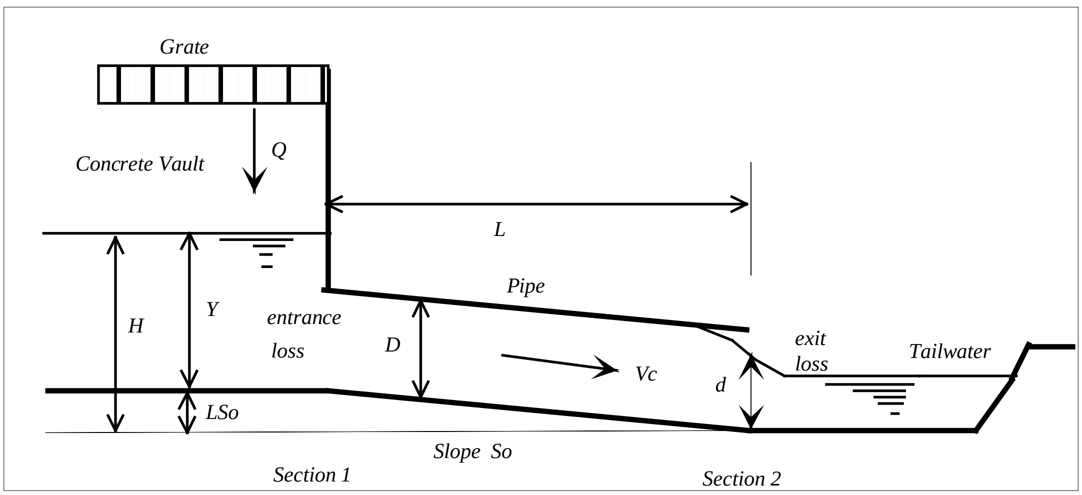

Figure 5.11 Outlet Culvert Hydraulics

If the tailwater depth is not known, it is suggested that the tailwater depth be estimated by the average of the culvert diameter and critical depth, d_c, as:

$$d = \frac{D + d_c}{2}$$ **(Equation 5-17)**

Let K be the sum of all the loss coefficients as:

$$K = K_e + K_x + K_b + K_n$$ **(Equation 5-18)**

The release capacity of the pipe, Q_P, is

$$Q_P = V_c A_c = A_c\sqrt{\frac{1}{K+1}}\sqrt{2g\left(Y + LS_o - d\right)}$$ **(Equation 5-19)**

in which A_c = pipe cross sectional area. **Equation 5-19** is similar to the orifice equation except that the orifice coefficient is calculated using the sum of all loss coefficients.

Table 5.3 Bend Loss Coefficients

Bend Angle in Degrees	Bend Loss Coefficient
	0.050
22.500	0.100
45.000	0.400
60.000	0.640
90.000	1.320

5.8.4 Spillway Sizing

The overflow spillway of a storage facility should be designed to pass flows in excess of the design flow of the outlet works. When the storage facility falls under the jurisdiction of the Colorado State Engineer's Office (SEO), such as the Dam Safety requirements, the spillway's design storm is prescribed by the SEO (SEO 1988). If the storage facility is not a jurisdictional structure, the size of the spillway design storm should be based upon the risk and consequences of a facility failure.

5.9 Preliminary Design

The preliminary design stage consists of refining the design of the basin (size, shape and elevation) and outlet structure (type, size, geometry). During preliminary design, it is necessary to address such subjects as public safety, appearance, water quality, access, maintenance, multipurpose benefits and other concerns of this kind. This is an iterative procedure that can use a variety of reservoir routing schemes to determine the detention basin's performance under the given stage-storage-discharge characteristics. The stage-storage-discharge characteristics are modified as needed until the outflow from the basin meets the specified allowable flow rates. No description of the theory of reservoir routing is provided in this Manual. This subject is described well in many hydrology reference books (e.g., Viessman and Lewis 1996; Guo 1999b). The computer design tool, UD POND, is available at www.UDFCD.org. It provides a reliable and relatively easy tool to facilitate detention basin design.

5.10 Final Design

The final design of the storage facility entails detailed hydraulic, structural, geotechnical, and civil design. This includes detailed grading of the site, embankment design, spillway design, outlet works hydraulic and structural design and detailing, trash rack design, consideration of sedimentation and erosion potential within and downstream of the facility, liner design (if needed), etc. For applications where pumping will be required (underground detention for example), the designer may need to collaborate with a mechanical or electrical engineer. Collaboration among geotechnical engineers, structural engineers, hydrologic and hydraulic engineers, land planners, landscape architects, biologists, and/or other disciplines is encouraged during the final design, so that attractive and safe multipurpose facilities are constructed that become community assets rather than eyesores.

5.11 References

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Chapter 6 - Floodplains

6.1 Overview

The goal of floodplain management is to reduce the potential risks to both existing and future developments, and infrastructure, in the 100-year floodplain. Over the years, the philosophy has changed from “keep water from people” by using structural controls to block or direct flood waters, to “keep people from water” through floodplain regulations, public education, design criteria, and other flood loss reduction strategies administered as part of Aspen’s stormwater management program.

This chapter outlines floodplain management guidelines that are intended to ensure that future improvements and developments, including but not limited to, roads, bridges, utilities, residential and commercial developments, do not impact or are not impacted by the floodplain and/or floodway and are in compliance with the National Flood Insurance Program (NFIP). All of the following restrictions and guidelines are part of the NFIP, and are required by the Federal Emergency Management Agency (FEMA), the Colorado Water Conservation Board (CWCB), and the City of Aspen Municipal Code Chapter 8.50.

Floodplain management is a decision-making and regulatory process, the purpose of which is to achieve the wise use of local floodplains. “Wise use” means to define and make choices among often competing demands for floodplain locations. It includes the responsibility to regulate uses that are compatible with, and balance the following goals: (1) minimize risk to human life and risk of property damage, (2) preserve and protect the natural and beneficial functions of floodplains, and (3) allow for economic development where necessary and appropriate.

City floodplain policy is based upon the following principles:

- Protect human life and health.
- Protect the storage capacity of floodplains and assure retention of sufficient floodway area to convey flood flows which can reasonably be expected to occur.
- Protect the hydraulic characteristics of the small watercourses, including gulches, streams, and artificial water channels used for conveying floodwaters.
- Minimize damage to public facilities and utilities located in Special Flood Hazard Areas.
- Minimize expenditure of public money for costly flood control projects.
- Alert potential property buyers that a property is in a Special Flood Hazard Area.
- Ensure that those who occupy the Special Flood Hazard Areas assume responsibility for their actions.
- Minimize the need for rescue and relief efforts associated with flooding that are generally undertaken at the expense of the public.
- Minimize prolonged business interruptions.
- Maintain a stable tax base by providing for the use and development of Special Flood Hazard Areas so as to minimize future flood blight areas.

6.2 Floodplain Development Regulations

One hundred-year (100-year) floodplains consist of the entire area inundated by the 100-year flood. Within the floodplain is the floodway. The floodway is defined as the channel plus any adjacent floodplain areas that must be kept free of encroachment so that the 100-year discharge can be conveyed **with no rise in the water surface above the base flood elevation (BFE)**.

The base flood elevation is the water surface elevation resulting from the 100-year flood. The BFE must be determined using the most updated FIS, not the FIRM.

The City of Aspen regulates FEMA identified floodplains (jurisdictional floodplains) as well as flood areas that have not been identified by FEMA (non-jurisdictional floodplains). The City's regulations follow those of FEMA (in some cases more stringent), unless the area in question is in a City defined 'Stream Margin', in which case the applicant must follow the criteria that offers the most protection.

The purpose of these regulations is to control the alteration of the natural floodplains; prevent or regulate the construction of flood barriers which will unnaturally divert flood waters or which may increase flood hazards in other areas; restrict or prohibit uses which may result in damaging increases in erosion or in flood heights or velocities; protect and preserve the natural riparian corridor; and to control filling, grading, dredging, and other development which may increase flood damages.

The City of Aspen requires that all proposed development and/or redevelopment in the 100-year floodplain, not just construction of buildings, be reviewed and permitted in compliance with this Manual and Chapter 8.50 of the City Code. The Development Engineer administers the ordinance through the issuance of permits, inspection of construction, and collection and maintenance of FEMA Elevation Certificates to show the final elevation of new and substantially improved construction. Note that garages, sheds, additions, athletic courts, driveways, and fill all require permits from City of Aspen Engineering Department.

6.2.1 Jurisdictional Floodplains

Jurisdictional Floodplains are FEMA designated floodplains, also known as special flood hazard areas and the 100-year floodplain. The 100-year floodplain information generated and/or published by FEMA can be found in "The Flood Insurance Study for Pitkin County and Incorporated Areas," dated October 19, 2004, or on the accompanying Flood Insurance Rate Map (FIRM) for Aspen. The FIS and FIRM can be located on the web at www.fema.gov or at the City of Aspen Engineering Department.

6.2.2 Non-Jurisdictional Floodplains

Non-jurisdictional floodplains are flood hazard areas not identified by FEMA. Flood hazard areas are defined as those areas where the potential for flooding poses a potential threat to public health, safety, and welfare. The City of Aspen requires hydrologic and/or hydraulic analysis of the potential flooding for property determined by the City of Aspen, and approved by the Colorado Water Conservation Board, to have potential flood hazards. Criteria for identifying unmapped flood hazard areas includes a drainage area of more than 130 acres, and may also include areas designated as "Zone A" by FEMA, areas with a history of flooding on the property or in the vicinity, and/or other factors.

6.2.3 City of Aspen Stream Margin

Based on the Aspen City Code Section 26.435.010.B; "areas located within one hundred (100) feet, measured horizontally, from the high water line of the Roaring Fork River and its tributary streams or areas within the one-hundred-year floodplain where it extends one hundred (100) feet from the high water line of the Roaring Fork River and its tributary streams are within a Flood Hazard Area (Stream Margin). Development in these areas are subject to heightened review, the Stream Margin Review, and restrictions to reduce and prevent property loss by flood, to ensure the natural and unimpeded flow of watercourses, and to protect and preserve the natural riparian buffer. Review shall encourage development and land uses that preserve and protect existing watercourses and the habitat surrounding those watercourses as important natural features".

6.3 Requirements for Development in Floodplains

A Floodplain Development Permit (see **Appendix D** for a copy of the permit**) is required for any development, redevelopment or construction that will occur within jurisdictional and non-jurisdictional floodplains.** Those activities include, but are not limited to, building or enlarging a structure, remodeling or improving a structure, the placement of a manufactured home, mining, dredging, filling, grading, paving, excavating, and drilling. A Floodplain Development Permit Application must include detailed results from a hydraulic analysis in accordance with FEMA guidelines, that:

- Determines the effects of the proposed improvements on the 100-year flood elevation
- Documents any necessary revisions to the floodplain delineation
- Compares pre-project and post-project conditions

It is a requirement of this Chapter that any development or redevelopment of residential, non-residential, utilities or any other kind of development or construction, review and address how the activity is related to the plans set forth in the 2001 Master Drainage Plan for the City of Aspen.

6.3.1 Floodplain Delineation

Flood hazard areas should be clearly identified, studied, and delineated on proposed project plans in order to regulate improvements and to reduce the amount of losses due to flooding.

The FEMA 100-year floodplains for the Roaring Fork River, Hunter Creek, Castle Creek, and Maroon Creek are delineated on the FIRM for Pitkin County and Incorporated Areas dated June 4, 1987. The FIS and FIRM can be located on the web at www.fema.gov or at the City of Aspen Engineering Department.

Depending on the topography of the property, past history of flooding on the property or in the vicinity, "Zone A" designation, proposed land use for the property, or other factors, the City might require delineation of new floodplain boundaries, cross-sections, base flood elevations, and/or other information in areas where a FEMA designated floodplains do not exist. The new floodplain information should be approved by the Colorado Water Conservation Board as areas of flood hazard.

Floodplain delineation is prepared using topographic maps, hydrologic analysis, and hydraulic calculations.

6.3.2 Hydrologic and Hydraulic Analysis

The City of Aspen requires hydrologic and/or hydraulic analysis of the potential flooding for properties located in FEMA floodplains, properties receiving drainage from more than 130 acres, or as determined by the City of Aspen to have potential flood hazards.

Hydrologic analysis involves the determination of discharge (peak rate of flow) in cubic feet per second, based on a scientific analysis of the physical flow process. Hydraulic analysis involves the determination of flood elevations and velocities based on scientific analysis of the movement and behavior of floodwaters in channels or basins. The following information is required for existing watershed and floodplain conditions (pre) and the conditions after the development (post).

- Hydrologic analysis for the 10-, 50-, and 100-year storm frequency discharges,
- Water surface profiles for the 10-, 50-, and 100-year flood frequencies,
- 100-year floodplain boundary,

- Effects of the proposed improvements on the 10-, 50-, and 100-year flood elevations,
- Calculations that show that the BFE is not increased; and
- Completion of a No-rise Certification (procedures and certificate are located in Appendix D).

6.3.3 Floodplain Modifications and Map Revisions

If modification of a FEMA-designated floodplain is proposed, a floodplain revision request should be submitted to FEMA for their review and approval. The applicant shall submit a request for a Conditional Letter of Map Revision (CLOMR) before the project, and then submit a Letter of Map Revision (LOMR) request upon project completion.

6.3.4 Building in the Floodplain

In order to construct or make improvements to buildings/structures in the 100-year floodplain, the lowest floor of the structure must be elevated to meet or exceed the base flood elevation (BFE) with one foot of freeboard. The BFE must be determined using the most updated FIS, not the FIRM. Prior to issuance of a Certificate of Occupancy, an Elevation Certificate needs to be approved by the Floodplain Administrator for the City.

Development in or near the floodway is prohibited if the encroachment causes rise in the water surface above the BFE.

6.3.4.1 Elevation

New construction and substantial improvement of residential structures must be elevated to the point where the lowest level is at or above the BFE with one foot of freeboard in one of the following three ways:

- Elevation on fill
- Elevation on piles, posts, piers or columns
- Elevation onto a non-livable space such as a crawlspace with flood vents

6.3.4.2 Elevation Certification

An Elevation Certification is an official form of the NFIP that ensures a property's lowest floor is elevated above the base flood elevation. **Both the City and FEMA require that the form be used for new construction and for substantial improvements to existing buildings, both to comply with the ordinance and for the owner to obtain a flood insurance policy.** See **Appendix D** for a copy of FEMA's Elevation Certificate. The form may be completed by a land surveyor, engineer, architect, or local official authorized by ordinance to provide floodplain management information.

6.3.4.3 Critical Facilities

Flooding does occur above and beyond the 100-year floodplain. For that reason, new critical facilities and substantial changes to critical facilities shall be regulated to the 500-year flood event. **New critical facilities should be located outside of the 500-year floodplain and have continuous non-inundated access during a 500-year flood event**. Substantial changes to critical facilities should meet these requirements to the maximum extent possible. Critical facilities that cannot be located outside of the 500-year floodplain will require protection to the 500-year level. "Critical facilities" for floodplain purposes means a facility (structure, infrastructure, equipment, service, etc.) that if flooded may result in severe consequences to public health and safety or interrupt essential services and operations for the community at any time before, during, or after a flood. Examples of critical facilities include police, fire, emergency management or responders, hospitals, urgent care, communications facilities, public utilities, primary access routes or evacuation routes, hazardous materials facilities, gas stations, schools, day cares, senior centers, community centers, etc.

6.3.5 Flood-Proofing and Certification for Non-Residential Structures

As an alternative to elevating a new, substantially damaged or substantially improved non-residential structure above the BFE with one foot of freeboard, that structure can be flood-proofed. A FEMA Flood-proofing Certificate Form is required both by the NFIP, and by an insurance agent for adjustment of flood insurance rates. It is also required that a registered professional engineer or architect certify that the flood proofing measures meet the NFIP design standards, which can be found in the following publications:

- Federal Emergency Management Agency, Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program, Technical Bulletin 2-93, 1993.

- Federal Emergency Management Agency, Non-Residential Flood proofing – Requirements and Certification for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program, Technical Bulletin 3-93, 1993.

Two major flood proofing techniques are wet flood proofing (allows water to enter structure) and dry flood proofing (prevents entry of flood waters).

<u>Wet Flood Proofing</u>
Aspen uses wet flood proofing as a flood protection technique only through the issuance of a variance from certain floodplain management requirements. Wet flood proofing refers to measures applied to a building and its contents that prevent or provide resistance to damage from flooding by allowing flood waters to enter the structure.

<u>Dry Flood Proofing</u>
Dry flood proofing refers to sealing the outside of a structure to prevent the entry of flood waters. Oftentimes, this involves covering openings below the flood level, protecting the interior or the house from seepage, and protecting service equipment outside the house. Dry flood proofing must be provided to at least one foot above the BFE.

<u>Relocation</u>
Relocation refers to moving a structure out of the flood hazard area. Although it is the most expensive approach to flood protection, this method offers the greatest defense from flooding. The process of relocation usually involves lifting a house off of its foundation, putting it on a flatbed trailer, hauling it to its new location outside of the flood hazard area, and lowering it into a new, conventional foundation.

<u>Levees and Floodwalls</u>
Levees and floodwalls are structural barriers that hold back flood waters. Levees are embankments of compacted soil and floodwalls are structures built of concrete or masonry. Both levees and floodwalls need to be built at least one foot higher than the BFE.

6.4 Acceptable and Un-acceptable uses in the Floodplain or Floodway

6.4.1 Storage of Materials

It is prohibited to store hazardous or floatable/movable materials in the floodplain. These materials have the potential to create public health, environmental or safety risks. For example, materials stored in the floodplain may become dislodged and roll and/or float downstream to cause culvert or bridge blockages and resulting overtopping of roadways which can create hazards for vehicles and pedestrians. Materials stored in the floodplain may also cause diversion of flood waters out of the floodplain where damage is possible or may cause undesirable erosion or sedimentation in the floodplain. Storage of some materials in the floodplain and floodway may be permitted based on approval by the Floodplain Administrator.

6.4.2 Permitted Uses

Permitted uses in the floodplain are considered carefully by the Floodplain Administrator so they do not create barriers to flood waters such as fences, walls, berms or other obstructions may create. Based on careful review, possible allowable uses may include; golf courses, bike paths, parks, open spaces, nature areas, greenspace, public stormwater management facilities, and other similar uses. If these uses include cut and fill they will be addressed from the standpoint of their impact on the floodplain.

6.4.3 Uses Not Permitted

Parking lots and sport courts with fences or netting are not permitted uses in Special Flood Hazard Areas.

6.4.4 Utilities

The protection of City and private utilities is very important from the standpoint of protecting the investment in the utilities and providing uninterrupted service to the City:

- All new and replacement water supply systems shall be designed to minimize or eliminate infiltration of floodwaters into the system.
- New and replacement sanitary sewage systems shall be designed to minimize or eliminate infiltration of floodwaters into the system and discharges from the system into floodwaters.
- On-site waste disposal systems shall be located to avoid impairment to them or contamination from them during flooding.
- Electrical, heating, ventilation, plumbing, and air-conditioning equipment and other service facilities shall be designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding.

6.5 Floodplains and Mudflows

Floodplains may correspond to or be in addition to mudflows in Aspen and the requirements in the Mudflow Chapter and Floodplain Chapter should be addressed together.

6.6 Definitions

BFE – Base Flood Elevation is the 100-year flood elevation or the water surface elevation resulting from a flood that has a one percent chance of equaling or exceeding that level in any given year (100-year flood).

Detention – Management practice designed to protect against flooding by storing water for a limited period of time. Online detention refers to storage that uses a structural control facility to intercept flow directly within a conveyance system or stream. Offline detention refers to a separate storage facility in which flow is diverted from the conveyance system.

Encroachment – Land development impingement into a floodplain, where the magnitude of flood peak discharge will be increased due to removal of floodplain storage.

FIRM – Flood Insurance Rate Map – The official map on which the Federal Emergency Management Agency has delineated both the areas of special flood hazards and the risk premium zones.

FIS – Flood Insurance Study – The official report provided by the Federal Emergency Management Agency that includes flood profiles, the Flood Boundary-Floodway Map, and the water surface elevation of the base flood (BFE).

Floodway – The channel, plus any adjacent floodplain areas, that must be kept free of encroachment so that the 100-year discharge can be conveyed with no rise in the water surface above the BFE.

Floodplains – Any land area susceptible to being inundated by flood waters from any source.

Free Board – An additional amount of height above the Base Flood Elevation used as a factor of safety in determining the level at which a structure's lowest flood must be elevated or flood-proofed to be in accordance with State or Aspen floodplain management regulations.

Lowest Floor – The lowest enclosed area (including basement, finished or unfinished). An \enclosure, usable solely for parking of vehicles, building access or storage; , is not considered a building's lowest floor, provided that such enclosure is not built so as to render the structure in violation of the applicable non-elevation design requirements of the City Code.

NFIP – National Flood Insurance Program – A federal program established by Congress to identify flood prone areas nationwide and make flood insurance available to the owners and leasers of property in the communities that participate in the program. In order to participate in this program, local communities must agree to implement and enforce measures that reduce future flood risks in special flood hazard areas.

Retention – Management practice used to prevent flooding and downstream erosion by storing water for long periods of time.

6.7 References

Colorado Floodplain and Stormwater Criteria Manual, Volume 1, January 2006

FEMA, 2008 - Federal Emergency Management Agency, Flood Insurance Study Guidelines and Specifications for Study Contractors, February 2008.

FEMA - Federal Emergency Management Agency, Appeals, Revisions and Amendments to Flood Insurance Maps, A guidebook for Local Officials (FIA-12)

FEMA, 2008 - Federal Emergency Management Agency, NFIP Regulations, Title 44, Chapter 1, Parts 60, 65, 70, and 72, revised November 2008.

FEMA, 1993 - Federal Emergency Management Agency, Wet Flood proofing requirements for Buildings Located in Special Flood Hazard Areas in Accordance
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National Flood Insurance Program (NFIP) Floodplain Management Requirements: A Study Guide and Desk Reference for Local Officials

Wet Flood proofing Requirements for Structures Located in Special Flood Hazard Areas in accordance with the National Flood Insurance Program. http://www.fema.gov/pdf/fima/job14.pdf

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Chapter 7 – Mudflow Analysis

7.0 Introduction

This chapter provides information on the potential and magnitude of mud floods and mudflows that may develop in Aspen due to rainfall events, snowmelt, or rain on snow events. This chapter also provides guidance on the design process for sites at risk for mudflows, including the allowable mud deposition and mitigation techniques.

Mudflows are very viscous, hyper-concentrated sediment flows, whose fluid properties change dramatically as they flow down alluvial fans or steep channels. The behavior of the mudflow is a function of the fluid matrix properties (i.e. density, viscosity, and yield stress), channel geometry, slope, and roughness. Viscosity is in turn a function of the type of sediment (clay or silt), the sediment concentration, and the water temperature. Mudflows have high sediment concentrations and high yield stresses, which may produce laminar flow [1]. Smaller rain events (i.e. 10-year or 25-year storm event) are more likely to cause mudflows than larger events such as the 100-year flood. Usually, the peak concentration of sediment during a mudflow event is about 45%, and the average sediment concentration is between 20% and 35%.

The probability that a mudflow event will occur in Aspen is relatively high. Geologic maps published by the U.S. Geological Survey show large areas on Aspen Mountain directly above the City that are defined as potentially unstable, and mudflows have historically occurred in and near the City.

7.1 Mudflow Analysis in Storm Drainage Master Plan

The FLO-2D Model was applied as a part of the Surface Drainage Master Plan developed in 2001 (WRC Engineering 2001) (Master Plan). The model was used to estimate the amount of runoff expected to occur during a rain event and the expected depth of flow, water and sediment. WRC developed a delineation of mudflow hazard areas (mudflow plain) in the downtown portion of the City and evaluated alternatives for reducing and/or managing mudflow hazards including drains and channels, cutoff walls, diversion of mudflows to abandoned mines and regulation of development in the mudflow plain. It is notable that the WRC analysis focused only on the downtown portion of the City—mudflows have the potential to occur in other parts of the City, especially in areas that are on or adjacent to steep slopes.

Based on economic analysis, the preferred alternative in the Master Plan was to regulate development within the mudflow plain by requiring modeling of the effects of development on the mudflow plain. When model results show that development activities will result in adverse impacts to nearby properties (i.e. a rise in the mudflow elevation), mitigation/refinement of project design is required to keep post-development mudflow elevations at or below pre-project levels to the maximum extent practicable.

7.2 Applicability

This chapter applies to all new development and redevelopment within the City of Aspen that lies in red, blue or yellow mudflow zones or other areas at risk for mudflow as determined by the City Engineer. The red zone are areas comprised of slopes greater than 30%. The blue mudflow zone includes areas on or within 200 feet of a slope greater than 30% defined on the City of Aspen slope map (can be located in the City GIS or Engineering departments) as seen in Figures 7.1 a - f. The yellow mudflow zone are those areas south of Durant that are located within the 2-ft mudflow depth on the 100-yr mudplain map in the Master Plan as shown in Figure 7.1.

[1] Mud floods are similar to mudflows, but they are less viscous, more turbulent and contain less sediment than mudflows (they behave more like “clear water” flood flows).

- Red or Blue mudflow zones – For development projects that will modify existing grades or create additional obstructions (buildings, roads, etc.) in red or blue mudflow zones, the applicant must provide an analysis of the 100-year mudflow event to demonstrate that the proposed development will manage mudflow impacts to his/her site and neighboring site to the maximum extent practicable, providing appropriate safety from mudflow impacts that are physically and economically feasible. Factors that will be considered in determining the “maximum extent practicable” for each site include mudflow depth, proximity to steep slopes, soil characteristics, slumping and earth movement, possible mudflow obstructions, potential mudflow paths, integrity/strength of the existing or proposed on-site structure(s) and neighboring structures, proposed mitigation techniques (both structural and non-structural),and economic reasonability and feasibility.

- Yellow mudflow zones – For areas located in the yellow mudflow zone or other areas as determined by the City Engineer, requirements of this chapter will be identified by the City Engineering Department on a case-by-case basis considering factors including mudflow depth in a 100-year event, presence or close proximity of steep slopes (typically >15 or 20 percent) on-site or up- or down-gradient of a development, soil characteristics, history of past mudflows, slumping and earth movement, and other factors.

Mudflow analysis is not required if the applicant can demonstrate that the potential area of blockage (i.e. length, width and height) of a proposed structure below the corresponding mudflow elevation from **Figure 7.1** will remain unchanged. However, impacts from mudflow must still be managed to the maximum extent practicable.

7.3 FLO-2D Overview

FLO-2D is a two-dimensional, finite difference flood routing model, which uses a kinematic wave or diffusive wave equation to estimate overland flow. In addition to modeling water-only flow, the program also models hyper-concentrated sediment flow. The following general description of the FLO-2D model has been adapted from the Master Plan and the FLO-2D Users Manual (O’Brien 2007).

FLO-2D requires a representation of the topography of the study area. This is accomplished by establishing a network of nodes and assigning x-y coordinates and elevations to each node. The nodes must be placed in a rectangular grid with equal spacing between nodes. Decreasing the node spacing increases the number of nodes and decreases the length of time step used in the model. Both factors increase the model’s run time.

One of the unique features of the FLO-2D model is its ability to simulate flow problems associated with flow obstructions or loss of flood storage. Area reduction factors (ARFs) and width reduction factors (WRFs) are coefficients that modify the individual grid element surface area storage and flow width. ARFs can be used to reduce the flood volume storage on grid elements due to buildings or topography. WRFs can be assigned to any of the eight flow directions in a grid element and can partially or completely obstruct flow paths in all eight directions simulating floodwalls, buildings or berms.

Flow in the model is generated by simulating rainfall on each node in the study area or by inputting a runoff hydrograph at select nodes (see **Chapter 3** for developing hydrographs). Rainfall and inflow hydrographs cannot be used simultaneously. The amount and direction of overland flow is calculated in eight directions – directly forward and backward, to each side, and in the four diagonal directions.

Mudflows are modeled using inflow hydrographs. The input data contains the hydrograph data, flow versus time, the concentration of sediment conveyed by the flow, and concentration by volume versus time. FLO-2D routes the hyper-concentrated flows, tracking the sediment volumes through the system. Changing sediment concentration, dilution effects, and the remobilization of deposits are simulated at each node. Mudflow cessation and deposition can be predicted by the model. Sediment concentration governs the movement of the fluid matrix.

The model also accounts for the initial rainfall abstractions and infiltration. Infiltration is estimated for each node using the Green-Ampt equation. The flow area and storage volume associated with each node can be reduced to represent buildings. Streets can also be modeled to increase the conveyance through these nodes.

Results generated by the FLO-2D model include outflow hydrographs at designated nodes, maximum flow depths and velocities, and a summary of the total inflow, outflow, storage, and losses within the study area.

Additional documentation related to FLO-2D can be found on the website http://www.flo-2d.com/ and in the Master Plan in the mudflow section (http://www.aspenpitkin.com/pdfs/depts/43/1963-20.pdf).

7.4 Requirements for New Development and Redevelopment

Mudflow analysis for new development and redevelopment shall be conducted by a Professional Engineer with past experience with mudflow analysis, preferably with past experience using FLO-2D. FLO-2D is the preferred method for mudflow analysis. However, the City is willing to accept other models or analyses that are based on the following factors:

- Type and quality of soils
- Evidence of groundwater or surface water problems
- Depth and quality of any fill
- Slope of the site and adjacent sites
- Weight that proposed structure will impose on slopes

For areas falling within the delineated mudflow plain, as established in the Surface Drainage Master Plan (Master Plan), where mudflow depths are greater than 2 foot, modeling analysis should follow the steps below. Mudflow analysis using modeling methods may also be required for other mudflow hazard areas not shown in the Master Plan at the discretion of the City Engineering Department.

The following steps are recommended and preferred for mudflow analysis:

1. Obtain current official FLO-2D model files from the City of Aspen. The model files developed by WRC as a part of the Master Plan, including modifications for development projects within the mudflow plain approved by the City since the Master Plan, define the "official" mudflow model for the City of Aspen. Model files reflecting effects of streets and buildings shall be used. Model files can be obtained from the City Stormwater Manager. The City also will provide hard copy and/or electronic model results from the most recent approved application to accompany the electronic model files.

2. Create a duplicate of the official model. The user should first run model files from the City's official model on their own system without making any changes to the input files. Results should be compared with previous results to confirm that the model is running properly on the user's system. Any differences should be resolved to obtain agreement between model runs on a user's computer and previous model runs. Minor differences (< 0.1 ft) may be acceptable and may arise from using different versions of the software.

3. Refine grid. To model a proposed development, a maximum grid spacing of 50 feet is required, as recommended in the Master Plan. If new properties need to be assigned to a node or nodes due to the refined grid, the properties of the nodes from the coarser grid should be retained for the finer grid unless more detailed information is available for the finer grid. The user should run the model with the refined grid for pre-project conditions (i.e. existing structures without modification for proposed development). This model run will establish baseline mud/water surface elevations.

4. Modify geometry input. To accurately model a proposed project the user must adjust area and width reduction factors for nodes where the proposed development is located. Other than adjustments to geometric parameters to accurately reflect the proposed development, model input values in the official model should not be altered by the user.

5. Compare predicted mud/water surface elevations with pre-project (baseline) conditions. Once the model has been run using the modified geometry to reflect the proposed development, mud/water surface outputs should be compared at nodes for pre- and post-project conditions. A rise in the mud/water surface elevation from the pre- to post-project conditions is allowable only if it affects just the property of the proposed project and the proposed project is designed for hydrostatic and dynamic forces of the mudflow.

6. Evaluate static and dynamic mudflow forces and identify potential mitigation measures. Static forces due to the mudflow can be calculated based on the density of the mudflow and the mudflow depth. The static force of the mudflow must be computed as hydrostatic pressure based on the full depth of the mudflow, as determined by the model, using 1.5 times of the hydrostatic force of water (1.5 x 62.4 lbs/ft^3 = 93.6 lbs/ft^3).

   Even more significant than static forces, dynamic forces associated with mudflows have the potential to cause structural damage—according to FEMA floodplain training literature, water moving at 10 miles per hour exerts the same pressure on a structure as wind gusts at 270 miles per hour. The forces from a mudflow, with even greater density than water, are even more significant. A number of empirical formulas for calculating the dynamic forces of mudflows are available. Based on review of applicable equations, the following is recommended for calculation of mudflow dynamic forces in Aspen:

$$P = \frac{9(62.4)H^2}{2}$$

   Where:

   P = Dynamic Force (lbs/ft)
   H = Depth of Mudflow (ft)

   The dynamic force is assumed to act at a height of one-third of the mudflow depth. A safety factor of 1.5 must be applied to both the static and dynamic forces. The developer/engineer must consult with the City before beginning the mudflow protection analysis to confirm the proper application of this section.

   Typical mitigation measures include elevating finished floor elevations of buildings above the mudflow plain elevation (plus freeboard), construction of retaining walls to stabilize steep slopes, and construction of diversion channels and/or deflection walls.

7. Prepare submittals to City. Required submittals include a tabular comparison of mud/water surface elevations at all nodes, revised mudflow plain mapping (e.g. update of mudflow depth map in Master Plan), and electronic copies of all model input and output files.

Once the City reviews and approves mudflow modeling for a proposed project, the model submitted will become the new “official” model that will be used for future proposed developments within the mudflow plain.

7.5 References

O’Brien J.S. FLO-2D Users Manual, Version 2007.06. June 2007.

WRC Engineering, Inc., Storm Drainage Master Plan for The City of Aspen, Colorado, November 2001.

Federal Emergency Management Agency, Department of Homeland Security, United States Code of Federal Regulations, Title 44 – Emergency Management and Assistance, Part 60 – Criteria for Land Management and Use, 60.4 and Subpart C.

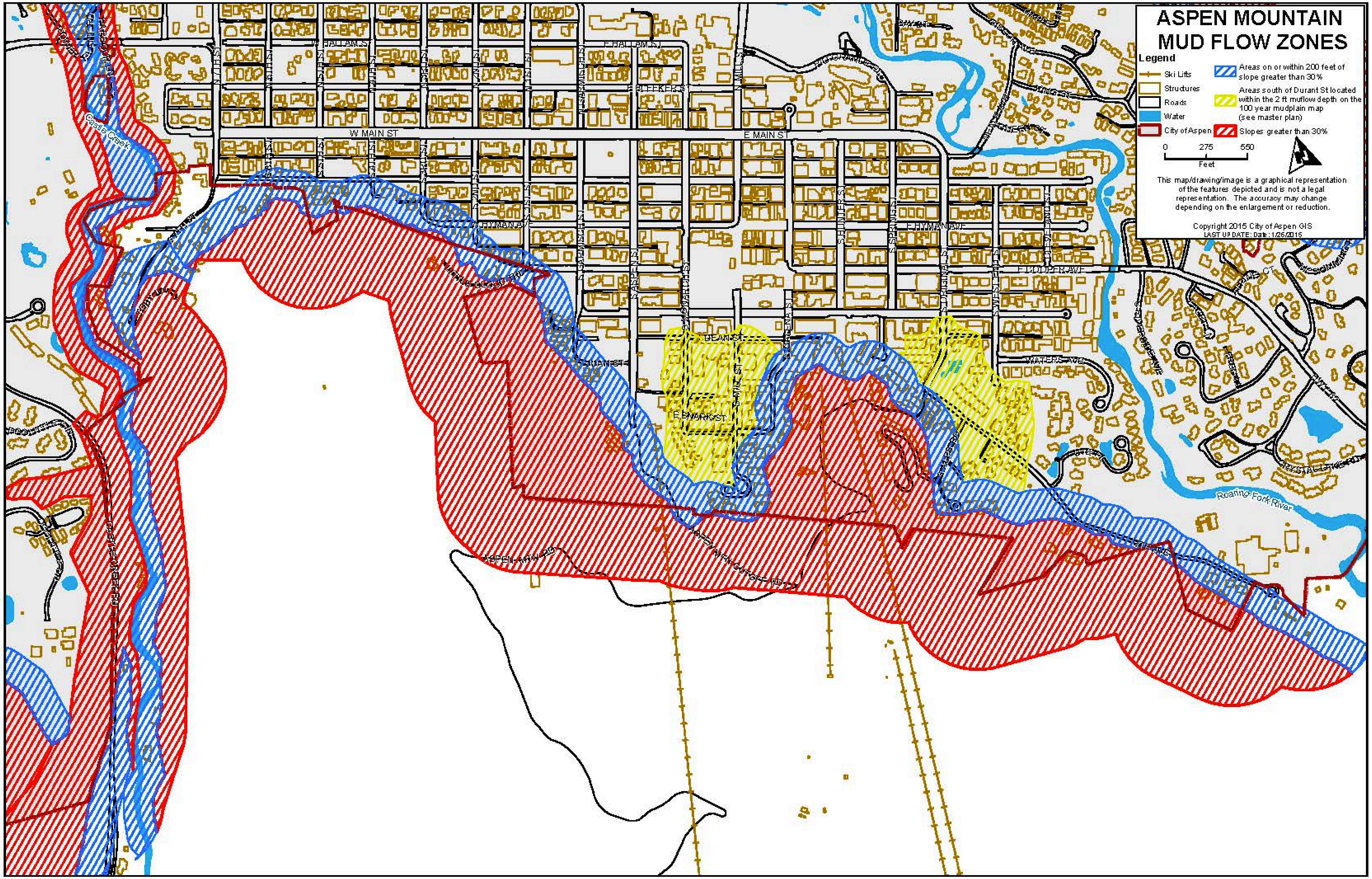


Figure 7.1 a – Aspen Mountain Mudflow Zones

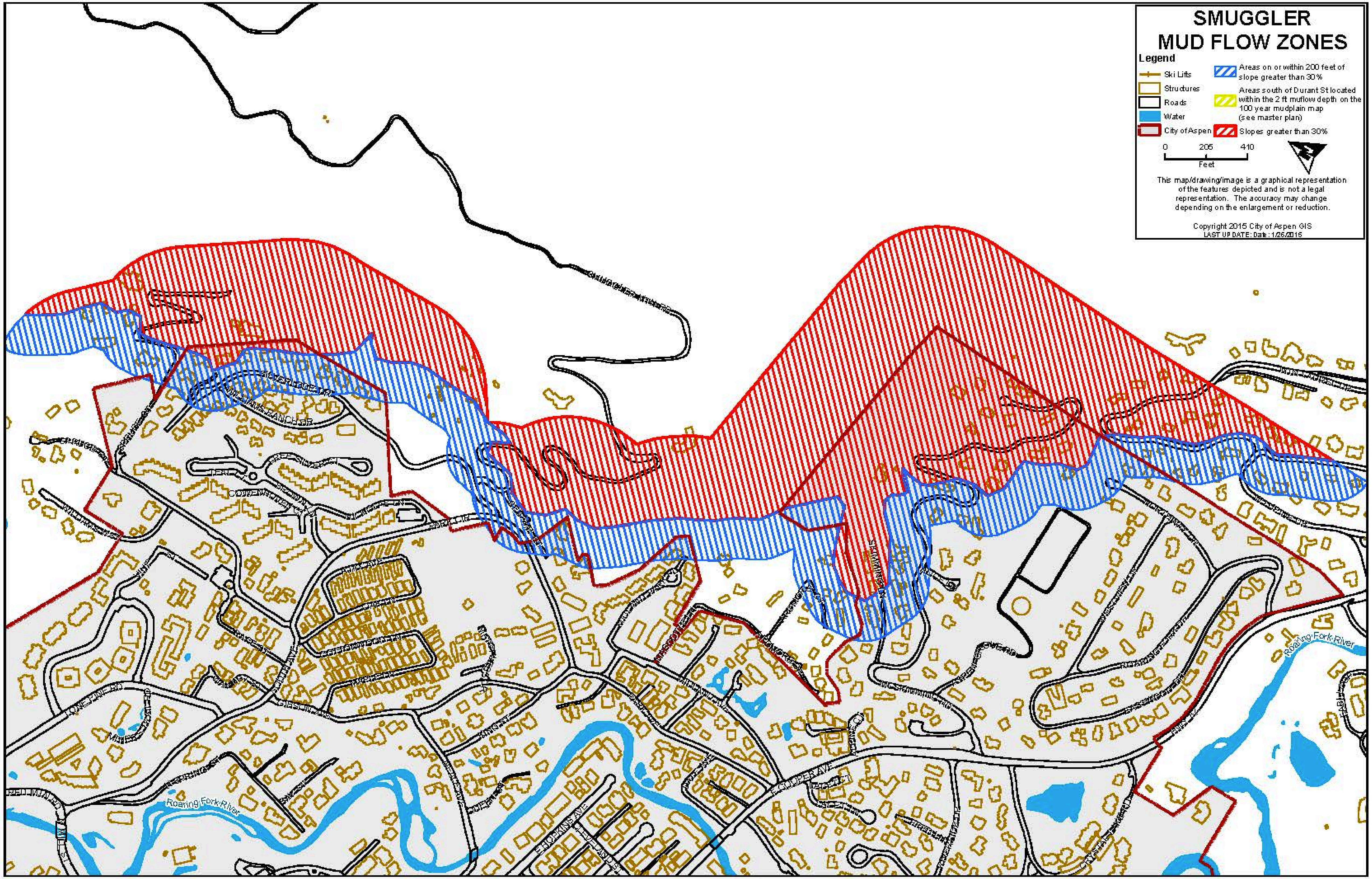


Figure 7.1 b – Smuggler Mountain Mudflow Zones

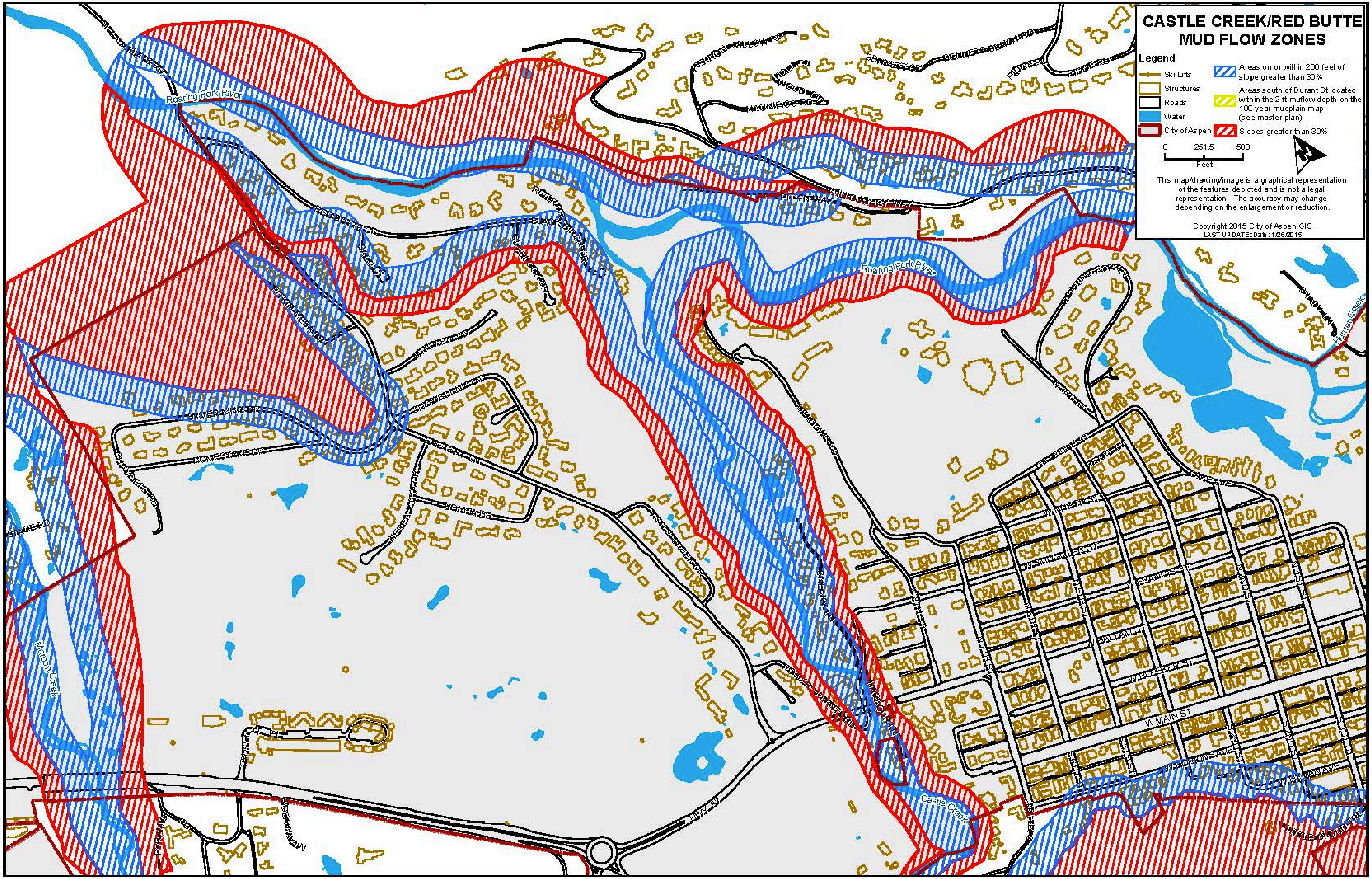


Figure 7.1 c – Castle Creek/Red Butte Mudflow Zones

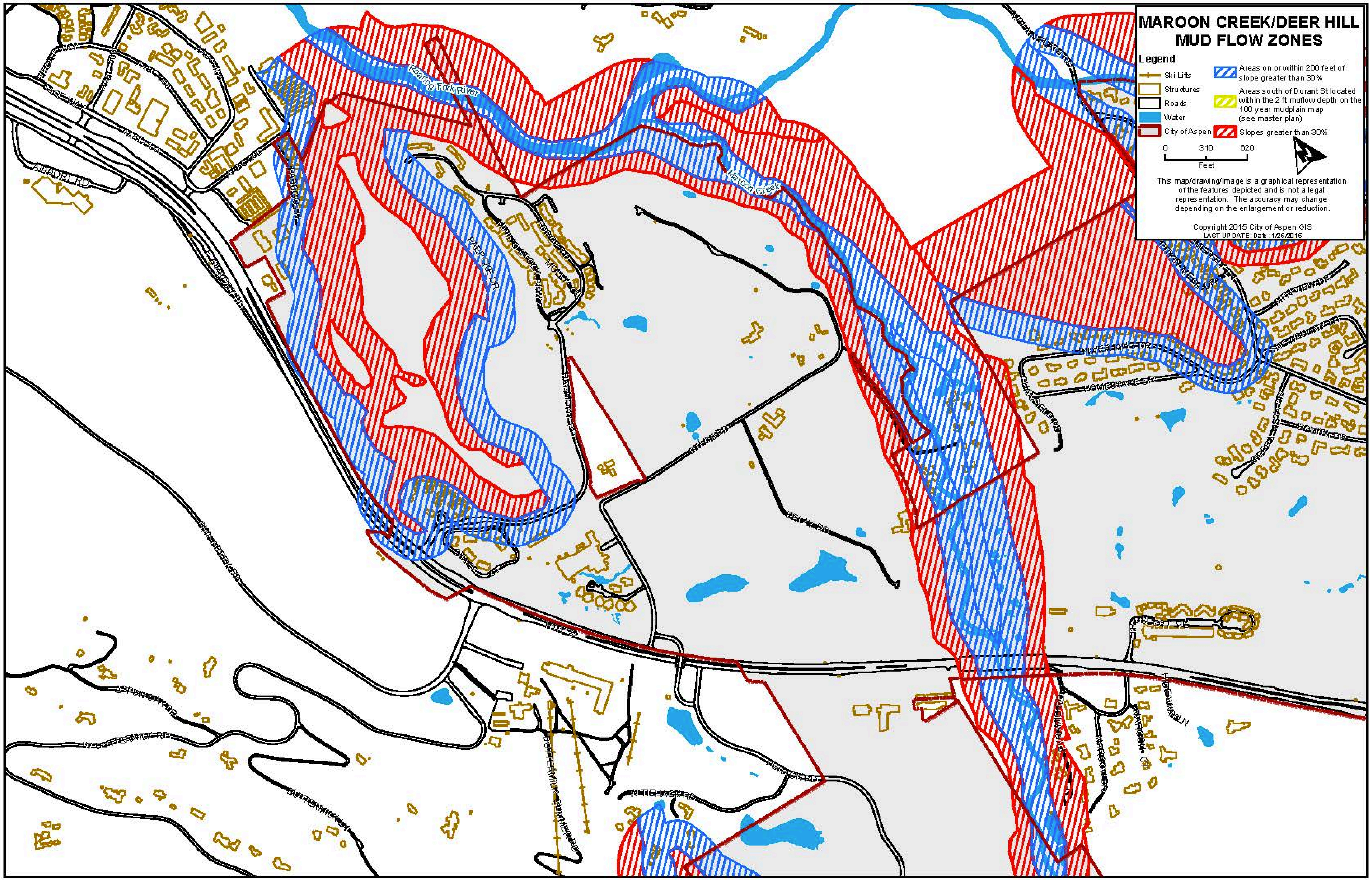


Figure 7.1 d – Maroon Creek/Deer Hill Mudflow Zones

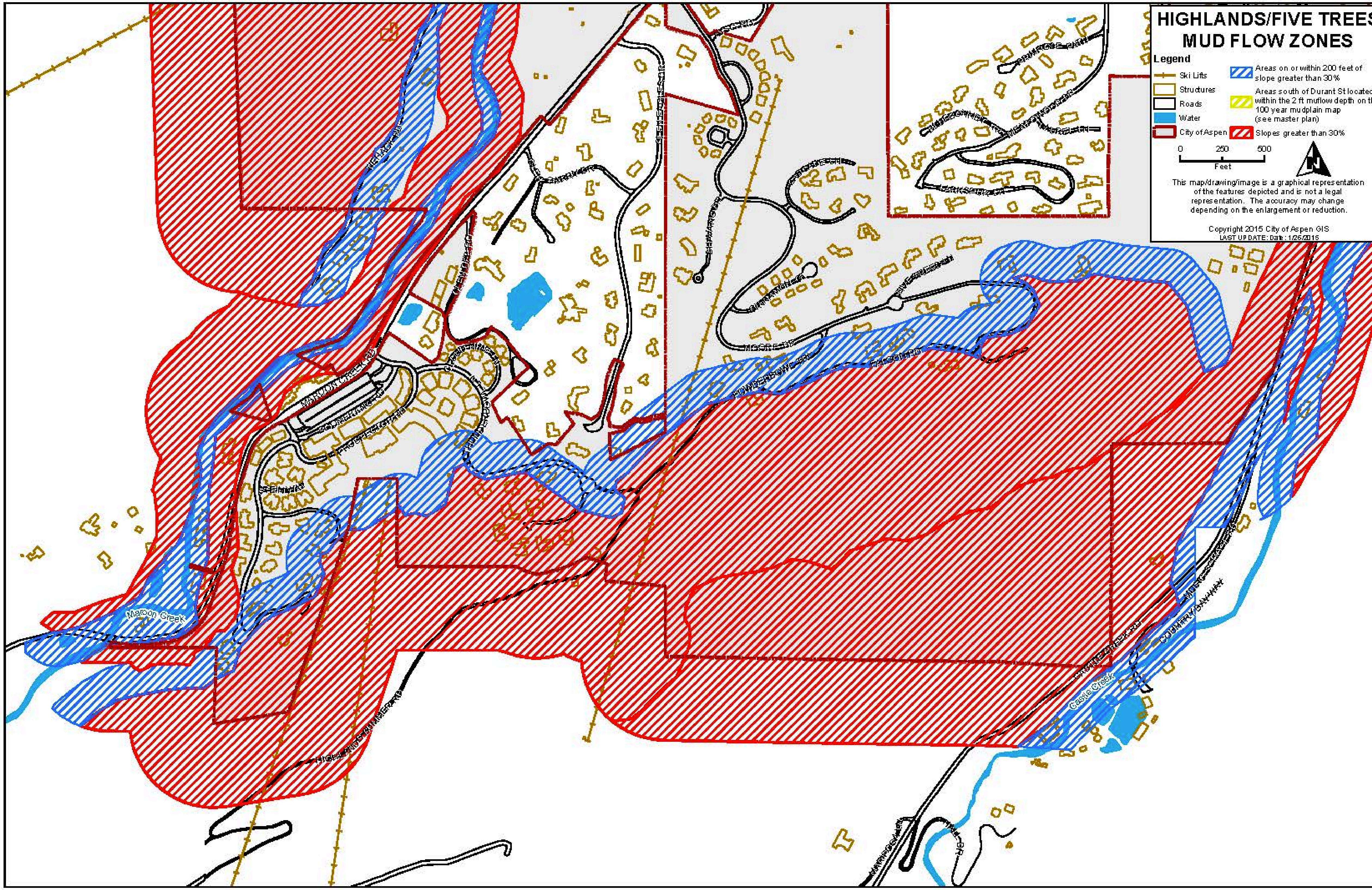


Figure 7.1 e – Highlands/Five Trees Mudflow Zones

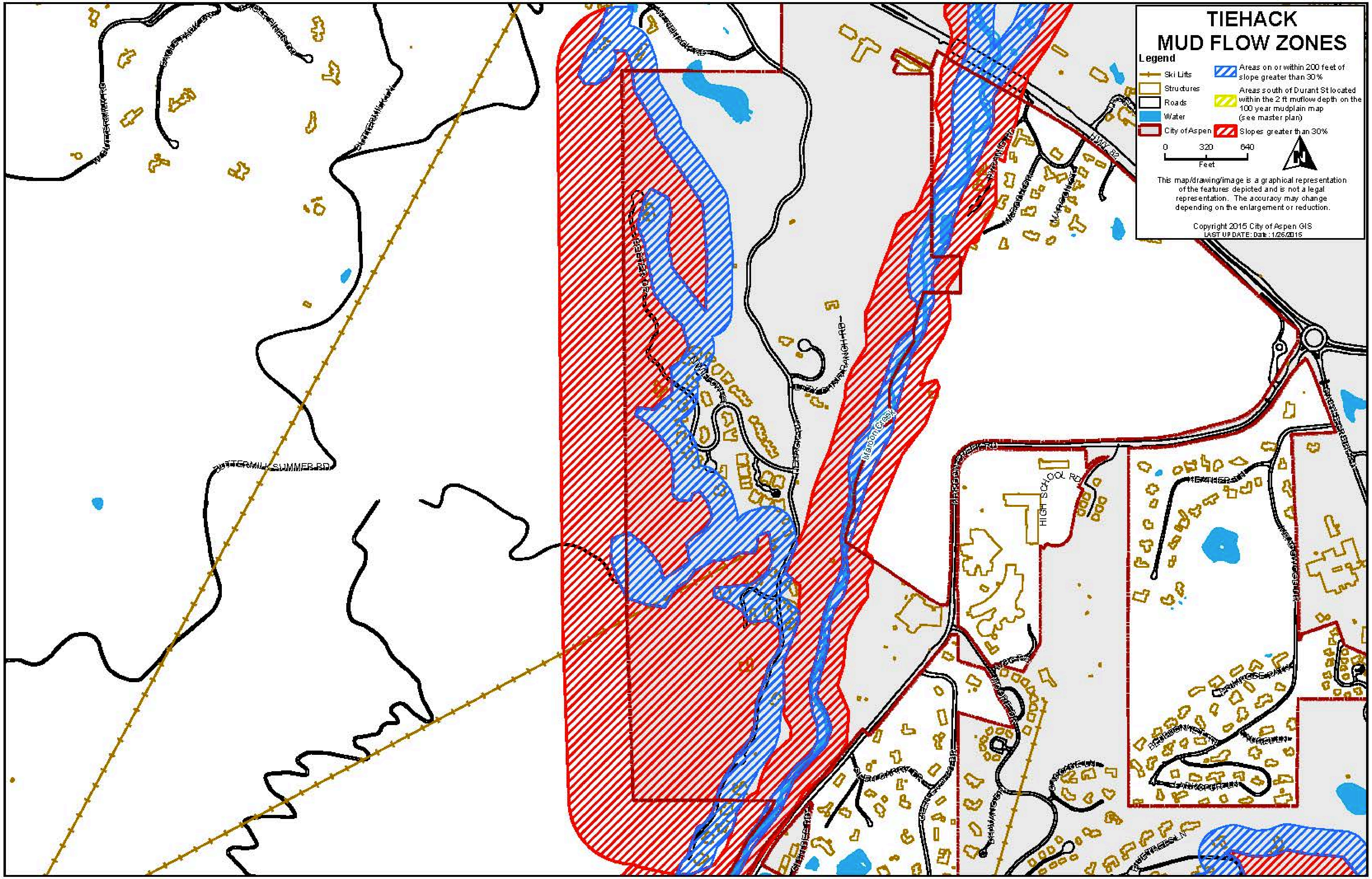


Figure 7.1 f – Tiehack Mudflow Zones

Chapter 8 – Water Quality

8.1 Overview

This chapter provides guidance and criteria for selection and design of stormwater best management practices (BMPs) for water quality. These water quality BMPs apply to public and private development and redevelopment projects within the City of Aspen (City). The overall goal of the water quality chapter is protection of receiving waters including the Roaring Fork River, Maroon Creek, Castle Creek and tributaries to these waterways.

8.1.1 Aspen and Roaring Fork River Water Quality

The impacts of Aspen's stormwater on the Roaring Fork River include stream hydrology, stream morphology (physical characteristics), water quality and aquatic ecology. The extent of impact is related to the area's climate, land use in the watershed, and the measures implemented to address the impacts. According to the *State of the Watershed Report* (SoWR) (2008) prepared by the Ruedi Water and Power Authority and the Roaring Fork Conservancy, nearly 20 percent of the riparian habitat and more than 15 percent of instream habitat in the Upper Roaring Fork sub-watershed is classified as "severely degraded." Urban development in Aspen, in addition to other land uses in the watershed, is a contributor to the watershed's effect on the Roaring Fork River.

Potential impacts of Aspen's urban development, without proper mitigation, on the Roaring Fork River include:

Stream Hydrology: Urban development affects the environment through changes in the size and frequency of storm runoff events. For example, in Aspen for an undeveloped site, snowmelt/rainfall events would be expected to generate runoff approximately 30 times during a typical year. For a developed, 100 percent impervious site, approximately 80 snowmelt/rainfall events per year would generate runoff. Development also changes base flows of the stream and stream flow velocities during storms resulting in a decrease in travel time for runoff. Peak flow rates and runoff volume increase as a result of urbanization resulting in more surface runoff and larger loads of some constituents found in stormwater.

Stream Morphology (physical characteristics): When the hydrology of the stream changes, it results in changes to the physical characteristics of the stream. Such changes include streambed erosion and sediment buildup, stream widening, and stream bank erosion. As the stream profile degrades and the stream tries to widen to accommodate higher flows, channel bank erosion increases along with increases in sediment loads. These changes in the stream bed also result in change to the habitat of aquatic life.

Stream Water Quality and Aquatic Ecology: Water quality is impacted through urbanization as a result of erosion during construction, changes in stream morphology, and washing off of accumulated deposits from the urban landscape. For example, runoff from downtown Aspen could include petroleum hydrocarbons from vehicles, vegetation debris from leaf fall, metals and solids from tire wear and streets, fine particulate matter and metals from atmospheric deposition on impervious surfaces and other pollutants. Water quality problems include turbid water, nutrient enrichment, bacterial contamination, and increases in organic matter loads, metals, salts, oil/grease, pesticides and herbicides. In addition, there may be temperature increases and increased trash and debris transported by stormwater runoff to streams and lakes.

Table 8.1 lists the common constituents in stormwater runoff and their impacts.

Table 8.1 Urban Runoff Pollutants

Constituents	Sources	Effects
Sediments—TSS, turbidity, dissolved solids	Construction sites, urban runoff, landfills, atmospheric deposition	Habitat changes, stream turbidity, recreation and aesthetic loss, contaminant transport, bank erosion
Nutrients—nitrate, nitrite, ammonia, organic nitrogen, phosphate, total phosphorus	Lawn runoff, atmospheric deposition, erosion	Algae blooms, ammonia toxicity, nitrate toxicity
Pathogens—total and fecal coliforms, fecal Streptococci viruses, E.coli, Enterococcus	Urban runoff, illicit sanitary connections, domestic/wild animals	Ear/intestinal infections, recreation/aesthetic loss
Organic enrichment—BOD, COD, TOC and DO	Urban runoff	Dissolved oxygen depletion, odors, fish kills
Toxic pollutants—metals, organics	Urban runoff pesticides/herbicides, underground storage tanks, hazardous waste sites/historic mining (Smuggler Mountain Superfund), landfills, illegal disposals, industrial discharges	Toxicity to humans and aquatic life, bioaccumulation in the food chain
Source: United States Environmental Protection Agency (USEPA) Handbook: Urban Runoff Pollution Prevention and Control Planning, 1993 with adaptations for City of Aspen.		

Although the Roaring Fork River, Maroon Creek and Castle Creek are headwaters streams with water quality far better than many streams in the nation, they nonetheless are impacted by Aspen's stormwater runoff. The 2008 State of the Watershed Report identified excessive sedimentation as a primary source of impacts to the Roaring Fork River and data collected by the City of Aspen from 2003 to 2006 show total suspended solids concentrations consistently higher than 130 mg/L and on many occasions (six out of twelve samples) in excess of 1000 mg/L. Primary sources of sediment in runoff include erosion from steep slopes (including Aspen Mountain), sand from winter application, sediment from construction sites, urban runoff from impervious areas where particulates accumulate and natural "background" sources of sediment.

Other water quality parameters cited in the State of the Watershed Report (SoWR) in the vicinity of Aspen include iron, lead, selenium, cadmium, pH, nitrite, total phosphorus and dissolved oxygen. Sources of metals in runoff include vehicular traffic areas including roads and parking areas, atmospheric deposition, and historic mining activities.

In addition to water quality data, the SoWR presented the results of in stream and riparian zone habitat assessments. These types of biological assessments are valuable for evaluating the cumulative, long-term effects of water quality and hydrologic modifications on waterways.

Figure 8.1, from the *SoWR*, illustrates riparian and in-stream habitat assessments for the Roaring Fork River and tributaries. Of particular note for Aspen are the Upper Roaring Fork, Castle Creek and Maroon Creek sub-watersheds. Although fifty percent or more of the areas surveyed near Aspen were ranked "high quality" or only "slightly modified," the Upper Roaring Fork sub-watershed contained instream and riparian areas characterized as "severely degraded." Runoff from Aspen contributes increased volumes and peak flows of runoff and additional loads of sediment and other pollutants that contribute to the condition of the river. From **Figure 8.1**, it is apparent that the effects of urbanization and runoff on the Roaring Fork are cumulative, with increased degradation moving downstream.

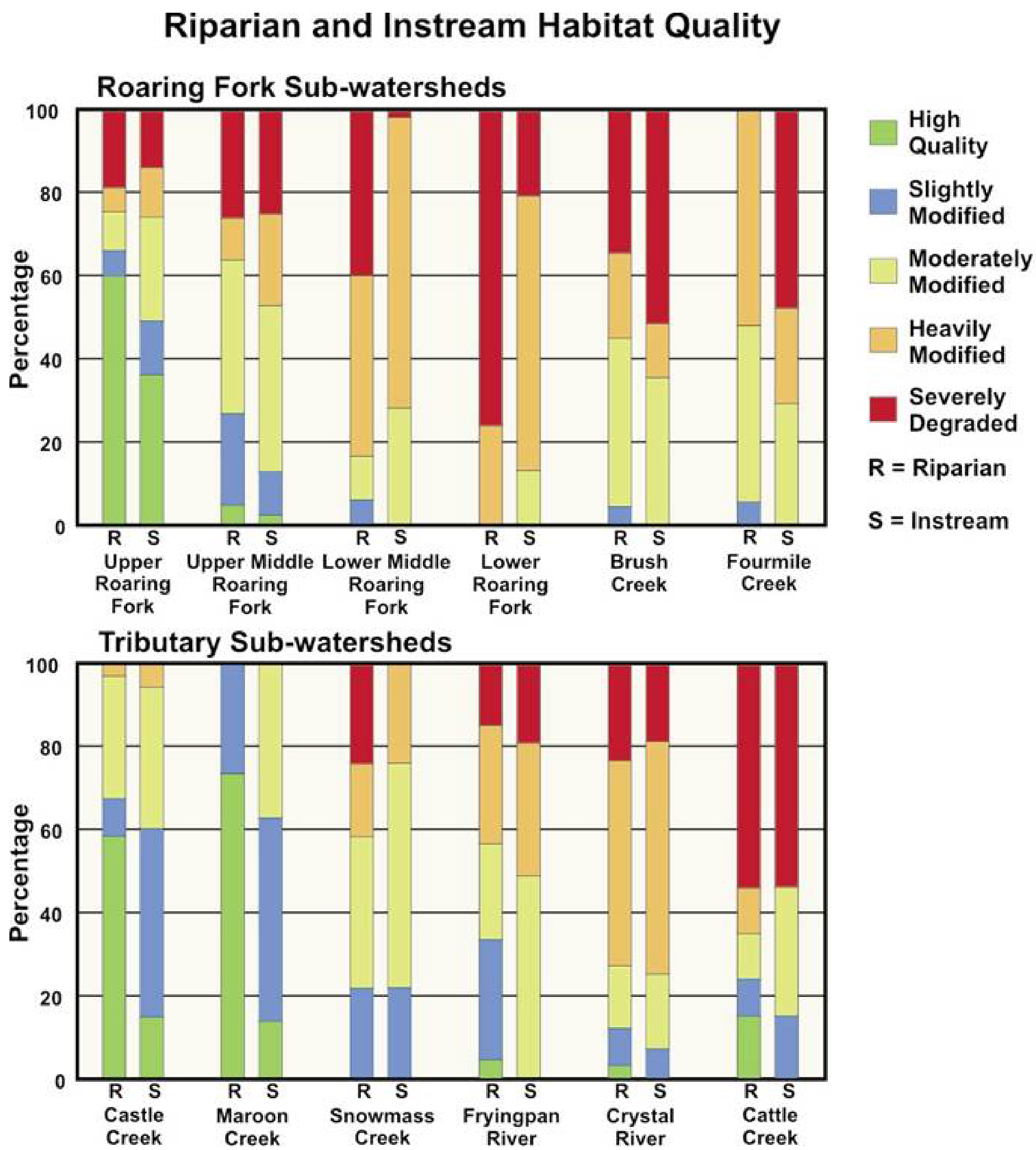


Figure 8.1 Riparian and Instream Habitat Quality for Roaring Fork and Tributary Sub-Watersheds (*State of the Watershed Report* 2008)

8.1.2 Priority Pollutants

There are many potential pollutants that can affect water quality of receiving waters ranging from oxygen depleting organic matter to pathogens to metals. Of special importance is sediment, identified in the Roaring Fork Conservancy report as a primary cause of impairment to the Roaring Fork River in the Aspen area. Sediments discharged to the Roaring Fork River can have many potentially adverse effects including “smothering” of aquatic habitat, increased turbidity/decreased light penetration, increased temperatures, oxygen depletion and impacts to fish. There are many potential sources of sediment in runoff in Aspen, some natural, others anthropogenic. Sources of sediment in Aspen include the following:

- Urban particulates from tire wear, surface wear, decomposing vegetative matter and litter, and dust from atmospheric deposition.
- Erosion from areas that have been disturbed or modified. This includes sediment from Aspen Mountain, construction sites, roadway cuts and forest fire areas.
- Erosion from landscaped areas and lawns.
- Sediment from road sanding.
- Natural sediment eroding from undeveloped watersheds.

Sediment can be removed from runoff by a number of physical processes including gravitational settling, filtration, and straining, among others. Removal of sediment can be a very effective way to address water quality for a range of parameters since many pollutants, including nutrients, pathogens and many metals will adsorb/absorb to sediments under typical environmental conditions. Therefore, by removing sediment, other pollutants attached to the sediments are controlled as well. Removal of sediment is a primary focus of this manual.

There are many types of measurements to characterize sediment, including settleable solids (SS), total suspended solids (TSS), suspended sediment concentration (SSC) and turbidity. Although monitoring of BMPs is not required and numeric limits for sediment in runoff are not specified in Colorado Water Quality Control Commission (CWQCC) regulations, measurement of sediment inflow and outflows from BMPs can be useful for characterizing performance. **To the extent that BMP monitoring for sediment removal is conducted (at Rio Grande Park, for example), measurements using TSS and turbidity are recommended for a high level of comparability with data collected elsewhere.**

8.1.3 Unique Challenges of High Mountain, Cold Weather Resort Environment

There are many challenges related to Aspen’s environment that were taken into consideration in developing water quality and BMP design criteria. These include cold climate effects, the steep slope/mountainous setting of Aspen and the fact that Aspen is a world-class resort town with very high land value. **Table 8.2** summarizes many of these challenges.

Table 8.2 Cold Climate and Physiographic Design Challenges in Aspen (adapted from Center for Watershed Protection 1997)

Condition	BMP 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 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 • Significant runoff from Aspen Mountain through the City
Resort Setting	• High land value creates space limitations for BMPs • Large portion of development occurs as redevelopment—space constraints and dense development • Need for attractive BMPs • Aspen’s “green” reputation—need to conduct development in an environmentally-sensitive manner and desire to integrate “green” BMPs when feasible

8.1.4 Overall Goals of Criteria

The overall goals of the criteria in the Manual include the following:

1. Provide full water quality treatment for up to the 80th percentile runoff event, corresponding to between a 6-month to 1-year event.

2. For events larger than the 80th percentile event, BMPs designed in accordance with these criteria will provide water quality treatment of the “first flush.”

3. Provide a high level of solids removal for typical suspended sediments found in Aspen urban runoff.

8.1.5 Acknowledgements

Throughout this chapter, information from other criteria manuals, technical papers and other references are cited. There is a considerable body of knowledge related to water quality protection that has been reviewed as a part of creating this chapter. One of the resources most heavily relied upon is the Denver Urban Drainage and Flood Control District *Urban Storm Drainage Criteria Manual Volume 3* (1991992 updated November 2010). The *Urban Storm*

Drainage Criteria Manual is an excellent resource that is routinely updated based on monitoring data, new technologies and methods, and experiences in the metropolitan Denver area. The authors of the Aspen Manual obtained permission from UDFCD to use text from the Urban Storm Drainage Criteria Manual. Entire sections of the UDFCD Manual have been adopted for the Aspen Manual with adjustments for Aspen's environment. If citations were provided every time in the text that information from UDFCD has been inserted, the Aspen Manual would be difficult to read due to the numerous citations; therefore, this acknowledgement is intended to inform users that information from the *Urban Storm Drainage Criteria Manual* is ubiquitous in this document. Users of the Aspen Manual should consult the UDFCD Manual when working on designs to obtain the most up-to-date technical guidance, while still giving due attention to climatic differences that are unique to Aspen.

Special thanks go to Ben Urbonas, P.E. of UDFCD (retired) who was the force behind creation of the original UDFCD Manual and many updates and Ken MacKenzie, P.E. of UDFCD who provided significant input to the UDFCD Manual and is the steward for the UDFCD Manual and updates.

In addition to citations from the *Urban Storm Drainage Criteria Manual*, other sections of this chapter draw on the City and County of Denver *Water Quality Management Plan*, with adaptations for land uses and types of development common to Aspen.

8.2 Water Quality Low Impact Design Requirements

The development of Aspen's stormwater quality management strategy has been based on low impact development design principles (adapted from City and County of Denver Water Quality Management Plan [2004]). In general **a project should attempt to reduce runoff, increase infiltration, and treat the remaining runoff (WQCV). A low impact design process is required and MUST BE DESCRIBED in the Drainage Report for each project that describes how the project accomplished these goals.**

Step 1: Consider stormwater quality needs early in the design process.

Left to the end of site development, stormwater quality facilities will often be "shoe-horned" into the site, resulting in forced, constrained approaches. When included in the initial planning for a project, opportunities to integrate stormwater quality facilities into a site can be fully realized. Stormwater management, water quality and flood control requirements are just as fundamental to good site design as other elements such as building layout, grading, parking, and streets. ***Dealing with stormwater quality after major site plan decisions have been made is too late.***

Step 2: Use the entire site when planning for stormwater quality treatment.

Often, stormwater quality and flood detention are dealt with only at the low corner of the site, and ignored on the remainder of the project. The focus is on draining runoff quickly through inlets and pipes to the stormwater facility. In this "end-of-pipe" approach, all the runoff volume is concentrated at one point and designers often find it difficult to fit the required detention into the space provided. This can lead to drainage plans with expensive, proprietary underground treatment devices, or deep, walled-in basins that detract from a site and are difficult to maintain. Spreading runoff over a larger portion of the site reduces the need for these undesirable alternatives.

Step 3: Avoid unnecessary impervious area.

Impervious area (parking, roofs, drives, etc.) is the most significant factor influencing urban runoff and water quality issues. Many impervious surfaces are necessary as a part of urban and sub-urban development (roofs over buildings, to provide shelter; roads for vehicles, for example). Not all impervious areas in typical developments are necessary, however. For example, in residential areas an extra-wide driveway that is used only infrequently could be considered “unnecessary” impervious area, especially if street parking is available nearby for infrequent additional parking. To reduce the impacts of urban runoff on the environment, each site plan should be carefully evaluated to eliminate unnecessary impervious surfaces. Potential ways to reduce unnecessary impervious surfaces include minimizing parking to the extent practical, narrower roadways and driveways, and the use of permeable pavement systems or green roofs to lower effective imperviousness where a hard but pervious surface is desired.

Step 4: Reduce runoff rates and volumes to more closely match natural conditions.

Before development, for frequent small events most of the rain that falls on the ground soaks into the soil or is captured by vegetation; very little rainfall runs off and flows downstream. However, after development, rain that falls on roofs and pavement mostly runs off (this is a “runoff event”). Whereas one runoff event per year may be typical prior to development, significantly more runoff events per year typically occur after urbanization (Urbonas et al. 1989). Peak flows and volumes of runoff are greater after urbanization than before development.

One of the most effective stormwater quality BMPs—potentially more effective than constructing a detention basin to treat the runoff—is **reducing urban runoff volumes to more closely match natural conditions.** The following techniques can be used to achieve this goal:

<u>Place stormwater in contact with the landscape and soil</u>. Instead of routing storm runoff from impervious areas to inlets to storm sewers to offsite pipes or concrete channels, an approach is recommended that places runoff in contact with landscape areas to slow down the stormwater and promote infiltration. Porous pavement areas also serve to reduce runoff and encourage infiltration. This practice is also known as Minimizing Directly Connected Impervious Area (MDCIA) and can reduce the effective imperviousness of the site. One of the most common and easiest to implement practices for reducing runoff is to direct roof downspouts to pervious areas. Whenever practical this practice should be used as an alternative to connecting roof drains to storm sewers or daylighting them to impervious areas. If there are concerns relative to foundations with directing downspouts to pervious areas, downspout extenders can be used to direct roof runoff to landscaped areas that are further away from the base of the structure. Additionally, lined bioretention/landscaped areas adjacent to structures can receive runoff from downspouts and effectively disconnect the impervious area.

<u>Select treatment areas that promote greater infiltration</u>. Bioretention, sand-filter detention and other infiltration-based BMPs promote greater volume reduction than extended detention basins, since runoff tends to be absorbed into the filter media or infiltrate into underlying soils. As such, they are more efficient for reducing runoff volume and typically can be sized for less overall treatment volume than extended detention facilities.

By employing these techniques, projects can reduce the increase in runoff and related stream degradation and pollutant loading that comes with conventional development. In addition, some of these techniques will reduce the required WQCV and may help to create a more attractive site. **Aspen strongly encourages implementation of these runoff reduction techniques on all new projects to the maximum extent practicable.**

Step 5: Integrate stormwater quality management and flood control.

In cases where an extended detention basin, wetland basin, sand filter basin, or underground treatment system is used to address stormwater quality, these BMPs can be modified to include flood control detention in addition to the WQCV. This will generally increase the overall size of the basin. In these situations, all the runoff from a site, from small and large storms alike, is routed to the combined detention basin. Site BMPs, like bioretention, are intended to promote a stormwater quality function, and are not normally designed to provide flood control detention as well. In these cases, all runoff is directed to the WQCV facility and larger events spill out over the surface or through an inlet and storm sewer to a separate flood control detention basin.

Step 6: Develop stormwater quality facilities that enhance the site, the community, and the environment.

Stormwater quality areas can add interest and diversity to a site. Gardens, plazas, rooftops, and even parking lots can become amenities and provide visual interest while performing stormwater quality functions and reinforcing urban design goals for the neighborhood and community. The integration of BMPs and associated landforms, walls, landscape, and materials can reflect the standards and patterns of a neighborhood and help to create lively, safe, and pedestrian-oriented districts.

The quality and appearance of stormwater quality facilities should reflect the surrounding land use type, the immediate context, and the proximity of the site to important civic spaces. Aesthetics will be a more critical factor in highly visible urban commercial and office areas than at a heavy industrial site. The standard of design and construction should maintain and enhance property values without compromising function. In some cases, this means locating a facility to preserve or enhance natural resources.

Step 7: Use a treatment train approach.

Considerable research has demonstrated that the most effective stormwater management is achieved through a “treatment train” approach with BMPs in series. Different BMPs use different processes to remove pollutants from stormwater. For example, an underground baffle vault might be effective at settling out coarse solids, but for removal of finer solids or other pollutants, a BMP using filtration might be necessary. Similarly, a BMP using filtration may clog quickly and become ineffective if pretreatment to remove coarse sediments is not provided before runoff enters the filter surface.

Step 8: Design sustainable facilities that can be safely maintained.

Stormwater quality facilities must be properly and consistently maintained to function effectively and ensure long-term viability. Regular maintenance is also important for public acceptance of these facilities. Typical maintenance operations to consider in designing facilities include:

- Mowing, trimming, and weed control
- Pruning of shrub and tree limbs
- Trash and debris cleanup, especially at grates and flow control structures
- Sediment removal
- Removal, replacement, and revegetation of porous landscape detention media
- Vacuuming/replacement of porous pavement and porous pavement detention media
- Structural repair

Keeping in mind these and other potential maintenance practices, it is also necessary to fully consider how and with what equipment BMPs will be maintained into the future. Facility design should provide for these operations ensuring adequate access with a minimum of disturbance, disruption, and cost. Removal of trash, debris, and sediment on a regular basis should be considered in the maintenance plan.

Step 9: Design and maintain facilities with public safety in mind.

The highest priority of licensed professional engineers and public officials is to protect public health, safety, and welfare. Stormwater quality facilities must be designed and maintained in a manner that does not pose health or safety hazards to the public. For the purpose of this discussion, public safety issues are largely related to public access. The following should be considered (as examples):

Pond Edges:

- Create safe pond edges with gradually sloping banks.
- Reduce perimeter wall heights as much as practicable.
- Include railings where vertical drops adjoin areas with public access.
- Locate facilities with steep sides away from major pedestrian routes
- Provide an emergency egress route.

Visibility:

- Avoid walled-in or steeply sloped, remote ponds that provide hiding places for illicit activity. Consider the need for site lighting.

8.3 Planning and Implementation Considerations

While much of this Chapter focuses on sizing and design criteria for stormwater BMPs, it is equally important to consider:

- Appropriate selection of BMPs based on project objectives,
- Integration of planned BMPs with other elements of the site plan,
- Effective implementation of BMPs once they are designed,
- Proper installation and construction of BMPs, and
- Maintenance of BMPs over the lifetime of the BMP.

8.3.1 Design Considerations

The following bullets provide an overview of design considerations for addressing stormwater quality and flood control requirements on a site.

- Create attractive facilities that add value to the site. While most designers focus on providing a functional stormwater management system for a site, they should also configure and detail the stormwater system to create an aesthetically pleasing facility. Preserving natural features and areas and effective integration of landscape elements and the stormwater system can enhance a project and the community.

- Develop an initial site design.

  - Identify a rough layout of lots, buildings, streets, parking, and landscape areas with a general idea of proposed site grades.

  - Estimate approximate areas associated with roofs, streets, walks, parking lots, and landscaping or open space.

- Consider the full range of BMP alternatives. The stormwater facilities shown in the Land Use-based BMP Selection Guidance (Section 8.3.2) provide examples of appropriate BMPs for a variety of land uses.

  - Determine which of the land uses in **Table 8.3** most closely match the site.

  - Consider the full range of alternative approaches for addressing drainage and stormwater quality for the site, including techniques to reduce runoff and distribute BMPs throughout the site.

  - Test the influence of several alternatives on the overall character and layout of the site, weigh pros and cons of each, and progress towards an optimum approach.

  - Consider long-term or life-cycle costs in the selection of alternative BMPs. These can be assessed by consulting references that discuss life-cycle costs of BMPs (Heaney et al. 2002; Watershed Management Institute 1997; Stormtech et al. 2003; Olson et al. 2009.), or by developing opinions of probable cost for the construction and maintenance of specific BMP alternatives for the site.

  - When selecting and designing BMPs that provide for infiltration (i.e., grass buffers and swales, porous pavement detention, porous landscape detention, and sand-filter detention), the designer needs to carefully consider geotechnical and foundation issues and the ability of the property owner to understand and properly maintain these facilities.

- Pursue a functional distribution of landscape areas. Keep detention basins shallow and provide some space for tree and shrub plantings.

  - Initially, provide an area about 10 to 15 percent of the size of the impervious area for stormwater quality treatment. This area may be reduced in later stages of design. For some types of development (i.e. Ultra urban, lot-line-to-lot-line, this may not be feasible.

  - Bioretention (porous landscape detention) areas should be more numerous, and distributed throughout the site. In general, it is prudent to locate porous landscape detention in close proximity to the impervious area being served.

  - For extremely constrained sites, an option may be to locate a BMP in the right-of-way. This option will be considered by the City on a case-by-case basis, and if water quality treatment within the right-of-way is allowed, it must also provide some degree of treatment for adjacent public spaces.

- Consider surface conveyance as an alternative to pipes.

  - Consider how runoff will be conveyed to stormwater quality facilities. Conveying flows on the surface is the best method for getting runoff to porous landscape and porous pavement detention because it allows the facilities to be shallow in depth and provides a defined surface flow route for extra flow unlike a pipe. If flow can be conveyed on the surface in grass swales or in strips of porous pavement, additional stormwater quality benefits will accrue and the required water quality capture volume will be reduced.

  - If runoff must be conveyed under the surface in a pipe, area inlets within a landscaped area are preferred over street or curb inlets, since this gives runoff a chance to sheet flow through vegetation and infiltrate prior to entering the storm sewer. In many locations along streets, area inlets may not be feasible; however, in residential areas where swales of bioretention areas are considered, area inlets may be appropriate.

- Integrate flood control detention. Multiple approaches exist for addressing flood control detention that dove-tail with stormwater quality management.

  - Locate flood control detention in landscape areas and in parking lots.

  - Retaining walls that fully enclose a landscape detention area are unacceptable as they create a deep basin without adequate access.

- Tailor approach to the specific pollutants of concern. The design criteria in this Chapter are geared to sediment removal since this has been identified as a cause of impairment to the Roaring Fork River.

8.3.2 Land Use-based BMP Selection Guidance

Six general land use types have been identified to communicate different conceptual strategies for stormwater quality treatment in Aspen. These general development types are derived from grouping classifications from the City of Aspen Zone District Map into common categories. **Table 8.3** lists the development type categories and corresponding City of Aspen Zoning.

Table 8.3 Land Use Types for Water Quality Planning and Associated City Zoning

Development Type	Zoning Categories
Ultra Urban/Commercial Core including High Density and Multi-family Residential, including Tourist Lodging	CC, R3, AH1-PUD, R/MF, R/MFA
Low to Medium Density Residential	R-6, R-15, R-15A, R-15B, R-30, RR
Commercial, including Ski-Area Base Development	L, CL, C-1, S/C/I, NC, MU, SKI
Institutional/Campus	A, PUB
Streets	T (overlay)
Parks, Natural Areas and Open Space	C, P, OS, WP

The following sections describe typical characteristics for each development type, as well as potential sites for stormwater quality treatment. Design recommendations have been developed for each, covering these four topics:

1. **Runoff Reduction:** Techniques that decrease runoff volume and reduce the Water Quality Capture Volume (WQCV) requiring treatment.

2. **WQCV Treatment:** BMPs that treat the required volume of storm runoff.

3. **Flood Detention:** Methods for attenuating peak runoff from larger storm events on site.

4. **Implementation Details:** Additional details for specific portions of a site.

Sketch diagrams show how some of the design recommendations may be implemented on a representative site, and additional details and photographs further describe treatment options. These guidelines are recommendations only; the designer may choose to mix and match approaches from different development types to best meet the needs of a particular project.

Table 8.4 summarizes general characteristics of development types, while **Table 8.5** provides an overview of potentially applicable BMPs based on development type. It should be noted in **Table 8.5** that there are often several different types of BMPs that may be considered for a specific type of development. Multiple types of BMPs may be desirable within a development—the developer and designer should carefully consider various combinations of BMPs to develop an optimal treatment strategy for a specific site. For most sites, it will be necessary to go beyond selecting a single BMP for stormwater quality treatment. This approach is mandatory where elevated sediment loads in stormwater runoff are anticipated. In such a case, pretreatment must be provided to remove coarse sediments. This will allow the next BMP downstream in the “treatment train” to function more effectively by reducing potential for clogging and reducing the required maintenance frequency.

In terms of BMP scale, there are several distinctions relevant to the Aspen area:

- On-site BMPs are BMPs that are constructed to serve a single development (and potentially some small adjacent areas). On-site BMPs typically provide treatment for an area that is on the order of 1 acre-or less. They are typically constructed as the development is built and they are generally privately owned and maintained.
- Sub-regional BMPs typically treat runoff from a neighborhood or small watershed area (multiple properties), typically ranging from more than 1 acre to approximately 130 acres. There is often an economy of scale for sub-regional facilities because the footprint required to provide an overall storage volume is generally less if a single facility is used as opposed to multiple smaller facilities with multiple embankments and appurtenances. An example of a sub-regional facility could be an extended dry detention pond in a neighborhood park that treats runoff from adjacent residences and businesses. For contribution areas larger than 5 acres (typical of a sub-regional BMP) commonly used BMPs include extended dry detention basins and constructed wetland basins, which would typically be publicly owned and/or maintained.
- Regional BMPs are large-scale BMPs that treat runoff from areas typically greater than 130 acres. In the Aspen area, examples of regional BMPs include the Jennie Adair Stormwater Wetlands and the Rio Grande Park sediment vault. Regional BMPs offer an economy of scale in terms of size requirements and costs; however, since the capital costs for a regional facility are typically large, funding of facilities to keep pace with development can be difficult. When on-site and sub-regional facilities are not feasible; however, regional; facilities may be necessary. Major advantages of regional facilities are that they are typically publicly owned and maintained and can provide multiple benefits, especially when integrated into a park.

For effective stormwater management in Aspen, a combination of on-site, sub-regional and regional facilities will be implemented.

Table 8.4 Land Use Type Characteristics

Development Type	Percentage Landscaping (Typ.)	Percentage of Surface Parking/Paving (Typ.)	Percentage Building Footprint	Parking Type	Examples
Ultra Urban/ Commercial Core including High Density and Multi-family Residential, including Tourist Lodging	0-5%	0-5%	90-100%	Structure	Downtown Aspen
Commercial and Industrial, including Ski-Area Base Development	0-5%	0-5%	90-100%	Structure	
Streets	0-5%	95-100%	N/A	Structure / Surface	Mill Street
Institutional/Campus	15-30%	10-25%	45-75%	Structure / Surface	Aspen Valley Hospital
Low to Medium Density Residential	40-70%	5-20%	10-45%	Structure/ Surface	
Parks, Natural Areas and Open Space	80-95%	5-15%	0-10%	Surface	Rio Grande Park

Table 8.5 Development Types and Applicable BMPs

Development Type/BMPs	Runoff Reduction/Conveyance BMPs							Storage Volume BMPs							Sub-Surface BMPs	
	MDCIA	Vegetated Swales	Grass Buffers	Pervious Pavement	Constructed Wetland Channel	Tree Canopy Credit	Green Roof	Grass Swale Sed.	Bioretention	Pervious Pavement Detention	Extended Detention Basin (EDB)	Sand Filter EDB	Constructed Wetlands Basin	Modular Suspended Pavement System	Sed./ Filtration Vaults	Dry Wells
Ultra Urban/ Commercial Core	●	⊘	⊘	● ✘Sand	⊘	●	●	⊘	● ✘Sand	⊘ ✘Sand	⊘	⊘ ✘Sand	⊘	●	●	○ ✘Sand
High Density and Multi-family Residential, including Tourist Lodging	●	⊘	⊘	● ✘Sand	⊘	●	●	⊘	● ✘Sand	● ✘Sand	⊘	⊘ ✘Sand	⊘	●	●	○ ✘Sand
Low to Medium Density Residential	●	●	●	● ✘Sand	○	●	●	●	● ✘Sand	● ✘Sand	●	● ✘Sand	○	●	⊘	○ ✘Sand
Commercial and Industrial including Ski-Area Base Development	●	⊘	○	● ✘Sand	⊘	●	●	⊘	● ✘Sand	● ✘Sand	●	● ✘Sand	⊘	●	●	○ ✘Sand
Institutional/Campus	●	●	●	● ✘Sand	○	●	●	●	● ✘Sand	● ✘Sand	●	● ✘Sand	●	●	⊘	⊘ ✘Sand
Streets	●	○	○	○ ✘Sand	⊘	○	⊘	○	○ ✘Sand	⊘ ✘Sand	⊘	● ✘Sand	⊘	●	●	○ ✘Sand
Parks, Natural Areas and Open Space	●	●	●	● ✘Sand	●	●	○	●	● ✘Sand	● ✘Sand	●	○ ✘Sand	●	⊘	⊘	⊘ ✘Sand
On-Site (OS), Sub-Regional (SR), or Regional (R)	**OS**	**OS**	**OS**	**OS**	**SR, R**	**OS**	**OS**	**OS**	**OS**	**OS**	**SR, R**	**OS, SR**	**SR, R**	**OS**	**OS**	**OS**

● = Highly Applicable

○ = Somewhat Applicable

⊘ = Not Recommended

✘Sand = Not for Use in Sanded Areas—some of these BMPs may be applicable if adequate pretreatment is provided

Ultra Urban

Characteristics: Ultra Urban sites are characterized by structured or underground parking, high to mid-rise buildings, and little to no landscape area at grade—most landscape areas are in the Right-Of-Way or over structure. Ultra Urban sites are primarily located in the Downtown Commercial Core where buildings occupy up to 100% of the property. Ultra Urban sites also include High Density Residential, Multi-family Residential, and Tourist Lodging that are characterized by 0-10% open space as paving or landscape area.

Potential Stormwater Quality Treatment Sites: Area for treatment is limited to roofs, plazas, and courtyards. Treatment generally occurs over or adjacent to buildings in contained systems or planters that drain to the storm sewer. Underground treatments vaults (some with pumped outfalls) are used in some situations where land values are extremely high and space is a premium. In these cases, a very high level of maintenance is required.

Design Recommendations:

1. Runoff Reduction

- Minimize directly connect impervious area by directing roof downspouts to landscaped areas, planter boxes or small “pocket” bioretention areas (i.e. landscaped area on patio with underdrain).
- Develop pervious pavement in plazas, courtyards, sidewalks, and parking areas where sanding is not used.

2. WQCV Treatment

- Drain roofs to bioretention in planters adjacent to buildings.
- Drain roofs to pervious pavement detention or bioretention in plazas and courtyards. Aggregate layer beneath pervious pavement or structural soils in bioretention areas may have significant storage.
- Below ground sediment or filtration vaults should be considered only as a last resort if surface solutions are unworkable and/or do not provide adequate WQCV. For extremely constrained sites, an option may be to locate a BMP in the right-of-way. This option will be considered by the City on a case-by-case basis, and if water quality treatment within the right-of-way is allowed, it must also provide some degree of treatment for adjacent public spaces.

3. Flood Detention

- Direct roof runoff to bioretention. Convey flows in excess of WQCV to below-grade vaults or directly to storm sewers in areas where sub-regional detention is provided.

4. Implementation Details

- Planting. Provide additional support for plants in urban settings where they are subject to the additional stresses of heat (summer), stacked snow (winter and spring) and restricted growing area.
- Roofs. Route roof runoff through the building or through external downspouts to vegetated areas.
- Sediment removal. Provide for the removal of debris, trash, and sediment loads that come from roof runoff, construction, sidewalks, outdoor sitting areas, plazas, parking areas, driveways, private roads, and street maintenance. For BMPs relying on infiltration for pollutant removal, pretreatment for sediment removal is absolutely necessary and

some practices, such as pervious pavement, may not be used in areas where sand is applied.

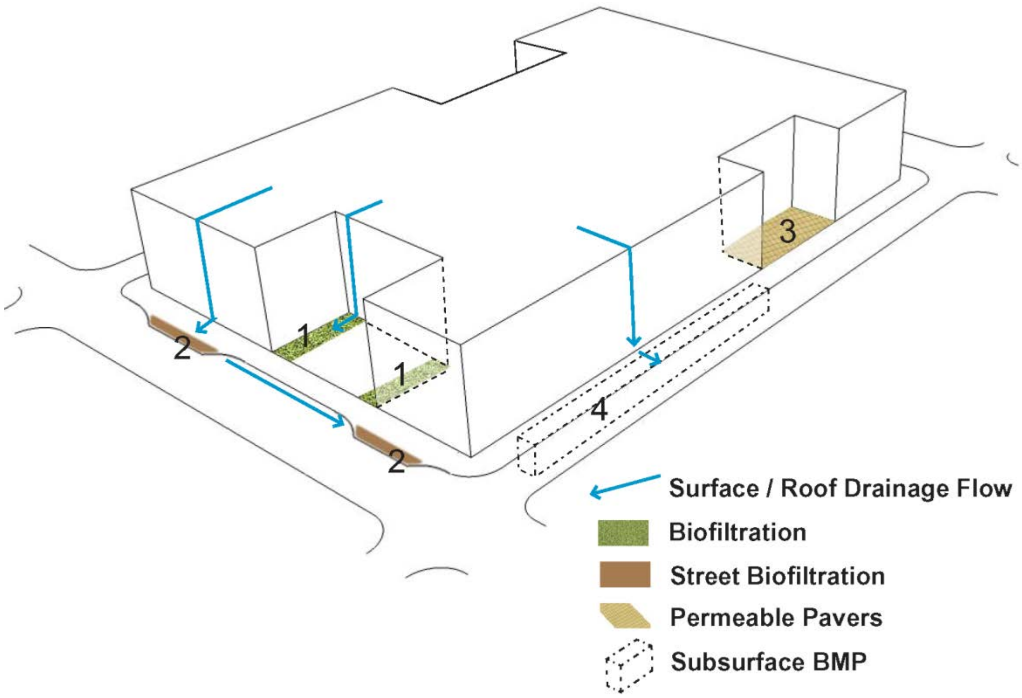


Figure 8.2 Ultra Urban Development Sketch

Key

1 Roof Drainage can be directed to Biofiltration planters adjacent to the building and interior courtyards. This formal urban detailing can create an attractive landscape edge.

2 Roof Drainage and site drainage directed to Biofiltration planters in street bulb outs and along sidewalks. These can be attractive planting areas also utilized for street traffic calming and planting of urban street trees.

3 Permeable Pavers can be utilized for outdoor plazas, patios, and parking spaces (if applicable)

4 Sub-surface BMPs provide stormwater runoff treatment and flood storage and should be considered where site availability for other BMP's are constrained.

Commercial Including Ski-Area Base Development

Characteristics: This type of development is predominantly impervious with little room for landscaped areas. Sites include commercial retailers, industrial facilities, grocery stores, gas stations and ski area base development. Impervious surfaces include parking, roofs, walks, and pedestrian plazas/courtyards account for up to 90 percent of the site.

Potential Stormwater Quality Treatment Sites: Treatment occurs in islands and/or perimeters of sites. Corner-of-the-site treatment options may include limited use of retaining walls that minimize the basin's footprint, but still provide for maintenance access.

Design Recommendations:

1. Runoff Reduction

- Drain roofs to grass buffers at parking islands, medians, and buffers.
- Sheet-drain parking to grass buffers and grass swales.
- Develop pervious pavement in low-traffic areas. Pervious pavement should not be used in areas where sand is applied.
- Where structures do not create an edge at or near the property lines, develop continuous grass buffers.

2. WQCV Treatment

- Drain runoff to bioretention at parking islands, medians, and buffers.
- Develop pervious pavement detention (storage in aggregate pore spaces) in areas with minimal traffic such as outer areas of parking and emergency access drives.
- Develop detention basin BMPs including extended detention and constructed wetlands. These BMPs are typically applicable only for contributing drainage areas of 5 acres or more. For smaller sites (1 to 5 acres), consider sand filter basins.
- Incorporate covering of storage area where materials such as restaurant waste, fertilizers, etc. could potentially be exposed to stormwater.
- Dry wells may not be used in areas where sand is applied or where there is potential for industrial contaminants such as oil and grease to be transported in runoff.

3. Flood Detention

- Provide flood detention within parking areas or underground using pore spaces in aggregate underlying pervious pavement. When extended detention or constructed wetlands are used for water quality treatment, consider expanding the facility to provide flood control benefits as well.

4. Implementation Details

- Parking. Break up extensive parking areas with pervious pavement detention or bioretention.
- Planting. Where the site is contiguous with open space buffers, develop plantings that create a smooth transition between these spaces.
- Stormwater Distribution. Sheet-drain large areas of paving to landscape, or spread flows with slotted curbs or level spreaders.

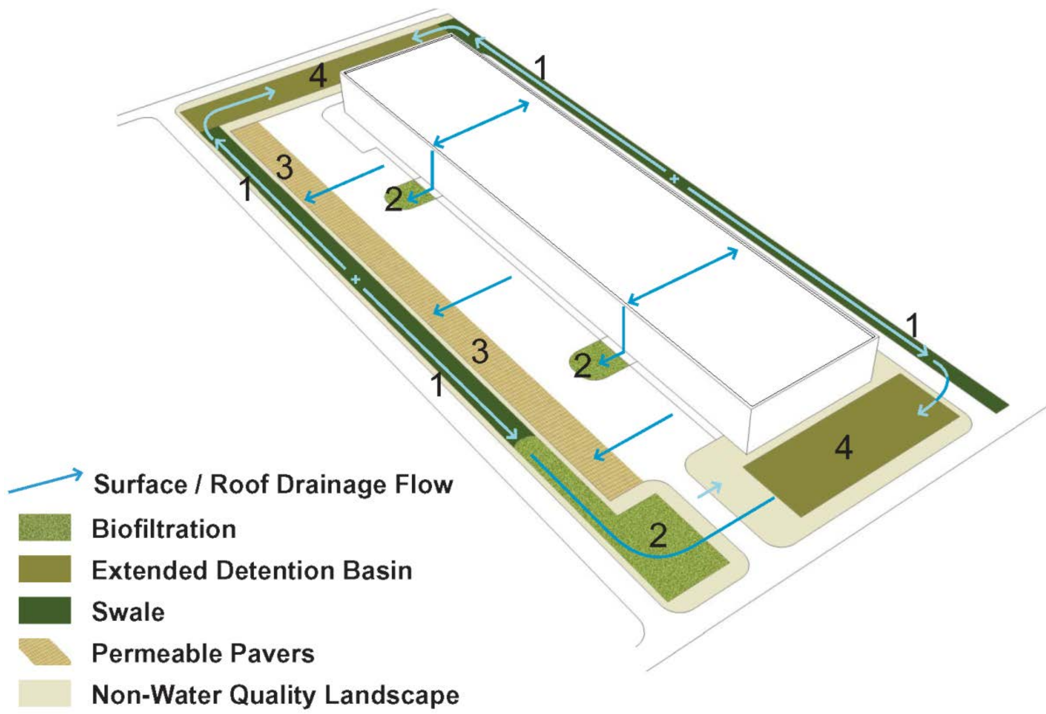


Figure 8.3 Commercial Development Sketch

KEY

1 Grass swales receive roof runoff from downspouts and direct it towards the detention basin at the back of the site. Site runoff is directed to grass swales, reducing runoff and removing large sediment.

2 Biofiltration planters receive and treat runoff from portions of the roof in the front and back of the building. These can be attractive planting areas and/or flower gardens

3 Permeable Pavers at driveways and parking stalls allows stormwater to infiltrate, reducing runoff volumes for the site

4 A linear detention basin at the back and sides of the site treats the WQCV and detains flood water. Sub-surface BMPs may be more applicable where space on site is limited

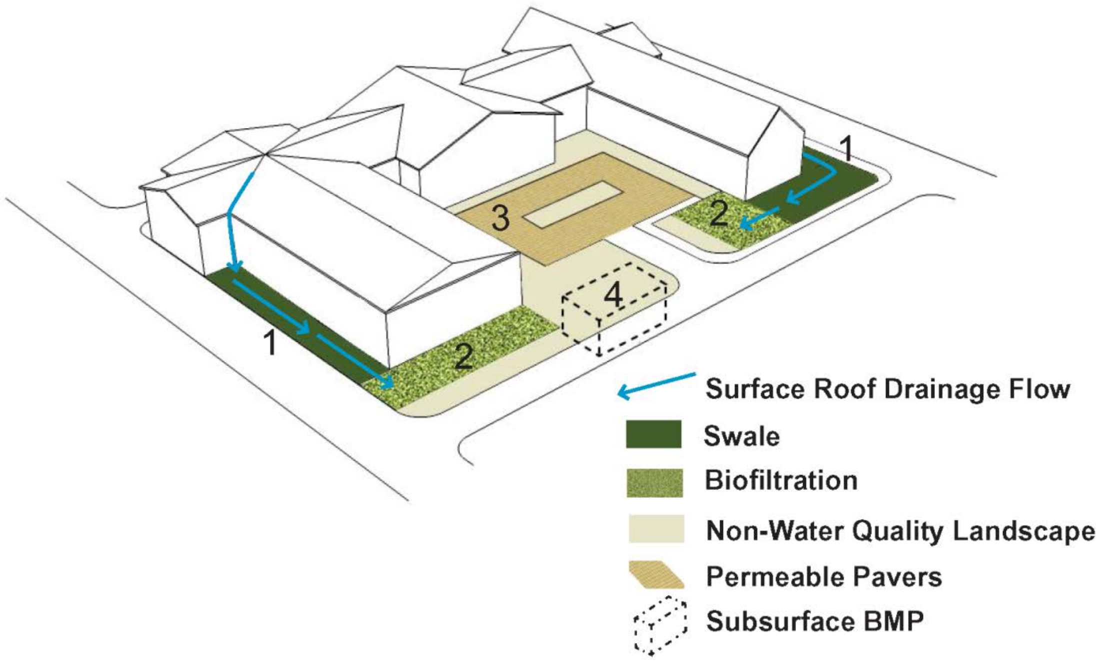


Figure 8.4 Ski Area Development Sketch

KEY

1 Grass swales receive roof runoff from downspouts and direct runoff towards the biofiltration planters or other BMPs.

2 Biofiltration planters receive and treat stormwater runoff. These can be attractive planting areas and/or flower gardens. These areas can also provide snow storage on site during winter months.

3 Permeable Pavers at driveways and drop offs allows stormwater runoff to infiltrate, reducing overall runoff volumes for the site

4 Sub-surface BMPs provide stormwater runoff treatment and flood storage and should be considered where site availability for other BMPs are constrained.

Streets

Characteristics: Streets in Aspen have the potential to contribute a large sediment load in the winter and spring, especially those that are sanded. Streets that run south to north in Aspen are generally steeply sloped while west to east streets are considerably milder. Streets in highly urbanized areas typically have curb and gutter and are served by a storm sewer system. In lower-density residential areas, many streets drain to roadside swales rather than inlets and storm sewers. BMP's located within streets and rights-of-way provide opportunities to greatly minimize sediment transport to the Roaring Fork River.

Potential Stormwater Quality Treatment Sites: Since streets are essential for traffic movement, it is generally not advisable to have frequent accumulation of runoff in streets (they may serve a conveyance purpose in large flood events, but for typical storms, they must remain passable). Therefore, the primary water quality treatment options for streets must fit in the adjacent right-of-way. Treatment options range from bioretention areas in medians and shoulders, to grassed swales and buffers to underground sedimentation vaults. In addition, in areas where right-of-way does not provide adequate space for stormwater treatment, "end-of-pipe" sub-regional or regional facilities may be an alternative for treatment.

Design Recommendations:

1. Runoff Reduction

- When feasible drain runoff from streets to vegetated areas including bioretention, swales and buffers. For many of these types of BMPs, which rely on infiltration to be effective, some degree of pretreatment for sediment removal is necessary.
- Consider pervious pavement for low traffic areas and on street parking. This practice can only be used in areas that are not sanded. Sanding of pervious pavement areas will result in plugging and failure of the BMP.

2. WQCV Treatment

- Drain streets to bioretention areas, medians, and buffers. Bioretention areas can be designed in areas with storm sewers so that the initial portion of runoff flows into the bioretention area while larger events bypass the surface treatment and enter the storm sewer via an inlet
- Consider pervious pavement detention (storage in aggregate pore spaces) in areas where pervious pavement is used.
- For areas with inlets and storm sewers consider on-line underground sedimentation vaults. Maintenance access for vaults is essential for allowing this type of system to function properly.
- Consider sub-regional or regional treatment when space constraints are severe.

3. Flood Detention

- Streets may be used for conveyance during large flood events in accordance with the streets and inlets section of the manual. Flood storage is not a compatible function for most of the BMPs that are applicable to streets. Sub-regional or regional detention may be the most appropriate method for addressing increases in peak flows caused by street imperviousness.

4. Implementation Details

- Sediment removal. Provide for periodic removal of sediment that accumulates in bioretention areas, swales or underground vaults. For BMPs relying on infiltration for pollutant removal, pretreatment for sediment removal is absolutely necessary and some practices, such as pervious pavement, may not be used in areas where sand is applied.

Figure 8.5 Typical Residential Street Biofiltration Planter
Slotted curbs allow stormwater runoff into biofiltration planters.

Figures 8.6 and 8.7 Typical Urban Street Biofiltration Planters
Curb cuts, and chases, with metal grated covers, convey stormwater runoff from the curb to biofiltration planters located along streets.

Figure 8.8 Typical Residential Street Permeable Pavers
Permeable pavers can be used for on-street parking lanes. They should only be used in areas that are not sanded during winter. Sanding of pervious pavement areas will result in plugging and failure of the BMP.

Institutional/Campus

Characteristics: An institutional/campus site consists of multiple buildings with a related purpose or function, organized around pedestrian-oriented spaces. Emphasis on automobile circulation and parking can vary considerably. The percentage of building footprint is nearly 50%-75% while nearly 15-30% of the site(s) are available for landscaping.

Potential Stormwater Quality Treatment Sites: Runoff reduction techniques, infiltration techniques, and WQCV detention options can be integrated into the landscape to create site amenities where space permits. Strategies shown in the High Density and Multi-family Residential Development Type Guidelines are also appropriate for confined spaces on campuses, including treatment in plazas, islands and buffers at surface parking, and roofs.

Design Recommendations:

1. Runoff Reduction

- Drain roofs, walks, drives and surface parking to grass buffers and grass swales throughout the landscape. Locate grass swales along paths and drives. Develop pervious pavement in areas with low traffic such as outer areas of parking and emergency access drives.
- Consider bioretention areas on buildings and parking structures in planter boxes with underdrains.

2. WQCV Treatment

- Drain surface parking to bioretention parking islands, medians, and buffers. (See BMP Fact Sheet)
- Develop pervious pavement detention (storage in aggregate pore spaces) in pedestrian areas or areas with minimal traffic such as outer areas of parking and emergency access drives.
- Develop detention basin BMPs including extended detention and constructed wetlands. These BMPs are typically applicable only for contributing drainage areas of 5 acres or more. For smaller sites (1 to 5 acres), consider sand filter basins.

3. Flood Detention

- Provide flood detention within parking areas or underground using pore spaces in aggregate underlying pervious pavement. When extended detention or constructed wetlands are used for water quality treatment, consider expanded facility to provide flood control benefits as well.

4. Implementation Details

- Roofs. Include treatment and runoff reduction on campus roofs (i.e. bioretention with underdrains) where density and land values make them viable.
- Parking. Design large parking areas with pervious pavement and bioretention in islands or medians where adjacent land cannot be employed for treatment.
- Planting. Consider foot traffic patterns when locating and selecting plantings for runoff reduction and WQCV treatment areas.
- Sediment removal. Provide for periodic removal of sediment that accumulates in detention basins. Include a concrete forebay or rock bench to provide equipment access. For BMPs relying on infiltration for pollutant removal, pretreatment for sediment removal is absolutely necessary and some practices, such as pervious pavement, may not be used in areas where sand is applied.

- Stormwater Distribution. Include slots or interruptions in curbs that control traffic in parking areas to disperse runoff as it flows to adjacent grass swales and buffers.

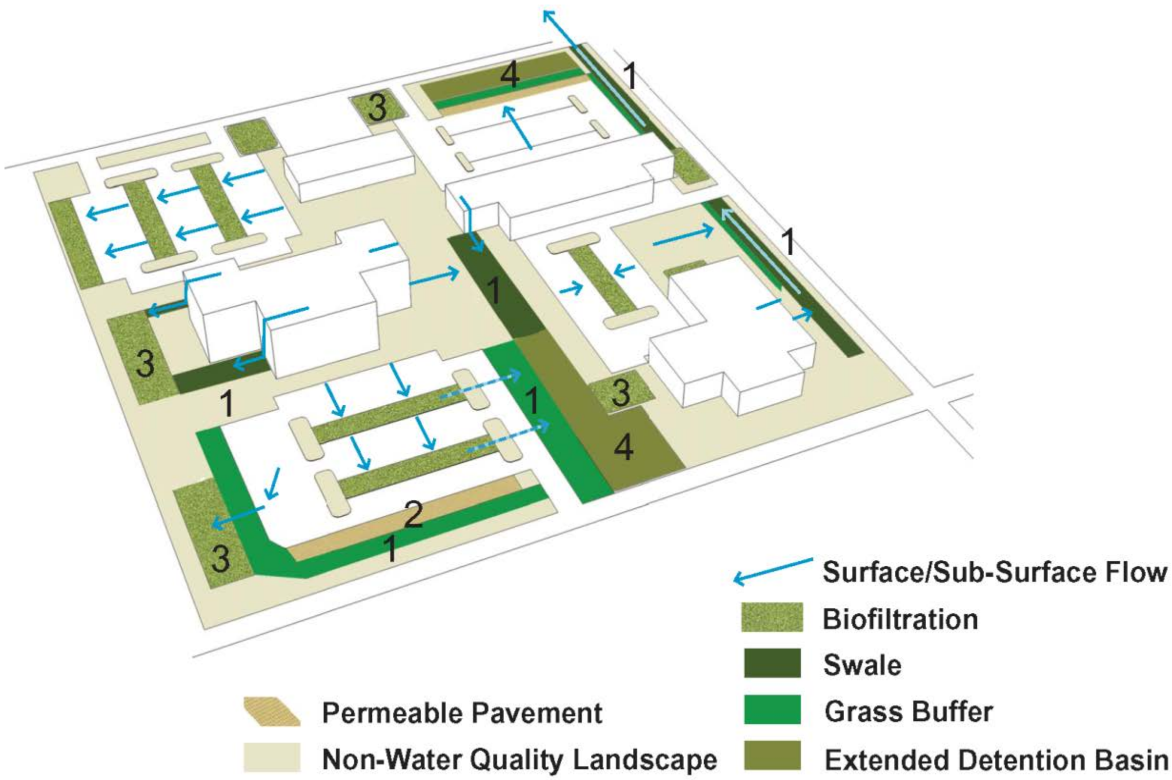


Figure 8.9 Campus and Institutional Development Sketch

KEY

1 Grass buffers and swales receive runoff from parking and paving throughout campus, and direct it to larger BMPs and detention facilities.

2 Permeable Pavers in surface parking lots treats runoff and reduces overall runoff volumes for the site

3 Biofiltration planters can be campus amenities while serving to treat stormwater runoff. These can be attractive planting areas and/or flower gardens

4 Extended detention basins can be located at the back or edges of site, and utilized to treat stormwater quality and provide flood control at the “regional” level for the campus.

Low to Medium Density Residential

Characteristics: Low to Medium Density development types refer to those areas normally zoned for low and medium density Residential uses. These areas are characterized by residential dwellings lined along City streets, and typically include open areas in the front and back of each structure. Paved surfaces are usually limited to driveways, parking courts, and patios. Low and Medium Density residential uses typically have a low percentage of the site as building footprint (10% to 45%)

Potential Stormwater Quality Treatment Sites: The focus in this development type is on reducing runoff from homes. Yards and gardens surrounding each structure or group of structures receive runoff from roofs as well as paved walks and drives.

Design Recommendations:

1. Runoff Reduction

- Drain roofs to grass buffers and grass swales in gardens and yards.
- Drain driveways, walks and patios to adjacent grass buffers either directly or through slot drains or pervious pavement. Provide sufficient slope and/or a ledge between the pavement and the landscape to accommodate future thatch buildup on lawns.
- Construct driveways and parking aprons using pervious pavement. Do not use excessively wide driveways that add unnecessary impervious area.
- Public Space: In appropriate neighborhoods with less-urbanized character, develop roadside grass swales with or without curbs. Allow swales to drain frequently to open space areas or storm sewers to maintain shallow swales.

2. WQCV Treatment

- In lawns or open space, develop bioretention to treat runoff from adjacent areas.
- In parks, greenways, or open space within residential areas, develop sub-regional detention basin BMPs, including extended detention, sand filter basins and constructed wetlands to serve larger tributary areas.

3. Flood Detention

- Locate residences at an elevation to accommodate the 100-year storm event within the adjacent roadway.
- Combine flood control and water quality functions in multi-use sub-regional facilities.

4. Implementation Details

- Roofs. Drain roofs to adjacent landscape to reduce runoff. Avoid storing water on foundation soils at the building perimeter.
- Planting. Design gardens and planting beds to accommodate and thrive on runoff from roofs and paving.
- Stormwater Distribution. Direct runoff to roadside swales with curb-less streets.

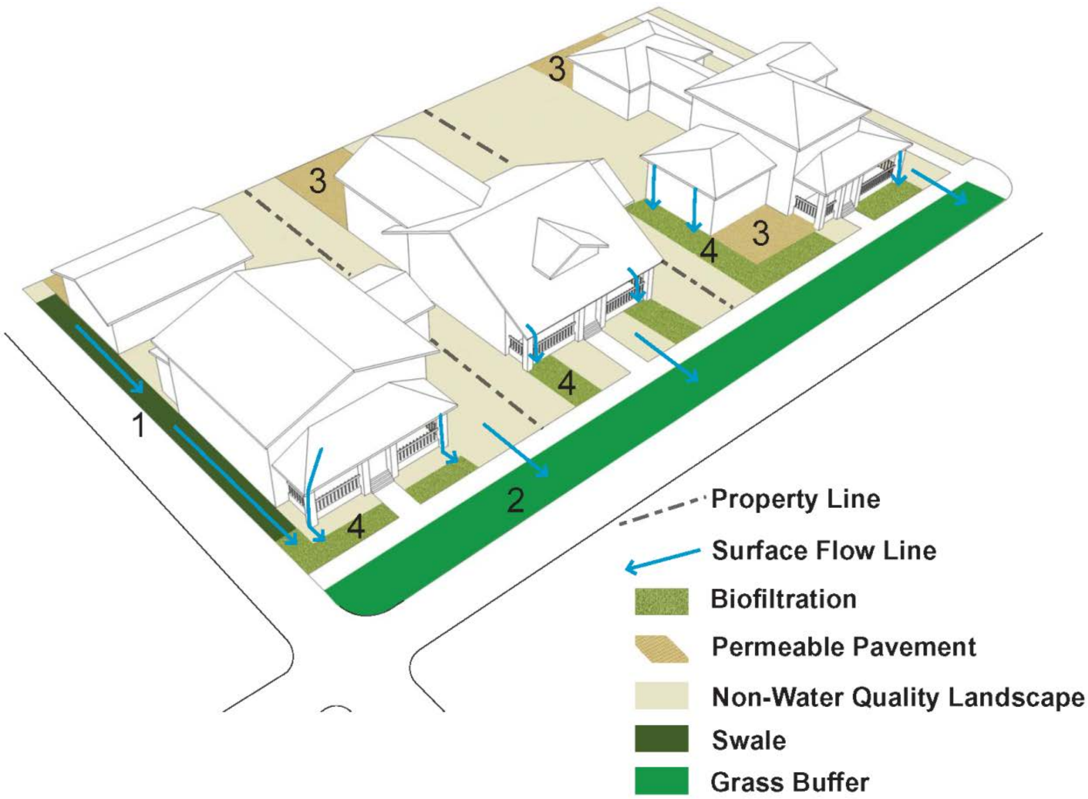


Figure 8.10 Medium/ Low-Density Residential Development Sketch

Key

1 Roof drains and runoff can be directed to shallow swales that convey stormwater to Biofiltration Areas

2 Positive drainage from the sidewalk to the street allows the tree lawn to act as a grass buffer and reduce runoff.

3 Porous pavement at driveways and patios allows runoff to infiltrate.

4 Roof drains and site runoff can be directed to Biofiltration areas. These can be attractive planting areas and/or flower gardens

Parks, Natural Areas and Open Space

Characteristics: Due to the minimal amount of impervious area in parks, supplemental efforts to reduce runoff are not typically required. In fact, Aspen Parks may efficiently serve to treat runoff from surrounding areas if approved by the Parks Department; however, this practice must preserve the quality of park features and programmed uses. The Jennie Adair Stormwater Wetlands facility is a good example of compatibility between parks and water quality treatment.

Potential Stormwater Quality Treatment Sites: The green areas in park spaces create a tremendous opportunity for reducing and treating runoff at a sub-regional or regional level. Stormwater quality facilities are best included in parks larger than an acre, where they do not take up more than a third of the total park area, and can be combined with other park uses. Treatment facilities may be in conflict with active recreation areas like sports fields.

Criteria for the Use of Parks as Stormwater Treatment Sites: Consider the following in determining a park's feasibility as a stormwater treatment site:

- Compatibility with design, historic designation or other protective constraints including wildlife habitat and protection.
- Compatibility with recreational uses. The level of organized and informal activity in a park must be considered.
- Technical constraints and opportunities including soil characteristics, turf management, or terrain.
- Potential for new natural areas and wildlife corridors.
- Size and configuration of the park.
- Facility safety.
- Aesthetics of facility and park.
- Maintenance and operations, funding resources, successful techniques for dealing with silt, debris, etc.
- The configuration and easements for underground utilities and their impact on the existing park land.

Design Recommendations:

1. Runoff Reduction

- Sheet-drain parking and paving to grass buffers and grass swales.
- Drain roofs to grass buffers, grass swales, and pervious pavement.
- Develop multi-purpose trails, maintenance routes, and parking areas to minimize directly connected impervious areas. Avoid concentrating runoff from roadways and parking lots by allowing runoff from those areas to sheet drain over landscape areas.
- Use pervious pavement to the maximum extent practicable for parking areas, patios, trails, etc.

2. WQCV Treatment

- Treat runoff from parking lots and roadways using bioretention and pervious pavement detention where practicable.
- Develop regional stormwater quality treatment in detention basin BMPs, including extended detention basins and wetlands. Construct all facilities as site amenities, with the ability to support diverse ecology, and the ability to be drawn down for clean out and maintenance. Incorporate public education and participation for these sub-regional and regional facilities.
- Do not combine WQCV facilities with active recreation.

- Implement source control BMPs. It is important to properly apply pesticides, herbicides, fertilizers and other chemicals. Use integrated pest management (IPM).

3. Flood Detention

- Consider constructing berms around existing ponds, lakes, and extended detention facilities to increase water storage capacities within the park.

4. Implementation Details

- Parking. Direct runoff from parking to adjacent landscape areas.
- Planting. Parks present a tremendous opportunity to include diverse plantings in larger treatment areas in natural areas and open space.

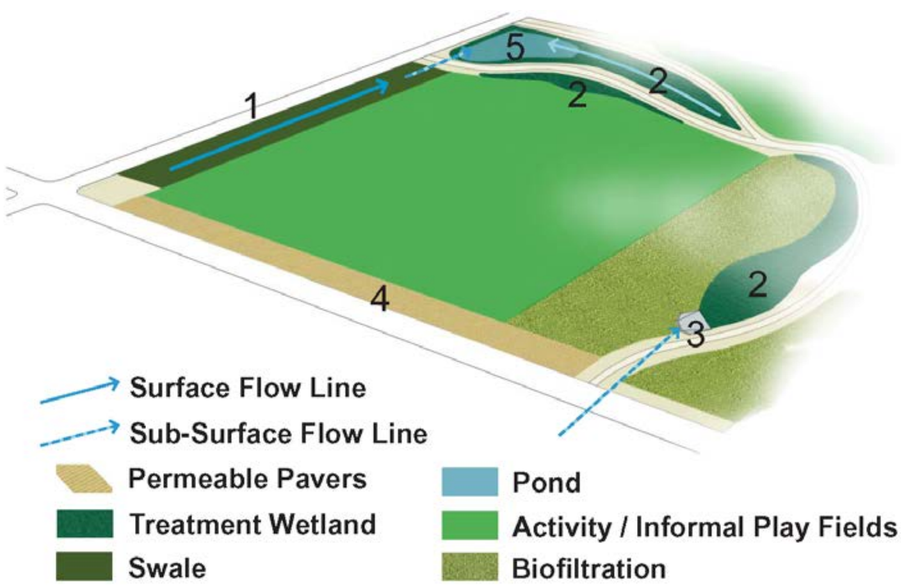


Figure 8.11 Park Development Sketch

KEY

1 Swales and buffers convey stormwater runoff from the fields, and streets (if applicable) before channeling to wetlands or ponds where stormwater can be treated and stored

2 Storm sewers can be daylighted in the park and channeled through treatment wetlands.

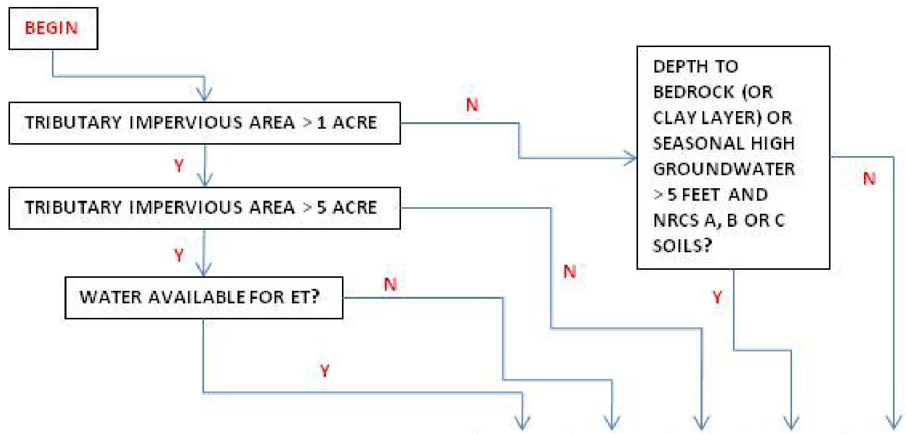
3 A forebay at the end of pipe will provide settlement of large particles. This will reduce the frequency of maintenance, and help manage an attractive wetland planting.

4 Permeable pavers may be used along street edges, or parking stalls to reduce overall stormwater runoff volumes

5 A wet pond can help manage “regional” flood volumes, while being an attractive amenity for the park as long as these do not significantly impact the integrity of the park’s design and functions.

8.3.3 BMP Selection Decision Tree

In addition to land use and development type, other factors are important for selecting the appropriate BMP for a site. These factors include soil type and permeability, size of tributary area, depth to groundwater and bedrock, pretreatment provided, and others. **Figure 8.12** provides a decision tree that can be used to determine appropriate BMPs for a site in conjunction with the development type guidance from **Section 8.3.2**.



MDCIA				□	□
Grassed Swale				□	□
Grassed Buffer	□	□	□	□	□
PPS with Infiltration to Sub-grade				◈	
PPS with Underdrain					◈
Constructed Wetlands Channel	□	□	□	□	□
Street BMPs/Sediment Traps				□	□
Bioretention				◈	
Bioretention with Underdrains					◈
Extended Detention Basins	○	○			
Sand Filter Extended Detention Basin	◈	◈	◈	◈	◈
Constructed Wetland Basin	○				
Subsurface Proprietary BMPs				○	○*
Subsurface Sedimentation Vault				○	○*
Subsurface Sand Filter				○	○*
Dry Well				○	

Notes:

□	Provides modest to moderate runoff reduction and pollutant removal
◈	Provides runoff reduction and WQCV
○	Provides WQCV
PPS	Pervious Pavement System
MDCIA	Minimize Directly Connected Impervious Area
*	Special Design Conditions Necessary to Anchor Against Groundwater

Figure 8.12 BMP Decision Tree

8.4 Design Event and Water Quality Capture Volume (WQCV) Requirements

The design event for Water Quality Capture Volume (WQCV) is the 80th percentile runoff event which corresponds to roughly a 6-month to 1-year storm event. The design brim-full emptying time for the WQCV shall be a minimum of 12 hours. Eighty percent of all runoff events, on a volumetric basis, are expected to be less than or equal to this design event and will be fully treated by BMPs that provide the WQCV. Based on calculations for fine sand-sized particles (60 microns) using settling velocities modified for low temperatures, a drain time of 12 hours for the WQCV should provide a very high level of removal (greater than 90%) for this size of particles (USEPA 1986). While extended drain times (longer than 12-hours) may provide a higher level of removal, they are not practical in Aspen due to the freezing conditions that frequently occur over night during the winter and spring.

Figure 8.13 shows the relationship between impervious area and the WQCV to be used for sizing the WQCV. The following guidelines apply for using **Figure 8.13**:

- The imperviousness used on the x-axis in **Figure 8.13** is the imperviousness of the area tributary to a stormwater BMP. This imperviousness is determined from a site plan by determining the preliminary location of a BMP and then delineating the area that will contribute runoff to the BMP. Impervious areas within the tributary area (watershed) including roofs, walks, drives, roads, etc. can be identified and added to determine the total impervious area within the tributary area. The total imperviousness, as a percent is calculated as: Impervious Area in Tributary Watershed/ Total Area in Tributary Watershed x 100. If a BMP is sized to provide only on-site water quality treatment, the WQCV may be calculated based on only on-site impervious area; however, the BMP must be sized to pass off-site flows from impervious and pervious areas without causing downstream problems. It is preferable to size a BMP for all tributary impervious area (on-site and off-site) as this will provide the greatest water quality benefit for the community.

- For sites that employ runoff reduction measures such as swales, buffers, trees and other BMPs that minimize directly connected impervious area or the effect of the impervious area, the total imperviousness should be adjusted to effective imperviousness before using **Figure 8.13** to determine the WQCV. Adjustment procedures for converting total imperviousness to effective imperviousness are described in **Section 8.4.1**.

- The WQCV in **Figure 8.13** has units of watershed-inches. To determine a volume in ft^3, the following conversion applies:

$$Volume\ (ft^3) = WQCV\ in\ Watershed\ inches\ x\ \frac{1 ft}{12\ in} x\ Area\ (sf)$$

For a site that is 100 percent impervious the WQCV corresponds to 0.26 watershed-inches (i.e. the storage volume required for a BMP is equivalent to 0.26 inches of runoff distributed over the area tributary to the BMP). 0.26 watershed inches is equivalent to approximately 950 ft^3/acre.

An example of how to determine the WQCV is provided in **Section 8.4.2**.

Figure 8.13 Aspen Water Quality Capture Volume

8.4.1 Calculating Effective Imperviousness Based on Disconnected Impervious Area or Tree Canopy Credit

The WQCV is a function of the imperviousness of the area tributary to the BMP. When certain low impact development (LID) and runoff reduction techniques are used such as grass swales, grass buffers, downspouts directed to pervious areas, etc., the **effective** imperviousness of a watershed may be lower than the **total** imperviousness. Two levels of MDCIA are defined for the purposes of this Chapter:

- **Level 1.** The goal of Level 1 is to direct the flow of runoff from impervious surfaces over grass-covered areas or pervious pavement, and to provide sufficient travel time to maximize the removal of suspended solids before the runoff leaves the site, enters a curb and gutter, or enters another stormwater collection system. Thus, at Level 1, *all* impervious surfaces are made to drain over grass buffer strips (criteria in **Section 8.5.1.3**) before reaching a stormwater conveyance system.

- **Level 2.** As an adjunct to Level 1, this level replaces solid street curb and gutter systems with no curb or slotted curbing and low-velocity grass-lined swales and pervious street shoulders. Conveyance systems and storm sewer inlets will still be needed to collect runoff at downstream intersections and crossings where stormwater flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways until inlets are provided to convey the flow to a storm sewer.

Figure 8.14 illustrates adjustments to effective imperviousness based on Level 1 and 2 MDCIA. **Section 8.4.2** provides an example of how to use **Figure 8.14** to determine effective imperviousness.

Another way to reduce the effective imperviousness of a tributary area is through a tree canopy credit. Trees are a valuable natural resource and can considerably reduce stormwater runoff through interception, transpiration, and infiltration.

The following method can be used to receive credit for the tree canopy in a tributary area.

Step 1: Identify the proposed impervious areas within the property lines and the existing tree canopy within the property lines. Tree canopies must be divided into deciduous and coniferous. Only existing, pre-project trees can be counted. The minimum canopy for consideration is 10 ft and the trunk of the trees counted must be within 50 ft of the impervious areas on a site. Show this step in aerial photo or landscaping plan for review.

Step 2: Calculate the coniferous tree canopy area and multiply by 0.30. Calculate the deciduous tree canopy area and multiply by 0.15. Sum these two totals.

Step 3: Subtract the sum in Step 2 from the impervious area.

Step 4: Divide the new reduced impervious area by the total tributary area and multiply by 100 to get effective imperviousness. Use Figure 8.14 to calculate WQCV for the tributary area/sub-basin in design.

If canopy in consideration is required to be removed by the City Forester, then that canopy credit will not be lost.

Section 8.4.2 provides an example of how to use tree canopies to reduce the effective imperviousness for a site.

8.4.2 WQCV and Effective Imperviousness Example

Problem: Determine the WQCV and effective imperviousness for a 6,000 sf lot with an imperviousness of 70% draining to a BMP. Assume Level 1 MDCIA (impervious areas disconnected to drain to pervious areas.

Solution: First apply **Figure 8.14** to determine effective imperviousness for Level 1 MDCIA and a total imperviousness of 70 percent. As shown in **Figure 8.15**, below, the effective imperviousness is approximately 68 percent.

Next, apply an effective imperviousness of 68 percent to **Figure 8.13** to determine the WQCV in watershed inches. As shown in **Figure 8.16**, the WQCV is approximately 0.135 watershed inches.

Finally, calculate the WQCV in cubic feet:

$$WQCV = 0.135\ watershed\ inches\ x\ \frac{1ft}{12\ in} x\ 6000\ ft^2 = 67.5\ ft^3$$

Problem: Determine the effective imperviousness and WQCV for a 7,000 sf lot with 3000 sf of impervious area. On the eastern portion of the property is a deciduous tree canopy of 600 sf and a coniferous canopy of 250 sf. On the western portion of the property is a deciduous canopy of 400 sf and a coniferous canopy of 500 sq ft.

Solution: First determine effective impervious area for the property.

Eff Imp Area = 3000 – (500+250)0.3 – (600+400)0.15 = 3000 – 225 – 150 = 2625 sf

Imperviousness = (2625 / 7000) 100 = 37.5% WQCV = 0.075 watershed-inches

Finally, calculate the WQCV in cubic feet:

$$WQCV = 0.063\ watershed\ inches\ x\ \frac{1ft}{12\ in} x\ 7000\ ft^2 = 43.75\ ft^3$$

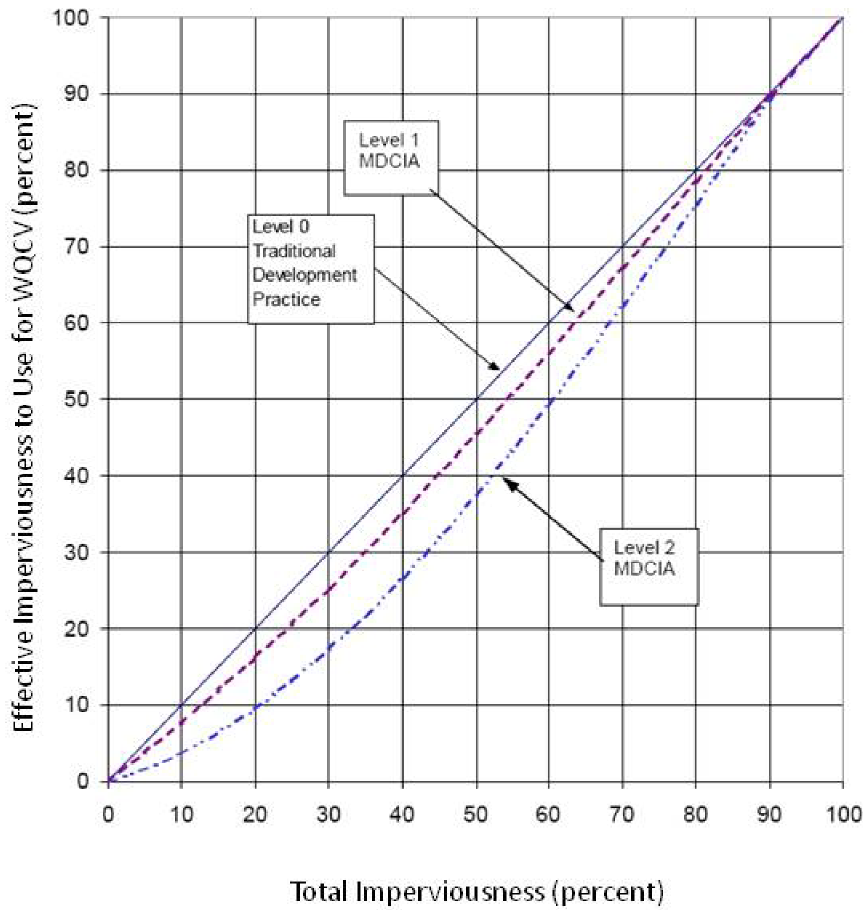


Figure 8.14 Imperviousness Adjustments for Level 1 and 2 MDCIA (UDFCD 1999)

When MDCIA and other LID practices are used, the WQCV should be calculated based on effective impervious area rather than total impervious area. Along with MDCIA, the use of pervious pavement systems (PPS) has the potential to reduce effective imperviousness. Specific guidance for adjustments to imperviousness for PPS is provided in **Section 8.5 Structural BMPs**.

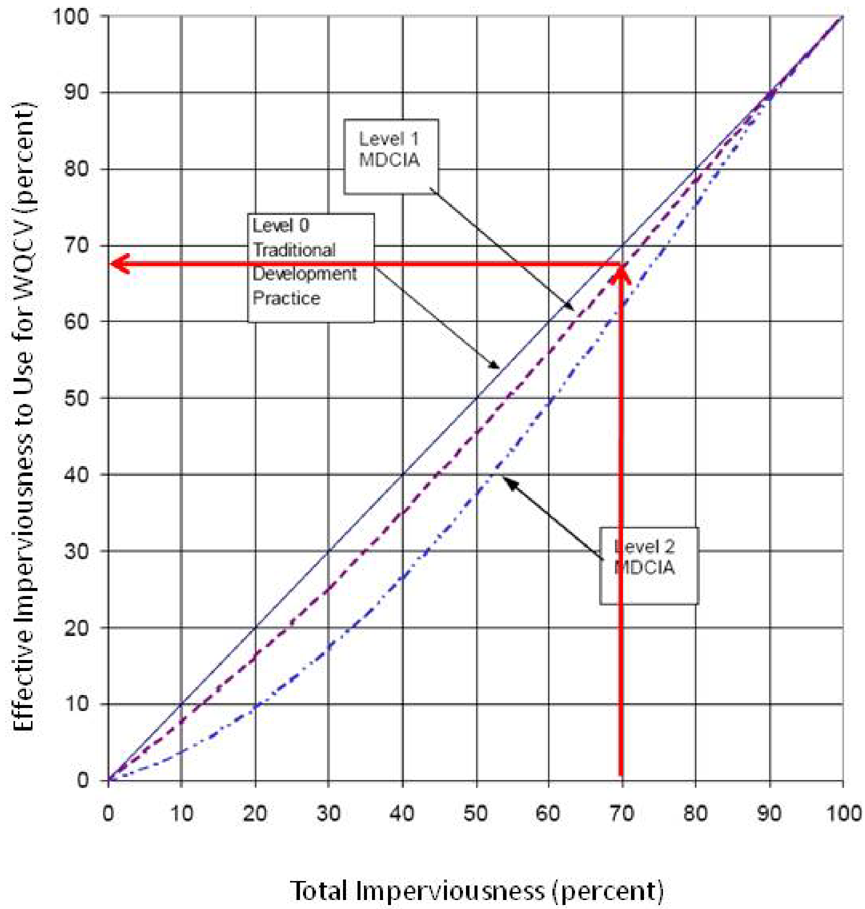


Figure 8.15 Imperviousness Adjustments Example (Total Imperviousness = 70 percent, Level 1 MDCIA)

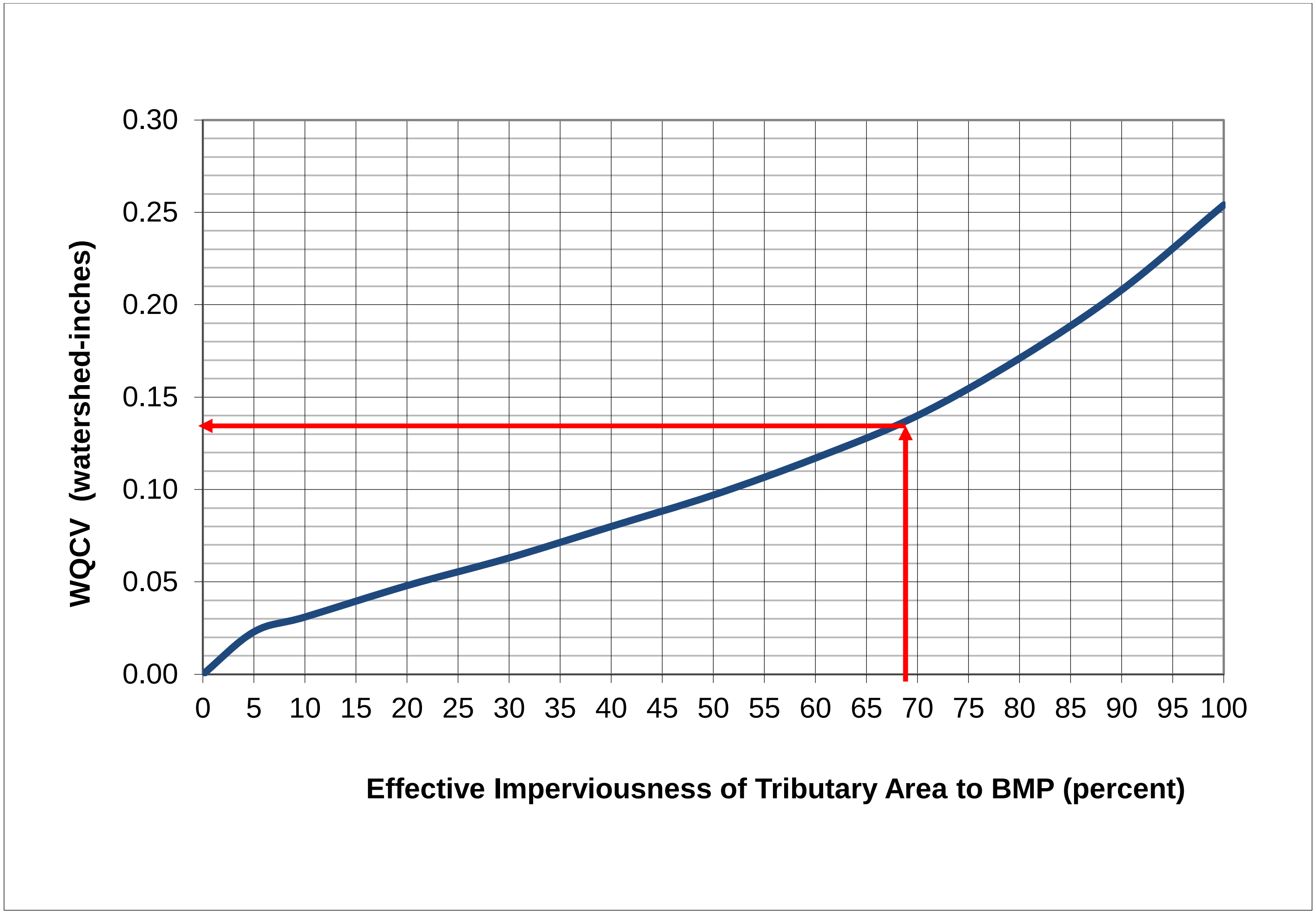


Figure 8.16 Aspen Water Quality Capture Volume Example (Total Imperviousness = 70 percent, Level 1 MDCIA, Effective Imperviousness = 68 percent)

8.5 Structural BMPs

This section provides design criteria for structural BMPs that are applicable for water quality treatment in Aspen. This is not an exhaustive list of structural BMPs nor are the BMP criteria set in stone. Stormwater quality treatment is a constantly evolving subject and alternate BMPs or modifications to stated criteria may be permitted at the discretion of the City Engineering Department.

8.5.1 Runoff Reduction/Conveyance BMPs

Runoff reduction measures such as MDCIA and pervious pavements reduce the amount of surface runoff requiring treatment by storage-based BMPs and reduce the “flashy” nature of urban hydrographs. Conveyance based BMPs such as grassed swales and buffers slow down runoff (lengthening the time of concentration), promote infiltration during conveyance and provide filtration of runoff as it passes through vegetation. When used in conjunction with a storage-based BMP, runoff reduction and conveyance BMPs provide the first step in a “treatment train.”

8.5.1.1 Minimizing Directly Connected Impervious Area (MDCIA)

Minimizing directly connected impervious area (MDCIA) requires a basic change in land development design philosophy. This change seeks to reduce paved areas, use porous pavement and direct stormwater runoff to landscaped areas, grass buffer strips, and grass-lined swales to slow down the rate of runoff, reduce runoff volumes, attenuate peak flows, and encourage filtering and infiltration of stormwater. The fundamental method for MDCIA is to first eliminate unnecessary impervious area or seek to replace impervious pavement areas with pervious pavements and then to strive to direct runoff from impervious areas to pervious areas such as buffers and swales before discharging to the collection system/storm sewer.

8.5.1.2 Grassed Swales

Figure 8.18 Native grass species can be utilized in swales when the longitudinal slope of a swale is flat-- less than 0.5 percent

Figure 8.17 A shallow grass swale collects runoff from roof downspouts and adjacent pavement. The flush curb allows sheet flows into the swale.

Description

A grassed swale (GS) is an integral part of the MDCIA development concept. They are densely vegetated drainageways with low-pitched side slopes that collect and slowly convey runoff. Design of their longitudinal slope and cross-section size forces the flow to be slow and shallow, thereby facilitating sedimentation while limiting erosion. Berms or check dams should be installed perpendicular to the flow as needed to slow it down and to encourage settling and infiltration.

General Application

A grassed swale can provide a reduction in the effective imperviousness for a site but does not hold volume and therefore cannot be used as a water quality treatment facility. A GS can be located to collect overland flows from areas such as parking lots, buildings, residential yards, roadways and grass buffer strips (GBs). They can be used instead of a curb-and-gutter system to disconnect impervious area. A GS is set below adjacent ground level, and runoff enters the swales over grassy banks or rundowns. The potential exists for wetland vegetation to become established if the swale experiences standing water or if there is a base flow. If that condition is possible, consider the use of underdrains. A site with a base flow should be managed as either a swale with an unlined trickle channel, or as a wetland bottom channel, the latter providing an additional BMP for stormwater runoff treatment.

Advantages/Disadvantages

A GS, which can be more aesthetically pleasing than concrete or rock-lined drainage systems, is generally less expensive to construct. This BMP generally provides some reduction in runoff volumes from small storms. Dense grasses can reduce flow velocities and protect against erosion during larger storm events. Swales in residential and commercial settings can also be used to limit the extent of directly connected impervious areas.

The disadvantages of using GSs without underdrains include the possibility of soggy and wet areas in front yards and the potential need for more right-of-way than is needed for a storm sewer.

Physical Site Suitability

A GS is practical only at sites with general ground slopes of less than 4 to 5 percent and is not practical for sites steeper than 6 percent. The longitudinal slopes of a GS should be kept to less than 1.0 percent, which often necessitates the use of grade control checks or drop structures.

When soils with high permeability (for example, Class A or B) are available, the swale will infiltrate a portion of the runoff into the ground; however, such soils are not required for effective application of this BMP. When Class C and D soils are present, the use of a sand/gravel underdrain is recommended.

Pollutant Removal

Removal rates reported in literature vary and fall into the low to medium range. Under good soil conditions and low flow velocities, moderate removal of suspended solids and associated other constituents can be expected. If soil conditions permit, infiltration can remove low to moderate loads of some of the soluble pollutants when flow velocities are very low. As a result, small frequently occurring storms can benefit the most.

Cold Weather Considerations

Since GSs function primarily based on filtration by vegetation and infiltration, they are most effective in the summer months when vegetation is healthy and the ground is not frozen. During melting periods, grass swales can be effective at slowly infiltrating snow accumulated in swales, which may be used as snow storage areas in the winter. If there are significant sediment loads to the swales, from sand removed from streets and stacked in swales or from other sources, excessive sediment may accumulate in the swale, choking out vegetation. Periodic maintenance may be required to remove excess accumulated sediment and to reestablish vegetation.

Design Considerations

Figure 8.19 shows trapezoidal and triangular swale configurations. A GS is sized to maintain a low velocity during small storms and to collect and convey larger runoff events, all for the projected fully developed land use conditions. If the design flows are not based on fully developed land conditions, the swales will be undersized and will not provide the intended pollutant removal, flow attenuation, or flow conveyance capacity.

A healthy turf grass cover must be developed to foster dense vegetation. Permanent irrigation in some cases may be necessary. Judicious use of GSs can replace both the curb-and-gutter systems and greatly reduce the storm sewer systems in the upper portions of each watershed when designed to convey the "initial storm" (for example, a 2- or a 5-year storm) at slow velocities.

Design Procedure and Criteria

The following steps outline the GS design procedure and criteria.

1. Design Discharge—Determine the 2-year flow rate to be conveyed in the GS. Use the hydrologic procedures described in Runoff Chapter of the Manual. If the swale is used for minor event conveyance purposes as well as for water quality, the overall capacity may be greater than the 2-year event. Swale geometry at the 2-year flow rate should follow the guidance in this section.
2. Swale Geometry—Select geometry for the GS. The cross section should be either trapezoidal or triangular with side slopes flatter than 4:1 (Horizontal/ Vertical). Even flatter side slopes will provide greater infiltration benefits. The wider the wetted area of the swale, the slower the flow and the more effective it is in removing pollutants.
3. Longitudinal Slope—Maintain a longitudinal slope of the GS between 0.2 and 1.0 percent. If the longitudinal slope requirements cannot be satisfied with available terrain, grade-control checks or small drop structures must be incorporated to maintain the required longitudinal slope. If the slope of the swale exceeds 0.5 percent in semi-arid areas of Colorado, the swale must be vegetated with irrigated turf grass. Milder slopes will provide greater water quality benefits.
4. Flow Velocity and Depth—Calculate the velocity and depth of flow through the swale. Using the Manning's equation and a Manning's roughness coefficient of n=0.06, find the channel velocity and depth using the peak 2-year flow rate determined in Step 1. Maximum flow velocity in the swale shall not exceed 1-foot per second and the maximum flow depth shall not exceed 1-foot at the 2-year peak flow rate. If these conditions are exceeded, repeat steps 2 through 4 each time altering the depth and bottom width or longitudinal slopes until these criteria are satisfied.
5. Vegetation—Vegetate the GS with dense turf grass to promote sedimentation, filtration, and nutrient uptake, and to limit erosion through maintenance of low flow velocities.
6. Drainage and Flood Control—Check the water surface during larger storms including the minor and major events to ensure that drainage from these larger events is being handled without flooding critical areas or residential, commercial, and industrial structures.

Maintenance

Table 8.6 outlines maintenance recommendations for GSs.

Table 8.6 Maintenance Recommendations for Grassed Swales (UDFCD 1999)

Required Action	Maintenance Objective	Frequency of Action
Inspections	Check the grass for uniformity of cover, sediment accumulation in the swale, and near culverts.	Routine – Annual inspection is suggested.
Lawn mowing and Lawn care	Maintain irrigated grass at 2 to 4 inches tall and non-irrigated native grass at 6 to 8 inches tall. Collect cuttings and dispose of them offsite or use a mulching mower.	Routine – As needed.
Debris and Litter removal	Keep the area clean for aesthetic reasons, which also reduces floatables being flushed downstream.	Routine – As needed by inspection, but no less than two times per year. Check each spring after snowmelt.
Sediment removal	Remove accumulated sediment near culverts and in channels to maintain flow capacity. Replace the grass areas damaged in the process.	Routine – As needed by inspection. Check each spring after snowmelt.
Grass reseeding and mulching	Maintain a healthy dense grass in channel and side slope.	Non-routine – As needed by annual inspection.

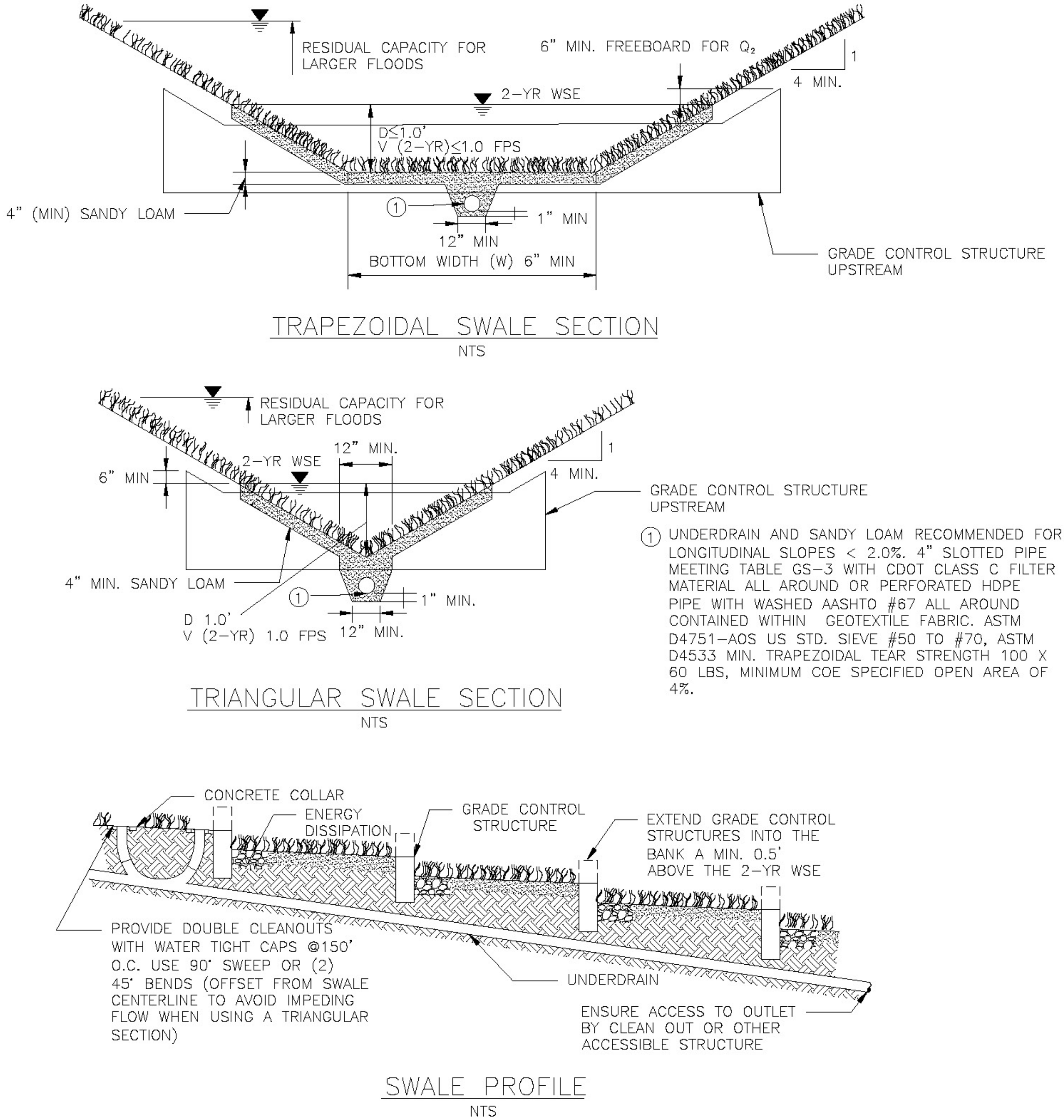


Figure 8.19 Grassed Swale Typical Sections and Profile (UDFCD 1999)

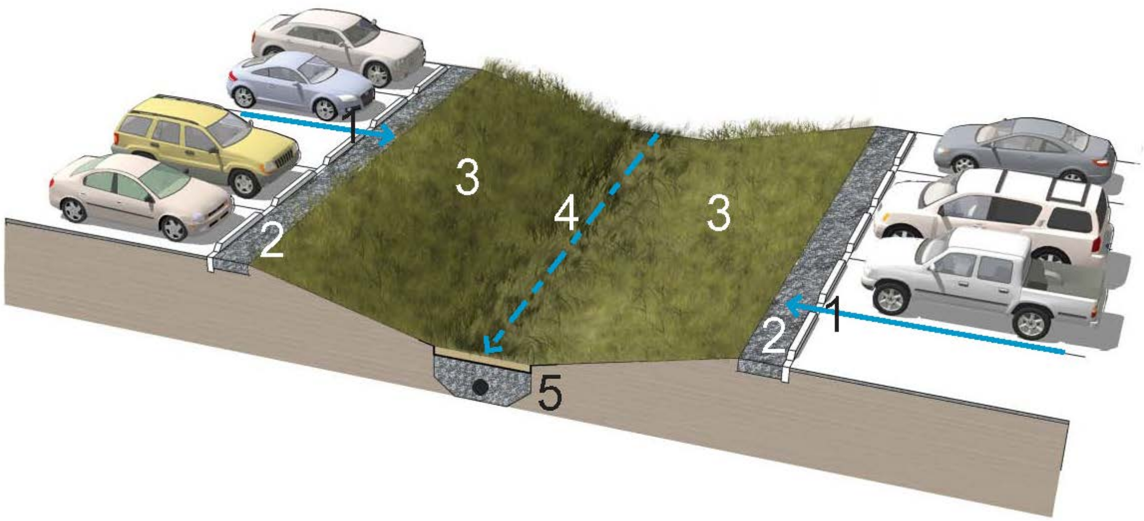


Figure 8.20 Typical Grass Swale Design Sketch

1: Inlet: Slotted curbs or curbless streets/ paved areas allow for sheet flows into the swale, side slopes serve as grass buffers. Control for sediment and erosion at inlets and wherever flows are concentrated.

2: Sediment Trap: A sloped edge, three inches below the pavement surface. Sediment trap can be landscaped or non-vegetated. Provide a non-vegetated trap, such as a gravel filter, if large volumes of sediment are anticipated. Provide sediment traps at pipe outfalls to dissipate energy and allow easier sediment removal. Locate sediment traps above the low flow conveyance of the swale to minimize re-mobilization of sediments.

3: Slopes: Longitudinal slopes should be shallow (less that 0.2-1.0) Provide check structures where longitudinal slopes exceed 1% or as needed along the length of the swale. Side slopes shall be 4:1 max., flatter preferred.

4: Vegetation: Dense turf grass is most commonly used. Plantings vary depending on context. Select appropriate plant materials for appropriate wet and dry cycles, and that can withstand storm flow velocities. Native grasses can be used where longitudinal slopes are less than 0.5%.

5: Underdrain/Liner: Underdrains are not required for Type A and Type B soils per UDFCD 2010; however, in some instances they may be considered for these soils types if there is concern with future reduced infiltration capacity due to sediment accumulation. Underdrains are required for Type C and Type D soils, or when swales are in close proximity to buildings, structures, or where geotechnical requirements dictate. Refer to Typical Sections and Profile **Figure 8.19**.

6: Soils: Consisting of native soils and/or soils as needed for specified plant types (not shown in graphic). Refer to Typical Sections and Profile **Figure 8.19.**

8.5.1.3 Grass Buffers (GB)

Description

Grass buffer (GB) strips are an integral part of the MDCIA land development concept and in the City of Aspen they are also considered a stormwater BMP that when appropriately designed can provide for the removal of sediment and provide the WQCV. They are densely vegetated areas of turf grass that require sheet flow to promote filtration, infiltration and settling to reduce runoff pollutants. GBs differ from grass swales as they are uniformly graded and designed to accommodate overland sheet flow rather than concentrated or channelized flow. They can be used to remove larger sediment from runoff from impervious areas.

Whenever concentrated runoff occurs, it should be evenly distributed across the width of the buffer via a flow spreader. GBs can also be combined with riparian zones in treating sheet flows and in stabilizing channel banks adjacent to major drainageways and receiving waters. GBs can be interspersed with shrubs and trees to improve their aesthetics and to provide shading. Irrigation in the semi-arid climate of Colorado may be required to maintain a healthy and dense grass on the GB to withstand the erosive forces of runoff from impervious areas.

General Application

A GB is located adjacent to impervious areas and can be used in residential and commercial areas and along streets and roads. Because their effectiveness depends on having an evenly distributed sheet flow over their surface, the size of the contributing area, and the associated volume of runoff have to be limited. Flow can be directly accepted from a parking lot, roadway or building roof, provided the flow is distributed uniformly over the strip.   Grass buffers can be used for treatment of the water quality capture volume.

Figure 8.21 A gravel mulch band next to the traps sediment before it enters the grass buffer.

Figure 8.22 A curbless street allows parking lot stormwater to flow evenly from the road through a grass buffer.

Advantages/Disadvantages

The grass and other vegetation can provide aesthetically pleasing green space. In addition, their use adds little cost to a development that has to provide open space, and their maintenance should be no different than routine maintenance of the site's landscaping. Eventually, the grass strip next to the spreader or the pavement will have accumulated sufficient sediment to block runoff. At that time, a portion of the GB strip will need to be removed and replaced. Grass and trees within these buffer strips can provide wildlife habitat. Because infiltration occurs and water quality capture volume can be treated within the buffer, the size of downstream drainage facilities can often be reduced. Gravel underdrains can be used where soils are not suited for infiltration.

Physical Site Suitability

The site, after final grading, should have a uniform slope and be capable of maintaining an even sheet flow throughout without concentrating runoff into shallow swales or rivulets. The allowable tributary area depends on the width, length, and the soils that lay under the GB. Hydrologic Soil Groups A and B provide the best infiltration capacity, while Soil Groups C and D provide best site stability. The swelling potential of underlying soils should also be taken into account when used adjacent to structures and pavement. Irrigation may be required for some types of vegetation.

Pollutant Removal

Pollutant removal depends on many factors such as soil permeability, site slope, the flow path length along the buffer, the characteristics of drainage area, runoff volumes and velocities, and the type of vegetation. The general pollutant removal of both particulate and soluble pollutants is projected to be low to moderate. GBs rely primarily upon the straining through grass and settling of solids, and to only a minor degree, on biological uptake and runoff infiltration.

Cold Weather Considerations

Cold weather considerations for GBs are similar to those of GSs. Performance can be expected to be best in summer months when vegetation is healthy and the ground is not frozen. Some infiltration may occur at the bottom of a ripe snowpack; however, it is likely the soils will be saturated, reducing the infiltration rate. Snow may be stored in GBs during winter months. If snow is stored in these areas, excessive sediment may accumulate in the GBs and impact vegetation. Periodic removal of excess sediment and replacement of vegetation should be anticipated.

Design Considerations

Design of GBs is based primarily on maintaining sheet-flow conditions across a uniformly graded, irrigated, dense grass cover strip. When a GB is used over unstable slopes, soils, or vegetation, the formation of rills and gullies that disrupt sheet flow will occur. The resultant short-circuiting will invalidate the intended water quality benefits and will render the GB no functional. GBs should be protected during construction (cannot be compacted) and from excessive pedestrian or vehicular traffic that can damage the grass cover and affect even sheet-flow distribution post-construction. A mixture of grass and trees may offer benefits for slope stability and improved aesthetics. If used adjacent to pavement, there should be a 1 – 2 inch drop into the buffer area.

Design Procedure and Criteria

The following steps outline the GB design procedure and criteria. **Figure 8.23** depicts a typical GB with key design criteria.

1. Minimum Length (L_G)—Calculate the minimum length (normal to flow) of the GB. The upstream flow needs to be uniformly distributed over this length, either by design water to sheet flow from the tributary area or through the use of a level spreader.

   $L_G \geq 0.7L_T$

2. Minimum Width - The minimum width (W_G) (the distance along the sheet flow direction) of the GB is five (5) feet.

3. Minimum Area – To meet WQCV requirements for an impervious area the minimum grass buffer area (A_G) shall be greater than or equal to the tributary area (A_T). There shall be a 1:1 ratio of impervious area to grass buffer area.

4. Geometry - A rectangular strip is the preferred shape for the GB and should be free of gullies or rills that concentrate the flow over it.

5. Maximum Slope—Design slope of a GB in the primary direction of flow should not exceed 4 percent.

6. Flow Distribution—Incorporate a device on the upstream end of the buffer to evenly distribute flows along the design length. Slotted curbing, modular block porous pavement (MBP), or other spreader devices can be used to apply flows. Concentrated flow supplied to the GB must use a level spreader (or a similar device) to evenly distribute flow onto the buffer.

7. Soils and Vegetation — GB are not permitted on compacted soils and evidence of infiltration ability might be required. Additionally, if GB are constructed as part of new construction, 6" of topsoil is recommended. It is recommended to vegetate the GB with irrigated dense turf in semi-arid areas of Colorado to promote sedimentation and entrapment and to protect against erosion. However, plantings can/should vary depending on context. Select appropriate plant materials for appropriate wet and dry cycles, and that can withstand storm flow velocities. Native grasses can be used where longitudinal slopes are less than 0.5%, but bunch grasses are not acceptable.

8. Outflow Collection – Provide a means for outflow collection. Much of the runoff during significant events will not be infiltrated and will require a collection and conveyance system. A grass swale (GS) can be used for this purpose and can provide another MDCIA type of a BMP. The buffer can also drain to a storm sewer or to a street gutter. In some cases the use of underdrains can maintain better infiltration rates as the soils saturate and help dry out the buffer after storms or irrigation periods.

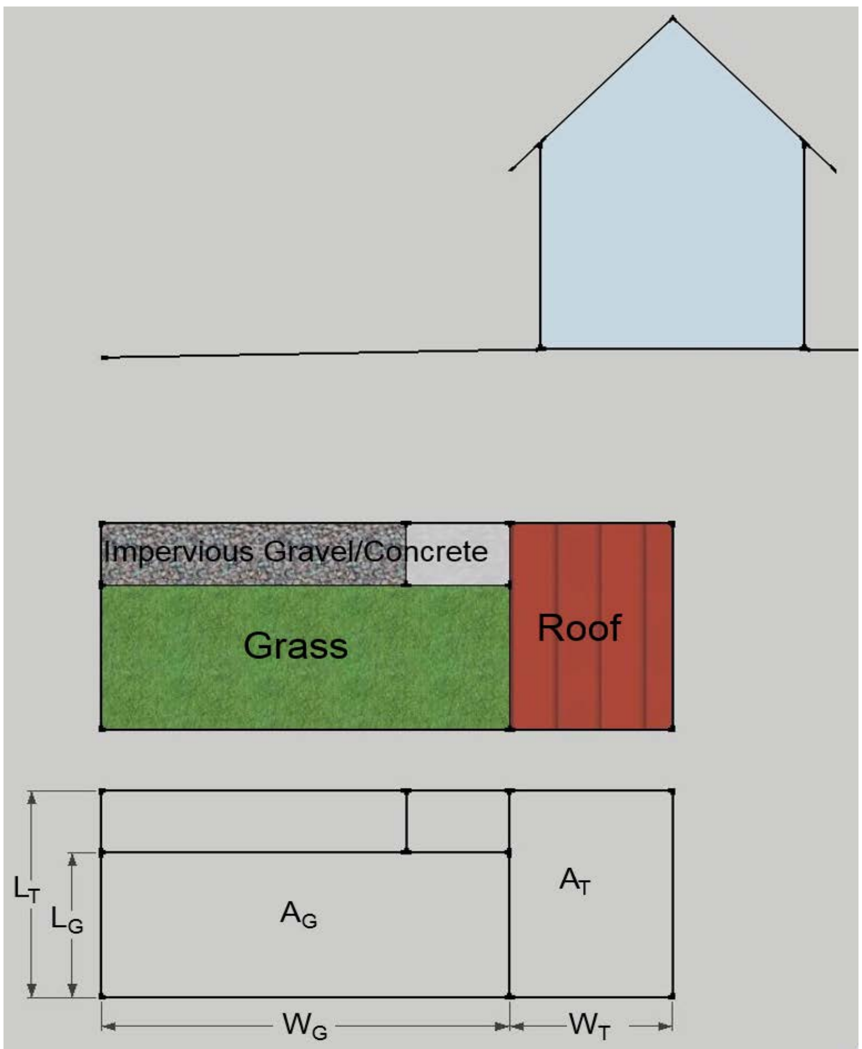


Figure 8-23. Example Grass Buffer Lawn

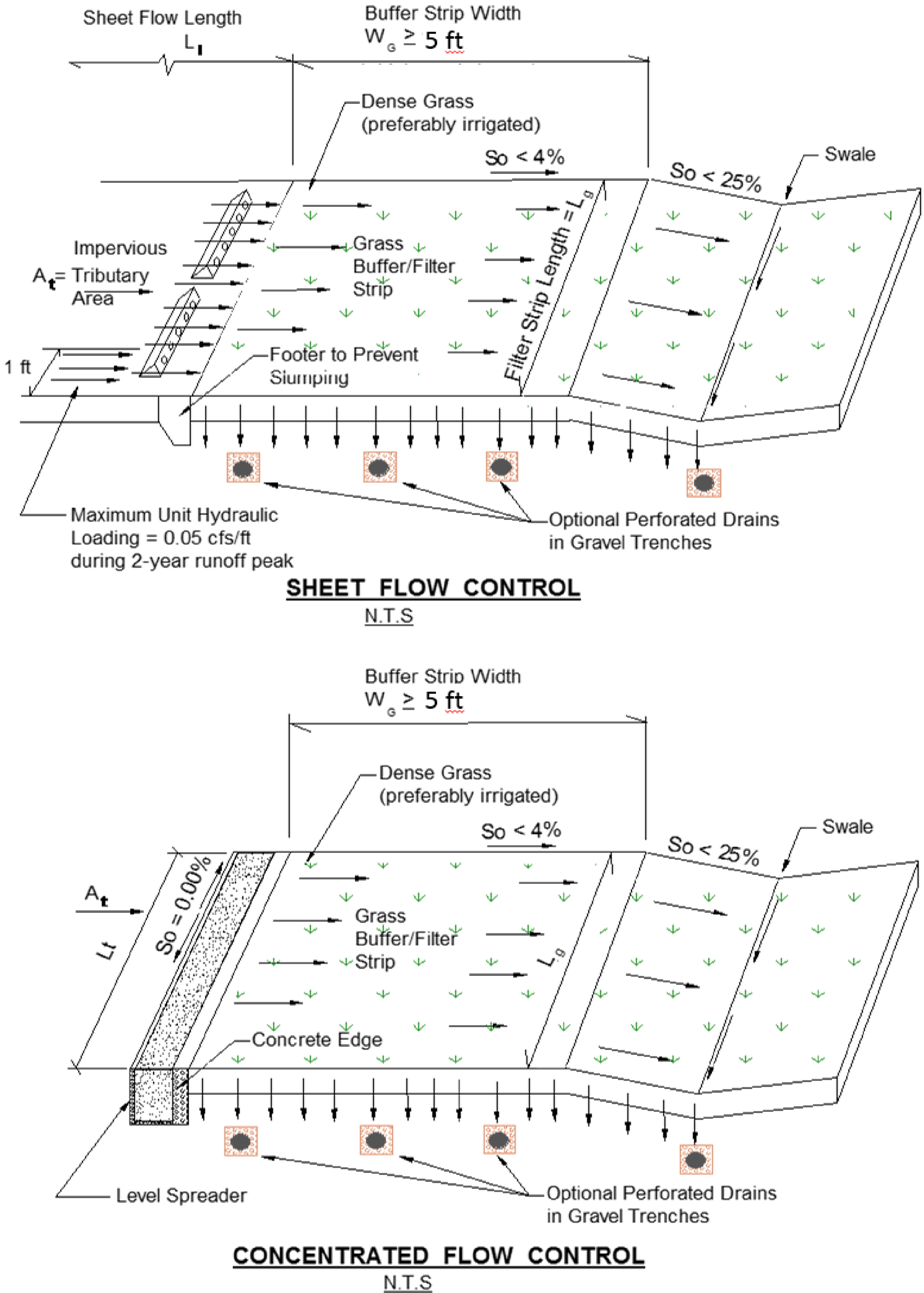


Figure 8.24 Typical Grass Buffer (GB)

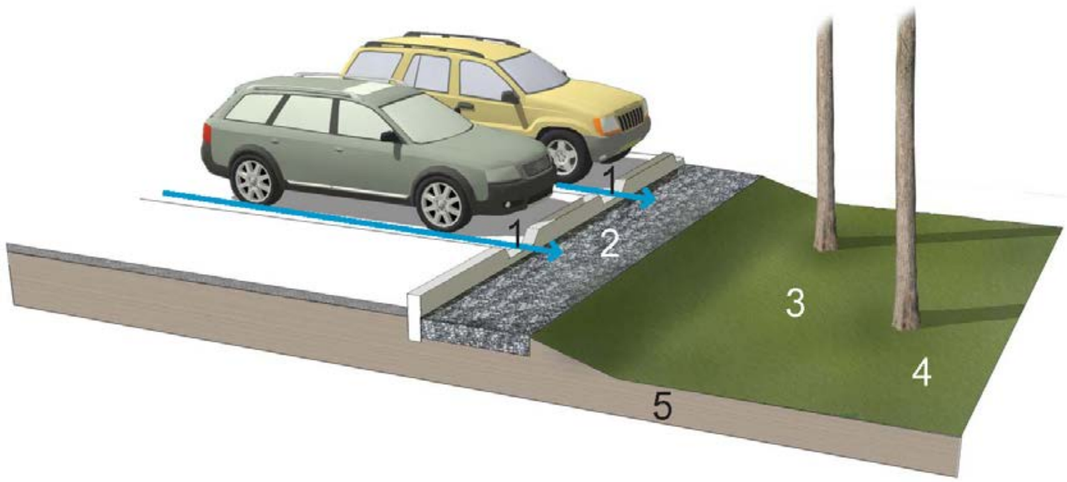


Figure 8.25 Grass Buffer Design Sketch

1: Inlet: Having no curbs or slotted curbs promotes uniform storm flows. Depress the grade three inches below pavement to provide positive drainage even with moderate sediment accumulation.

2: Sediment Trap: In areas with high sediment loads, include a rock mulch strip contained by a landscape edger.

3: Vegetation: Irrigated dense turf or native grasses—may include other dense groundcovers. Provide a gradual positive slope to allow gradual deposition of sediment while maintaining positive drainage

4: Outlet/Overflow: Grass buffers should drain to a grass swale, storage BMP, or depression with inlet and storm sewer.

5: Infiltration Matrix: Native soils.

Maintenance

Table 8.7 outlines maintenance recommendations for GBs.

Table 8.7 Maintenance Recommendations for Grass Buffers (UDFCD 1999)

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing	Maintain a dense grass cover at a recommended length of 2 to 4 inches. Collect and dispose of cuttings offsite or use a mulching mower.	Routine – As needed or recommended by inspection.
Lawn care	Use the minimum amount of biodegradable, nontoxic fertilizers and herbicides needed to maintain dense grass cover, free of weeds. Reseed and patch damaged areas.	Routine – As needed.
Irrigation	Adjust the timing sequence and water cover to maintain the required minimum soil moisture for dense grass growth. Do not overwater.	As needed.

Required Action	Maintenance Objective	Frequency of Action
Litter removal	Remove litter and debris to prevent gully development, enhance aesthetics, and prevent floatables from being washed offsite.	Routine – As needed by inspection.
Inspections	Inspect irrigation, turf grass density, flow distribution, gully development, and traces of pedestrian or vehicular traffic and request repairs as needed.	Annually after spring runoff and after each major storm (that is, larger than 1.0 inches in precipitation).
Turf replacement	To lower the turf below the surface of the adjacent pavement, use a level flow spreader, so that sheet flow is not blocked and will not cause water to back up onto the upstream pavement.	As needed when water padding becomes too high or too frequent a problem. The need for turf replacement will be higher if the pavement is sanded in winter to improve tire traction on ice. Otherwise, expect replacement once every 5 to 15 years.
Rock Mulch Strip	Remove litter and debris from rock mulch strip.	As needed. Expect to replace rock mulch once every 5 to 15 years depending on size and concentration of runoff area.

8.5.1.4 Pervious Pavement (PP)

Figure 8.26 Modular block permeable pavement in this small parking lot allows runoff from roof downspout, promoting infiltration and reducing the overall storage volumes for the site.

Figure 8.27 Modular block permeable pavement is used for an on-street parking lane on this residential street.

Description

Pervious Pavement (PP) covers a variety of stabilized surfaces that can be used for the movement and parking of vehicles (automobiles, trucks, construction equipment, etc.) and storage of materials and equipment. Pervious pavement differs from conventional pavement. It is designed to infiltrate stormwater runoff instead of shedding it off the ***surface***. PP offers the advantage of decreasing the effective imperviousness of an urbanizing or redevelopment site, thereby reducing runoff and pollutant loads leaving the site.

Pervious pavement can be designed with and without underdrains. Whenever underdrains are used, infiltrated water will behave similarly to interflow and will surface at much reduced rates over extended periods of time. All types of pervious pavement help to return stormwater runoff hydrology to more closely resemble pre-developed conditions. However, the actual consumptive use of water falling onto the ground is considerably less than under pre-developed conditions and for grass lawns in urban areas. The designer needs to consult with a geotechnical engineer as to the suitability of each type of pervious pavement for the loads and traffic it will support and carry, and the geologic conditions the pavement will rest upon.

For modular block pavement and reinforced grass pavement, the WQCV can be provided by providing adequate aggregate depth to provide the storage required for the WQCV in the pore volume beneath the pavement. Because of the very limited net open area of a cobblestone block pavement, it is generally not feasible to attain enough infiltration to provide WQCV storage beneath the pavement. All of the types of pervious pavement discussed reduce effective imperviousness.

The following sections describe three types of pervious pavement that may be used in Aspen. Porous concrete and asphalt are not allowed in Aspen, largely because of experience with failures of these types of pervious pavements in other parts of Colorado.

Modular Block Pavement (MBP)

This pavement consists of concrete block units with open surface voids laid on a gravel sub-grade with open surface voids. These voids occupy at least 20% of the total surface area that are filled with sand (ASTM C-33 sand fine concrete aggregate or mortar sand) or sandy loam turf that has at least 50% sand by weight in its volume. However, unless the pavement will be watered regularly (i.e., using a sprinkler system) to keep the vegetation viable, concrete sand infill is the recommended material.

Modular block pavement may be sloped or flat. Modular block pavement has been in use in United States since the mid-1970s. Although field data that quantify their long-term performance are somewhat limited, the data collected locally, and at other part of United States, and the episodic reports from Canada, Australia, Asia, and Europe, indicate that properly installed modular block pavements are reliable and have experienced few problems under a wide range of climates.

Cobblestone Block Pavement (CBP)

This pavement consists of concrete block units replicating the appearance of cobblestone that create open voids by beveling the corners of each block and/or wider spacing between the blocks. One of the commercial "cobblestone" products that meets this description is Eco-stone™ made by Pavestone Co®. These "cobblestones" are laid on a gravel sub-grade. The surface area has voids that occupy at least 8% of the total surface area and are filled with sand or stone per the manufacturer recommendation and compliance with PICP standards.

Cobblestone block pavement may also be laid on a sloped or on a flat grade. This type of pavement has been in use since the 1980s. Field data that quantify the long-term performance of cobblestone block pavement are limited; however, the data and the episodic reports from other parts of the United States, Canada, Australia, Asia and Europe indicate that when properly installed, Cobblestone block pavement is reliable and has experienced few problems under a wide range of climates.

Reinforced Grass Pavement (RGP)

This is a stabilized grass surface intended for use in parking lots that experience intermittent use. Past experience has shown that RGP may not be suitable for heavy vehicles, especially those associated with critical services such as fire trucks. It has been shown to function well under wet-weather conditions and, when properly designed and installed, it will infiltrate rainwater at rates that equal or exceed the infiltration rates of NRCS Hydrologic Soil Group Type B soils. The grasses need to be mowed on a cycle that depends on the grass types and whether or not irrigation is used. Use of irrigated grasses should be considered for more actively-used parking lots.

Another type of reinforced grass pavement design is based on the Federal Aviation Administration's (FAA) recommendations for *Aggregate Turf* originally developed for use with light aircraft that do not exceed a gross load of 12,500 pounds. This design offers a very stable surface and has a relatively simple cross-section. When it is installed using good site preparation, compaction and the specified gravel-topsoil mix, it has functioned well on small general aviation airports for many years.

General Application

Modular Block and Cobblestone Block Pavement

Modular block pavements and cobblestone block pavements are best suited for use in low vehicle movement zones, such as roadway shoulders, driveways, parking strips and parking lots. Vehicle movement (i.e., not parking) lanes that lead up to one of these types of porous pavement parking pads may be better served, but not always, by solid asphalt or concrete pavement. The following are potential applications for these two types of porous pavement:

- Low vehicle movement zones
- Crossover/emergency stopping/parking lanes
- Residential street parking lanes
- Private and public building driveways
- Maintenance roads and trails
- Roadway shoulders and parking lanes
- Emergency vehicle and fire access lanes
- Low vehicle movement commercial and industrial parking lots, including driveways
- Commercial/retail parking lots
- Equipment storage areas

Reinforced Grass Pavement

Reinforced grass pavement is best used in overflow parking zones or in parking lots that experience occasional uses (e.g., once-a-week-used portions of church and football stadium parking lots), roadway shoulders, residential street parking lanes, and emergency vehicle access lanes. Vehicle movement lanes (i.e., not parking pads themselves) that lead up to one of these reinforced grass pavement surfaces need to be served by solid asphalt or concrete pavement. The following are potential applications for this type of porous pavement:

- Crossover/emergency stopping/parking lanes
- Roadway shoulders and parking lanes
- Maintenance roads and trails
- Commercial/retail parking lot overflow areas
- Church parking areas more remote from buildings
- Residential parking areas with light use.

Advantages/Disadvantages

Aside from the potential for high particulate pollutant removal and the removal of other constituents similar to what a sand filter would provide, pervious pavements can dramatically reduce the surface runoff from most rainstorms and snowmelt events and virtually eliminate surface runoff from smaller storms. These reductions in runoff volumes translate directly to proportional reductions in pollutant loads leaving the site. Its use can result in stormwater surface runoff conditions that approximate the predevelopment site conditions, something that can be used in selecting surface retention and infiltration parameters that are close to pre-developed conditions when using stormwater runoff hydrologic models. Even when underdrains are used, the response time of runoff is significantly delayed and approaches the characteristics of what hydrologists call *interflow* (flow that enters the subsurface via infiltration and then reemerges to the surface with a time delay). As a result, drainage and downstream flooding problems can be significantly reduced. These can translate in savings since the downstream facilities needed to address site runoff, such as *WQCV*, detention volumes and conveyance facilities can be smaller. For modular block and reinforced grass pavements, the WQCV can actually be provided in the aggregate pore space beneath the pavement surface. If aggregate is deep enough, flood control benefits (i.e. minor storm) may also be achieved.

Another advantage that the use of pervious pavement offers is that creative selection by land planners and landscape architects of pervious pavement materials, patterns and colors can also provide aesthetic enhancements to what often are very mundane surfaces. Some types of pervious pavements may be snowmelted.

The primary disadvantage of pervious pavements is that they cost more to install and maintain than conventional concrete or asphalt pavement. These added costs can be somewhat offset by the cost savings in the downsizing of on-site and downstream drainage systems and facilities such as detention basins, numbers of inlets, storm sewers and channels. Other disadvantages of pervious pavements can include uneven driving surfaces and potential inconvenience of walking on these types of surfaces in high heel shoes. Pervious pavements are not compatible with sanding activities. Snow plowing has the potential to damage many types of pervious pavements, and special plowing techniques may be necessary.

Physical Site Suitability

Pervious pavements can be installed even when free draining sub-soils are not present at the site by providing them with underdrains. An underdrain insures that the gravel sub-grade is drained when the sub-soils or site conditions do not allow infiltration.

Not all types of pervious pavements may be suitable for heavy equipment/fire lane access. Applications of pervious pavements that are anticipated to experience heavy loads should be evaluated to assure that the pervious pavement is compatible with the intended use.

In the case where the installation is located on top of expansive soils, the installation of an impermeable liner along with underdrains is strongly recommended. The liner is needed to prevent wetting the underlying expansive clays. In addition, pervious pavements installed over expansive soils should not be located adjacent to structure foundations in order to reduce the potential for damages to structures.

An impermeable liner with underdrains shall be utilized anywhere pavers are installed immediately adjacent to a structure. The impermeable liner shall be installed along the foundation of the structure and extend a minimum of 10' away from the structure walls. Liners and underdrains shall direct runoff away from the building foundation.

A continuous impermeable liner with underdrains shall also be used whenever commercial or industrial sites may have activities, or processes, that could result in the storage and/or handling of toxic or caustic chemicals, fertilizers, petroleum products, fats, or greases. An impermeable liner has to be designed to prevent groundwater and soil contamination should such products or materials come into contact with stormwater and could infiltrate into the ground. If the site is expected to have contaminants mentioned above, the underdrains shall be directed or connected to runoff capture and treatment facilities.

Construction Considerations

The construction phase and staging is critical to producing PPS that are structurally sound and have good rates of stormwater infiltration into surface of the pavement and into the underlying sub-grade or underdrains. It is important to understand that permeable pavement systems are examples of high performance infrastructure that have two functions: a structural pavement and a stormwater management BMP. It is not sufficient to use the same construction practices for PPS as for conventional, non-porous pavement. Issues of concern that can affect the eventual performance of the PPS include but are not limited to the following:

- Excessive compaction of the sub-grade and heavy equipment traffic over these surfaces.
- Sediment loading from adjacent construction areas. Pervious pavements should be constructed as late in the phasing of a project as feasible, and if there are adjacent disturbed areas redundant erosion and sediment control measures should be provided (i.e. silt fence and wattles).
- Proper gradation and installation of the fracture-faced aggregate and sand materials at

various levels of the PPS cross section.

- Proper use and installation of geotextiles and geogrids.
- Impermeable geomembrane (liner) installation, seaming and liner penetrations.
- Underdrain installation, including providing adequate slope and avoiding damage to the underdrain pipe.
- Edge restraints for permeable interlocking concrete pavers and concrete grid pavement.
- Achieving uniform gradation of aggregate and soils for reinforced turf type of pavements.

Pollutant Removal and Effective Imperviousness

Specific field data on the reductions of pollutant concentrations by various pervious pavements are very limited as of 2009. However, reductions in the concentrations of total suspended solids and associated constituents, such as metals, oils and greases appear to be relatively high. At the same time, the fact that all pervious pavements significantly reduce the average annual runoff volume makes them very effective in reducing pollutant loads reaching the receiving waters. Filtration of stormwater runoff through the sand and gravel of the modular block voids and entrapment in the gravel media are the primary removal mechanisms of pollutants. Adsorption and ion exchange that occur as stormwater travels through the underlying soils before the stormwater reaches groundwater are secondary removal mechanisms.

When using pervious pavements, the site designer can take advantage of the fact that it reduces the effective surface runoff rates and volumes. Based on field testing and observations of modular block pavement by the Denver Urban Drainage and Flood Control District at a test site in Lakewood and other information gleaned from literature, interim recommendations for reducing *total site imperviousness* to *effective imperviousness* were developed. Because this represents the best currently available data, these guidelines have been adopted by Aspen. The use of these interim guidelines is recommended when planning stormwater quality and drainage facilities for new land development and redevelopment sites. These guidelines are summarized in **Figure 8.28** and are called “interim” because they are based, in part, on limited amounts of short-term data and best professional judgment that considered the type of pavement, its long term maintenance needs, its sealing potential and its loss of void space volume over time.

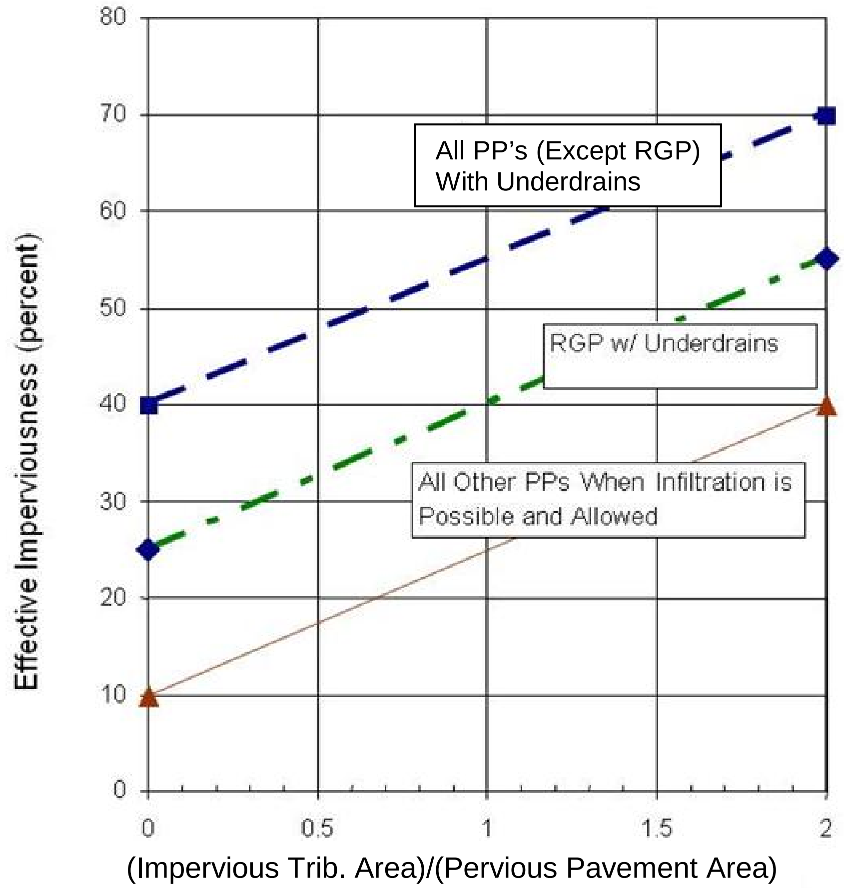


Figure 8.28 Recommended Effective Percent Imperviousness for PPS (Based on the Ratio of the Impervious Area Tributary to Porous Pavement)

The following notes apply to using **Figure 8.28**:

1. It is recommended that impervious areas be made to drain to pervious pavements where possible. **Figure 8.28** shows the effective imperviousness values used for all paved area (impervious and pervious) in situations where impervious areas drain to pervious pavements. To calculate the ratio shown on the x-axis, divide the impervious area that drains to pervious pavement by the area that is pervious. For example if 500 ft^2 of impervious area flows uniformly over 500 ft^2 of pervious pavement the ratio in **Figure 8.28** is 1.0. If modular block pavement is used without underdrains, the effective imperviousness for a ratio of impervious area to pervious pavement area of 1.0 would be approximately 25 percent according to **Figure 8.28**. The effective imperviousness, 25%, would apply to the entire 1000 ft^2.

2. Use no more than two units of impervious area for each unit of PP. All impervious areas exceeding this ratio shall be treated as 100% impervious in hydrologic calculations, including runoff volumes. For example, the maximum amount of impervious area that could drain to a 500 ft^2 pervious pavement area would be 1000 ft^2. Any imperviousness beyond that should not be directed to the pervious pavement area or, if it must be directed to the pervious pavement area, it should be treated as 100

percent impervious area in all calculations.

3. Whenever impervious areas cannot be made to run onto the pervious areas in a uniform sheet-flow fashion, identify individual areas and what ratios apply to each and then composite them treating each as a separate area.

Cold Weather Considerations

PPS have been applied in cold weather climates including the northeast, northern states in the Mid-West and even Canada. In cold climates PPS have an advantage of quicker melting of accumulated snow due to circulation of air beneath the surface. Potential challenges in cold climates include plugging from accumulated sediment (sanding) and freeze-thaw deterioration. These disadvantages can be minimized in the following ways:

- PPS may not be used in areas that are sanded or in locations where adjacent tributary drainage areas are sanded.
- Signage should be used for PPS to caution against sanding.
- Achieving a well-drained sub-base is critical to avoid problems with freezing. Studies in the northeast have shown that PPS with at least 12 inches of sub-base material are more resistant to freeze-thaw damage. It may be feasible to install a snowmelt system beneath the surface of cobblestone block or modular block pavements; however, care should be taken to assure that the snowmelt tubing does not interfere with infiltration.

Design Considerations

Design criteria for pervious pavements vary depending on the wearing course. Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual provides extensive guidance for all of the types of pervious pavements in this Manual. Because of the length of the UDFCD guidance (more than 80 pages) and the desire to keep the Aspen Manual streamlined, the following is provided as general guidance and criteria for pervious pavements. The designer should refer to the Denver Urban Storm Drainage Criteria Manual for detailed guidance, figures, etc. All pervious pavement designs in the City of Aspen should be checked against the most current version of Volume 3 of the UDFCD guidance since pervious pavement criteria are currently evolving.

Modular Block and Cobblestone Block Pavements

Figure 8.29 below shows one type of locally available modular block pervious pavement. There are other block patterns that may be used, provided they have at least 20 percent (≥ 40% preferred) of their surface area as open annular spaces. This is the minimum open surface area to be considered as modular block pavement.

Figure 8.29 Modular Block Pavement

Figure 8.30 is of a typical cobble block pervious pavement available locally. It has to have at least eight percent (8%) of its surface area as open annular spaces to qualify as cobblestone block pervious pavement.

Figure 8.30 Cobblestone Block Pavement

Figure 8.31 below shows typical cross-sections for modular block and cobblestone block pervious pavements.

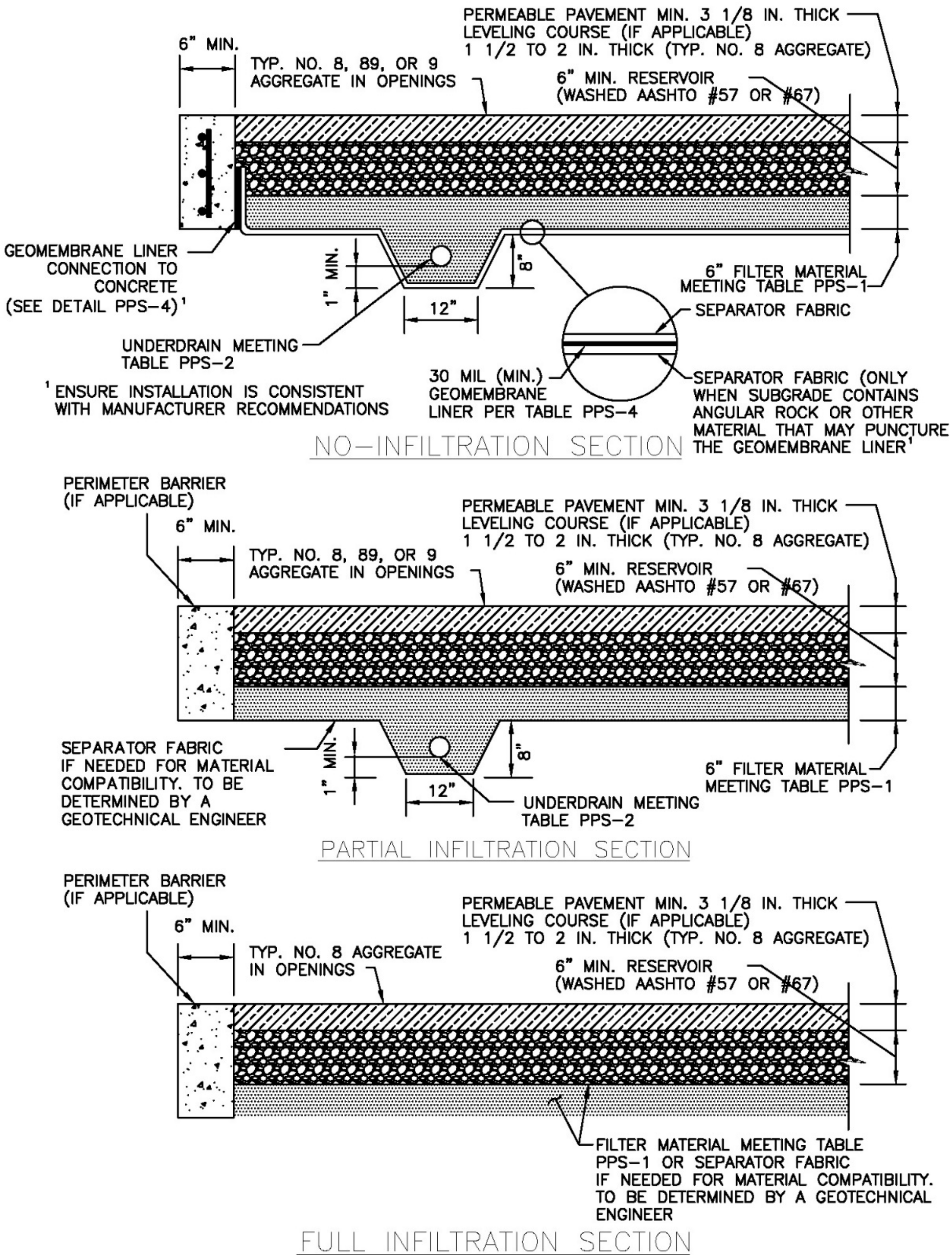


Figure 8.31 Typical Pervious Pavement Cross Section

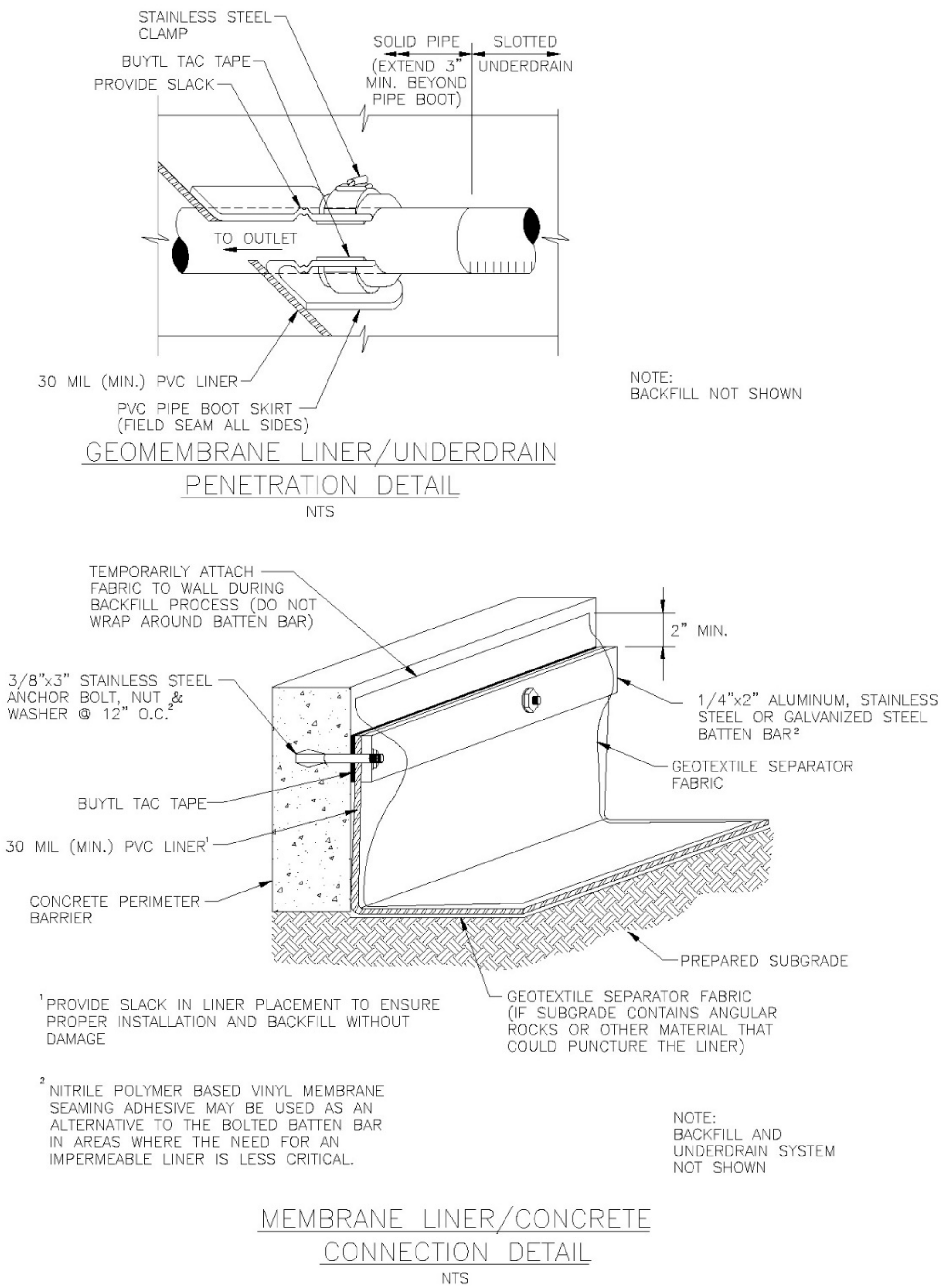


Figure 8.32 Membrane Liner/Concrete Connection Detail

Table PPS-1. Gradation Specifications for Class C Filter Material (Source: CDOT Table 703-7)

Sieve Size	**Mass Percent Passing** Square Mesh Sieves
19.0 mm (3/4”)	100
4.75 mm (No. 4)	60-100
300 µm (No. 50)	10-30
150 µm (No. 100)	0-10
75 µm (No. 200)	0-3

Table PPS-2. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4”	1-1/16”	0.032”	0.413”	1.90 in^2
6”	1-3/8”	0.032”	0.516”	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

Table PPS-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation <50%[2]	Elongation >50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 33 mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, Must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	K fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

Table PPS-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A

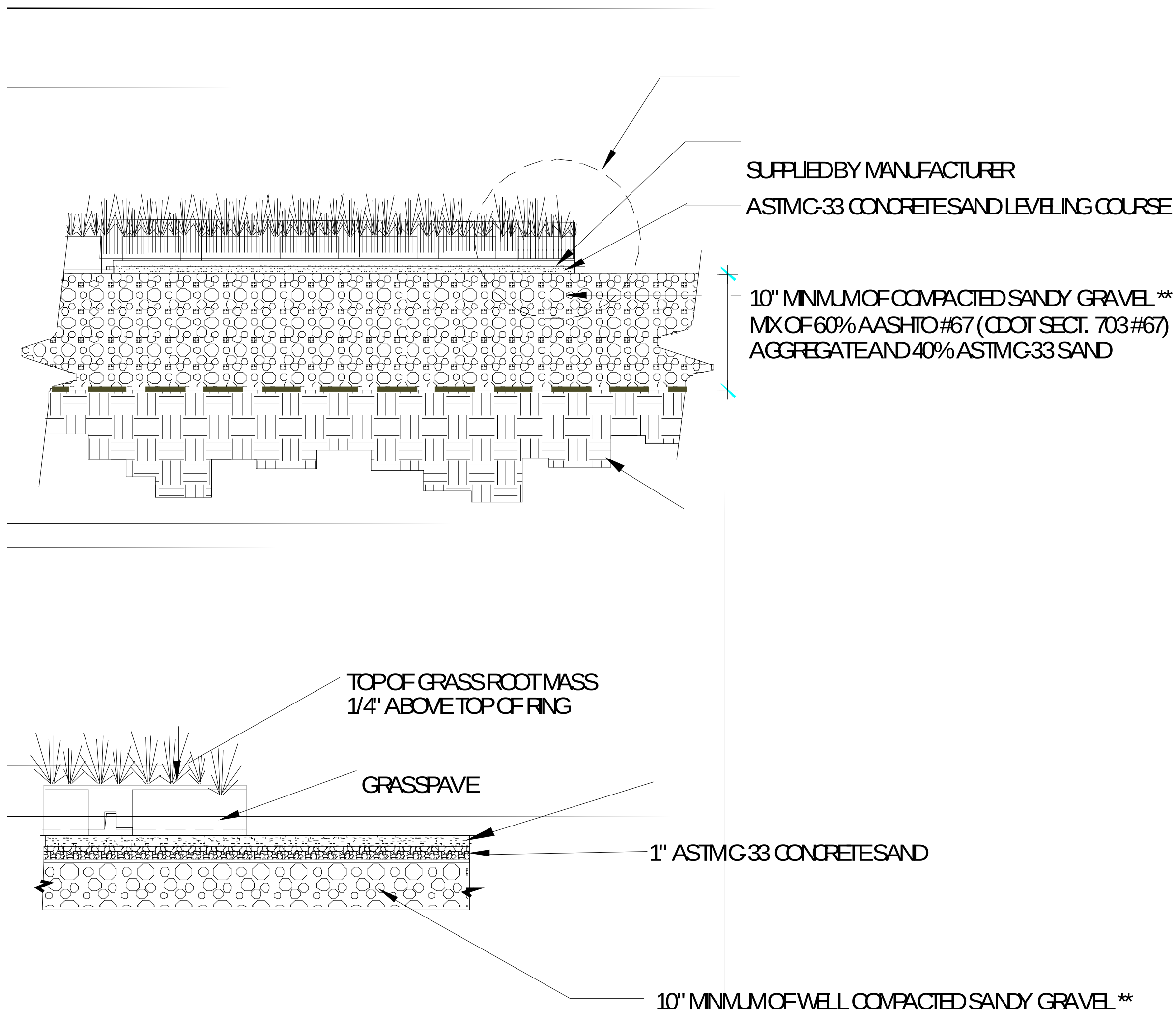
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

Reinforced Grass Pavement

Figure 8.33 shows typical cross-sections and details for one type of reinforced grass pavement based on a product called Grasspave2™ by Invisible Structures, Inc. Other products that achieve the same end goal and structural stability are also available. Regardless of which brand of product is used, the manufacturer's instructions should **be closely followed except as called for differently in this Chapter.**

The typical section of an RGP design based on the Federal Aviation Administration's (FAA) recommendations for *Aggregate Turf* is illustrated in **Figure 8.34**. The thickness is designed same as for asphalt pavement; however the design includes extra base course thickness for compensate in the carrying capacity of asphalt pavement sections.

When designing and installing *Aggregate Turf*, it is critical that the sub-grade be adequately compacted, especially when the gravel and pavement is being placed on fill. Additional guidance is provided in Volume 3 of the Denver UDFCD Urban Storm Drainage Criteria Manual



NOTES:

1. INSTALL GRASS TURF REINFORCING LAYER PER MANUFACTURER'S RECOMMENDATIONS INCLUDE MODIFICATIONS SHOWN ON THIS DRAWING.

2. DETAIL BASED ON INVISIBLE STRUCTURES, INC., ET AL DETAILS, BUT MODIFIED TO SUIT USDCM REQUIREMENTS.

**** GREATER DEPTH OF PAVEMENT MAY BE REQUIRED BY PAVEMENT DESIGNER**

Figure 8.33 Typical Reinforced Grass Pervious Pavement Cross Section

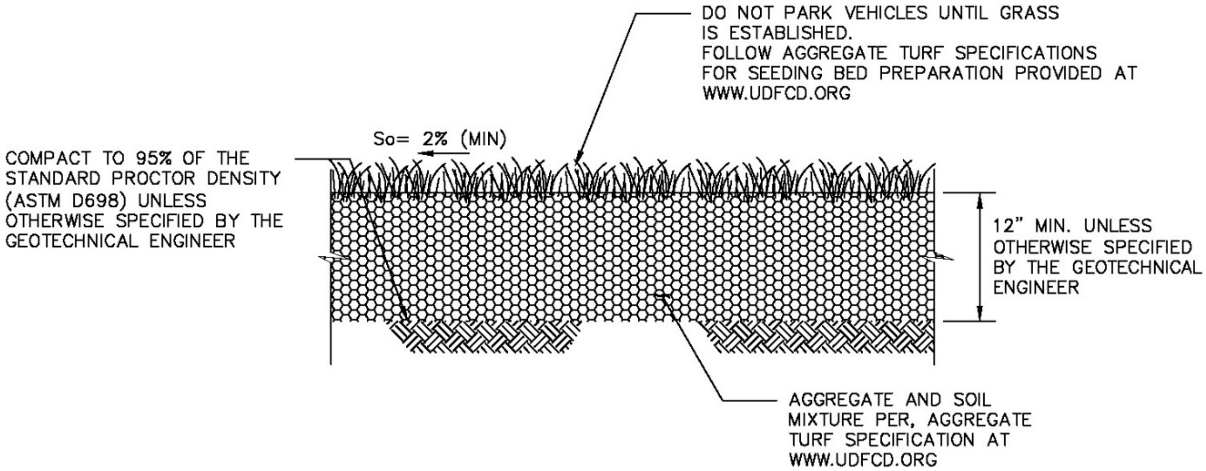


Figure 8.34 Typical Aggregate Turf Reinforced Grass Pervious Pavement Cross Section

Design Procedure and Criteria

Modular Block Pervious Pavement

1.	Select Blocks	Select MBP that have 20% or more (40% preferred) of the surface area open. Follow Manufacturer's installation instructions, except that *Porous Pavement Infill* and *Base Course* materials and dimensions specified in this section shall be strictly adhered to.
2.	Infill materials and Leveling Course	The MBP openings shall be filled with ASTM C-33 graded sand or very sandy loam and shall be placed on a one-inch thick leveling course of C-33 sand.
3.	*Base Course*	The *Base Course* shall be AASHTO No. 3 coarse aggregate; all fractured surfaces. For volume calculations assume 30 percent of total volume to be open pore space. Unless an underdrain is provided, at least 6-inches of the sub-grade underlying the *Base Course* shall be sandy and gravely material with no more than 10% clay fraction.
4.	Impermeable Liner Under the *Base Course*	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.

5.	Membrane Installation	Place by rolling membrane parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up impermeable membrane to the top of perimeter walls. Attach membrane to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
6.	Perimeter Wall	Recommend that a concrete perimeter wall be installed to confine the edges of the MBP block areas.
7.	Contained Cells – Lateral Flow Barriers	Install lateral-flow cut-off barriers using 30 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed: $$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$ in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft.), S_O = Slope of the base course (ft/ft), D = Depth of gravel *Base Course* (ft).
8.	Sub-drain System	When the MBP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a sub-drain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume to empty each cell in 6-12 hours.
9.	Design Area Ratio and Effective Imperviousness	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divided by porous pavement area). In certain cases where the land use of the contributing drainage basin is known to carry low sediment levels, a slightly higher design area ratio may be permitted. The interim recommendations for the "Effective Imperviousness" are given in **Figure 8.28** and may be used when sizing detention basins, *WQCV* and stormwater conveyance systems.

Cobblestone Block Pervious Pavement

1.	Select Blocks	Select CBP blocks that have 8% or more of the surface area open. Follow Manufacturer's installation instructions, except that *Porous Pavement Infill* and *Base Course* materials and dimensions specified in this section shall be strictly adhered to.
2.	Infill materials and Leveling Course	The CBP openings shall be filled with AASHTO No. 8 fractured aggregate and shall be placed on a one-inch thick leveling course of same No. 8 aggregate.
3.	*Base Course*	The *Base Course* shall be AASHTO No. 67 coarse aggregate; all fractured surfaces. For volume calculations assume 30 percent of total volume to be open pore space.

4. Impermeable Liner Under *Bottom Sand Layer*

When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.

5. Membrane Installation

Place by rolling membrane parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets.

Bring up impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.

6. Perimeter Wall

Recommend that a concrete perimeter wall be installed to confine the edges of the MBP or CBP block areas.

7. Contained Cells – Lateral Flow Barriers

Install lateral-flow cut-off barriers using 30 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed:

$$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$

in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft.),

S_O = Slope of the base course (ft/ft),

D = Depth of gravel *Base Course* (ft).

8. Sub-drain System

When the CBP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a sub-drain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell in 6-12 hours

9. Design Area Ratio and Effective Imperviousness

The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area). In certain cases where the land use of the contributing drainage basin is known to carry low sediment levels, a slightly higher design area ratio may be permitted. The interim recommendations for the "Effective Imperviousness" are given in **Figure 8.28** and may be used when sizing detention basins, *WQCV* and stormwater conveyance systems.

Reinforced Grass Pavement

1. Select Type of RGP to be Used

Select which type of RGP will be used. The two types that are described in this *Manual* are *Reinforced Grass*, as illustrated in **Figure 8.33** and *Aggregate Turf*, as illustrated in **Figure 8.34**.

2. *Base Course* for

Provide the required *Base Course* of AASHTO No. 67 (CDOT Section 703) coarse aggregate for the *Reinforced Grass* type of RGP as called for in **Figure**

	Reinforced Grass	**8.33**. The aggregate shall have all fractured surfaces. No Base Course is required for *Aggregate Turf.*
3.	Impermeable Membrane Under the *Base Course*	For *Reinforced Grass* type of RGP, and when expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.
4.	Membrane Installation	Place by rolling impermeable membrane parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up impermeable membrane to the top of perimeter walls. Attach membrane to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
5.	Design Area Ratio and Effective Imperviousness	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area). In certain cases where the land use of the contributing drainage basin is known to carry low sediment levels, a slightly higher design area ratio may be permitted. The interim recommendations for the "Effective Imperviousness" are given in **Figure 8.28** and may be used when sizing detention basins, *WQCV* and stormwater conveyance systems.

Construction/Installation

The construction phase is very critical in having a successful pervious pavement installation. Successful PP installations are structurally sound and have good rates of stormwater infiltration into surface of the pavement and into the underlying sub-base or underdrains. It is not sufficient to use the same construction practices for pervious pavement as for conventional, non-porous pavement. Issues of concern are excessive compaction of the sub-grade and heavy equipment traffic over these surfaces, proper gradation and installation of the gravel and sand materials at various levels of the pervious pavement section, proper use and installation of geotextile and impermeable liner membranes, edge restraints for modular block types of pervious pavements, achieving uniform gradation of gravels and soils for reinforced turf type of pavements and other issues that can affect the eventual performance of the pervious pavement.

Sub-grade

When the native soils in the sub-grade are suitable for infiltration (i.e., NRCS Hydrologic Group A, B and C), it is important maintain their infiltration capacities as much as possible. When the sub-base is deliberately compacted to provide greater pavement stability or is inadvertently compacted by construction equipment traffic over them, infiltration capacity will be significantly reduced. To prevent the latter, it is crucial that heavy construction equipment, especially rubber-tired machinery, be kept off the sub-grade. This will require the use of light track equipment, delivery of gravels via conveyors, delivery of concrete via extended chutes (not conveyors) or lift pour buckets, and stopping all work when the sub-grade is wet or thawing.

When compaction of the sub-grade is needed for structural support of the pavement that will carry or park vehicular traffic, an underdrain system may be needed to compensate for the loss of infiltration capacity. This will be the case if the sub-grade soils have significant fractions of silt or clay and are not granular in nature (e.g., not Type A or B).

Compaction of the sub-grade is recommended for sites where the pavement will be placed on top of fill. Unless the fill is composed of predominantly granular materials, the engineer needs to plan for underdrains for all PP types except *Aggregate Turf*, which essentially duplicates natural grass surfaces.

Preventing Clogging from Excess Sediment

It is common to install pavement before all site work such as landscaping and finishing of buildings is completed. As a result, sediment loads from construction and landscaping activities after the pervious pavement is installed can be very high. It crucial to protect all surfaces of the pervious pavement from runoff and sediment deposits until all construction activities are completed and the areas tributary to the pervious pavement are fully stabilized.

Regardless of the type of pervious pavement being used, the highest priority during construction has to be to prevent sediment from entering the *base course* and the surface of pervious pavement. The following practices will help to keep the pervious pavement form being clogged during these construction periods:

- Keep muddy equipment and materials away from the pervious pavement area
- Install silt fences and temporary swales to divert water away from the pervious pavement area
- Cover the surfaces with heavy flexible impermeable membrane whenever construction activities threaten to deposit sediment onto the pervious pavement area

Base Course Each lift shall not exceed 6-inches and shall be compacted by using a 10-ton, or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.

If the design calls for an upper layer of the *Base Course*, install it using the same layer thicknesses and compaction requirements described above. Follow-up the installation of the uppermost layer of the *Base Course* by installing the specified geotextile fabric on top of it. The leveling course or porous pavement, as required by the plans, is then applied over the uppermost geotextile fabric.

When a sand leveling course is called for in the plans, compact it using the drum roller before laying the paver units on top of it. If the top of the *Base Course*, sand filter layer or the leveling course layers are disturbed and not uniform, they shall be re-leveled and re-compacted. The top of each layer below the leveling course shall uniform and will not deviate more than $\pm$1/2-inch when a 10 foot straight edge is laid on its surface. The top of the leveling course shall not deviate more than $\pm$3/8-inch in 10 feet.

Modular Block and Cobblestone Block Installation

Place the paver blocks tightly against each other on top of the compacted sand leveling course. Before compacting the pavers into place, cut and place paver units to tightly fill spaces between adjacent pavers and the restraining wall at the edges.

Compact the installed paver blocks initially using a plate compactor that exerts a minimum of 5,000 lbs/ft^2 when using 4-inch thick pavers and a minimum of 6,800 lbs/ft^2 when using pavers thicker than 4-inches. After initial compaction, fill the paver openings and joints to the top with ASTM C-33 sand and compact again. If the sand or gravel infill drops more than 1/8 inch below the top of the paver block, add more sand and re-compact. Remove excess sand or gravel by broom sweeping the surfaces. Paver installation can be done by hand or using mechanical equipment specially designed for this type of work. If the latter is used, follow the requirements and procedures provided in the ICPT (1998) *Technical Specification 11 – Mechanized Installation of Interlocking Concrete Pavements*.

Reinforced Grass Pavement Installation

For the *Reinforced Grass* type of installations adhere strictly to the recommendations of the manufacturer for the installation of this pavement.

Maintenance

Tables 8.8 through 8.10 outline maintenance recommendations for pervious pavements.

Table 8.8 Maintenance Recommendations for Modular Block Pervious Pavement

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Sod maintenance	If sandy loam turf is used, provide lawn care, irrigation system, and inlay depth maintenance as needed.	Routine – As dictated by inspection.
Inspection	Inspect representative areas of surface filter sand or sandy loam turf for accumulation of sediment or poor infiltration.	Routine and during a storm event to ensure that water is not bypassing these surfaces on frequent basis by not infiltrating into the pavement.
Rehabilitating sand infill surface	To remove fine sediment from the top of the sand and restore its infiltrating capacity.	Routine – Sweep the surface annually and, if need be, replace lost sand infill to bring its surface to be ¼ below the adjacent blocks.
Replacement of Surface Filter Layer	Remove, dispose, and replace surface filter media by pulling out turf plugs or vacuuming out sand media from the blocks. Replace with fresh ASTM C-33 sand or sandy loam turf plugs, as appropriate.	Non-routine – When it becomes evident that runoff does not rapidly infiltrate into the surface. May be as often as every two year or as little as every 5 to 10 years.
Replace modular block pavement	Restore the pavement surface. Remove and replace the modular pavement blocks, the sand leveling course under the blocks and the infill media when the pavement Surface shows significant deterioration.	Non-routine – When it becomes evident that the modular blocks have deteriorated significantly. Expect replacement every 10 to 15 years dependent on use and traffic.

Table 8.9 Maintenance Recommendations for Cobblestone Block Pervious Pavement

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect representative areas of surface filter fine gravel infill for accumulation of sediment and poor infiltration.	Routine and during a storm events to ensure that stormwater is infiltrating and not bypassing the pavement surface on frequent basis.
Rehabilitating fine grave infill surface	To remove fine sediment and trash accumulations from the top of the gravel and restore its infiltrating capacity.	Routine – Vacuum sweep the as indicated by inspection and if need be replace lost or clogged gravel infill to bring its surface to be ¼ below the adjacent blocks.
Replace cobble block pavement	Restore the pavement surface. Remove and replace the cobble pavement blocks, the leveling course under the blocks, the infill media, gravel base and geotextile materials when the pavement surface shows	Non-routine – When it becomes evident that the modular blocks have deteriorated significantly and the underlying gravels have accumulated much sediment and/or when the geotextile fabrics underneath it are clogged. Expect replacement every 10

	significant deterioration or when the pavement no longer infiltrates stormwater at rates that are acceptable.	to 25 years dependent on use and traffic.

Table 8.10 Maintenance Recommendations for Reinforced Grass Pervious Pavement

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect all surface areas for healthy grass growth, areas of dead grass, tire rutting, surface erosion, accumulation of sediment and slow infiltration.	Routine and during a storm events to ensure that water is infiltrating and not bypassing the pavement's surface on frequent basis.
Repair sod surface	To repair worn out or damaged sod with sod grown in very sandy loam type soils.	Routine – As needed. Repairs may be needed as often as every year.
Repair and replacement of sod	Major repair of damaged and aged sod. Remove and replace, as needed the sod layer to maintain a healthy vegetative cover or when sod layer builds up significant amount of silt (i.e., >1.5 inches) above the originally installed surface layer.	Non-routine – When it becomes evident that many parts of the sod has deteriorated or when runoff does not rapidly infiltrate into the surface. Major replacement of sod may be as little as every 10 to 25 years.

8.5.1.5 Green Roofs (GR)

Figures 8.35 and 8.36 Two local examples of green roofs are pictured above. These roofs have a significant impact on stormwater runoff and are aesthetically pleasing while providing extra insulation for homes. A wide variety of plants can be used on green roofs. These plants help reduce the impervious area of roofs to nearly zero in some cases.

Description

Green Roofs incorporate several different layers of materials at varying depths depending on the design. These layers include a waterproof layer to protect the roof, a drainage layer, a root barrier, and a soil substrate which can range from lightweight with little organic material, to standard topsoil. There are two basic types of green roofs, intensive and extensive, both of which are defined by the depth of the soil placed on them. Intensive roofs have 6 inches or more of soil and are typically designed for the use of shrubs, large gardens, or small trees. This type of roof is recommended if access to the green roof is desired. Extensive green roofs have anywhere between 1.5 to 6 inches of soil. They require little to no maintenance and don't have to be regularly accessed. Typically in the design of extensive green roofs smaller drought resistant plants are utilized which lowers maintenance requirements.

General Application

There is a wide range of areas where green roofs are utilized. Extensive green roofs (soil depth 1.5 to 6 inches) are ideal for retrofits and new designs. They can be placed across an entire roof, or above areas that typically see significant amounts of sunlight. For example roofs above porches, garages, sheds, and sunrooms are all candidates for a retrofit or design. Due to the large soil loads of intensive roofs an intensive green roof typically should be designed before initial construction and be designed with sufficient reinforcement to avoid damage to the roof. Impermeable liners installed on green roofs shall be carefully applied so as not to damage the roof.

Advantages/Disadvantages

Green roofs have several advantages. The first is that they negate the need for WQCV on an area that would, on a typical roof, be impervious area. According to several different studies, stormwater events of one inch of rainfall in one hour typically produced no runoff. Green roofs can be used in areas where other BMPs would be impractical due of the cost of the land. Green roofs help to improve urban air quality and are an excellent insulator. They reduce heating and cooling costs as well as energy use. Green roofs have the ability to extend the life of a roof by reducing thermal stresses and ultraviolet rays. Finally, green roofs reduce urban "heat island" effects and can lower the temperature on building roofs by up to 40 to 50 degrees.

A disadvantage of a green roof is they cost more than traditional roofs for materials, installation, and maintenance. Also, if not installed or maintained properly leaks in the roof could occur which could lead to damages and failure if left untreated for an extended time period. Another disadvantage of green roofs is if a storm is large enough to generate a runoff event, green roofed buildings typically produce a larger TSS and chemically changed water than asphalt roofs.

Physical Site Suitability

Typically a flat or mostly flat roof is better suited for both intensive and extensive rain gardens. However, if a roof is sloped, designers should not be deterred. A green roof can be designed on a sloped roof with additional reinforcement to support the weight. This BMP is recommended for areas where space is limited and the installation of other BMP's are infeasible.

Pollutant Removal

Green roofs are capable of retaining the full rainfall depth of smaller storms. Due to this retention component, when compared to traditional roofs, green roofs reduce stormwater runoff and thus reduce pollutant loads which are typically carried by runoff. In larger storm events where runoff is generated from a green roof there is potential for the green roof to add solids and chemicals to the stormwater. Runoff generated from a green roof typically contains a higher pH (more basic water), higher concentrations of phosphorous, potassium, and produced harder water (i.e. more calcium and magnesium). These higher values closely resemble that of other landscaped areas. Pollutants that flow into a green roof are removed through evaporation, infiltration and plant uptake, in much the same way as a rain garden or bioretention area.

It has also been shown that in more urban areas when compared to traditional roofs, green roofs reduce the amount of cadmium, copper and lead in runoff by over 95 percent and zinc by 16 percent.

Cold Weather Considerations

Green roofs will be most effective between late spring and early fall months when the ground is not frozen and vegetation is healthy. The weight of snow in addition to the weight of soil must be taken into account when designing a green roof so that the structure does not fail under the combined load. The extra stress of freeze thaw should be taken into account when designing root and waterproof barriers as there is potential for damage throughout the freeze thaw cycle. Also due to the natural insulation of the roof snow may melt at a slower rate than on a typical roof. This could lead to potentially larger drifts of snow and larger runoff events in the spring.

Design Considerations

Green roofs can be installed during initial construction or placed on buildings as part of a retrofit. The amount of stormwater that a green roof mitigates is directly proportional to the area it covers, the depth and type of the growing medium, slope, and the type of plants selected. The larger the green roof area, the more stormwater mitigated. Pictured below is a typical cross section of a green roof.

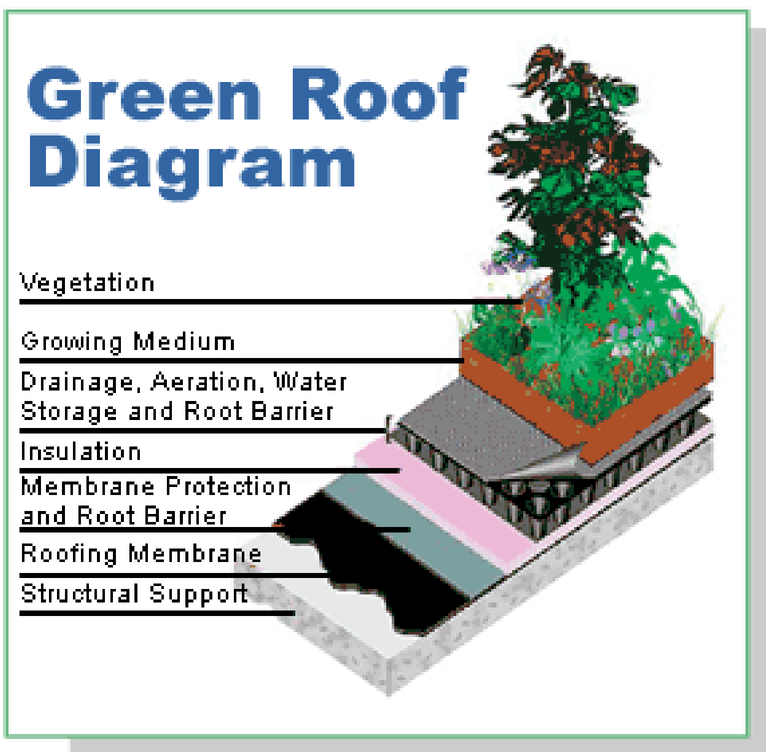


Figure 8.37 Green Roof Layers

Note the different layers all must be present in the final design, although insulation may be put inside of the roof. These layers are all essential to the functionality of the green roof and should all be designed for using these guidelines: ASTM international standards E2396-05 through E2399-05 and ASTM international standard E2400-06. Following these guidelines will help insure that the green roof is designed correctly and limit the potential for unforeseen circumstances and damages.

Design Procedure and Criteria

1. The types of soil used in a green roof vary depending on whether the roof is going to be extensive or intensive. For an extensive roofs at least 2 inches of a lightweight growth substrate consisting of sand and 10% organic material. For intensive roofs a soil depth of greater than 6 inches is required. Due to the high structural demand required by an intensive garden and hugely varying depths of soil a case by case approach will be used for intensive roofs.
2. Green roof areas can act as a WQCV for impervious areas which cover other sections of the roof.
    a. The storage capacity of a green roof can be determined using the following equation:

$$Volume = \frac{Depth\ of\ Material * (\%\ sand) * (0.3)}{0.255}$$

Where:

- $Depth\ of\ Material$ is the depth of the soil medium in the green roof.
- $\%\ sand$ is the percentage of sand used in your soil medium
- 0.3 is the porosity of sand
- 0.255 is the maximum WQCV for impervious areas

3. Typically the plants that are used in an extensive green roof are *Sedum Spurium and Sedum Album*—otherwise known as succulents. These plants are particularly hardy and will survive with the least amount of effort. Ornamental grasses can also be used on an extensive roof but a larger amount of soil should be used. In an intensive roof, a much wider range of plants can be used. This can be determined on case by case bases depending on the design.
4. A level spreader system is required if impervious areas are draining onto a green roof area. Examples of this include perforated piping, gravel pour out, and filter fabrics.

8.5.1.6 Constructed Wetlands Channels (CWC)

Description

Constructed wetland-bottomed channels takes advantage of dense natural vegetation (rushes, willows, cattails, and reeds) to slow down runoff and allow time for settling out sediment and biological uptake. It is another form of a sedimentation facility and a treatment plant.

Figure 8.38 Man-made Constructed Wetland Channels can enhance the ecological value of open spaces while treating and managing urban runoff.

Constructed wetlands differ from "natural" wetlands as they are artificial and are built to enhance stormwater quality. Sometimes small wetlands that exist along ephemeral drainageways on Colorado's high plains may be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

Regulations intended to protect natural wetlands recognize a separate classification of wetlands constructed for a water quality treatment. Such wetlands generally are not allowed to be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality enhancement is separate from the disturbance of a natural wetland. Nevertheless, any activity that disturbs a constructed wetland should be first cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

General Application

Wetland bottom channels can be used in the following two ways:

- A wetland can be established in a totally man-made channel and can act as a conveyance system and water quality enhancement facility. This design can be used along wide and gently sloping channels.

- A wetland bottom channel can be located downstream of a stormwater detention facility (water quality and/or flood control) where a large portion of the sediment load can be removed. The wetland channel then receives stormwater and base flows as they drain from the detention facility, provides water quality enhancement, and at the same time conveys it downstream. This application of a wetland channel is recommended upstream of receiving waters and within lesser (i.e., ephemeral) receiving waters, thereby delivering better quality water to the more significant receiving water system.

A CWC requires a net influx of water to maintain their vegetation and microorganisms. A complete water budget analysis is necessary to ensure the adequacy of the base flow.

Advantages/Disadvantages

Constructed wetlands offer several potential advantages, such as natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. Constructed wetlands provide an effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles. In other words, they offer yet another effective BMP for larger tributary basins.

The primary drawback to wetlands is the need for a continuous base flow to ensure their presence. In addition, salts and scum can accumulate and unless properly designed and built, can be flushed out during larger storms.

Other disadvantages include the need for regular maintenance to provide nutrient removal. Regular harvesting and removal of aquatic plants, cattails, and willows is required if the removal of nutrients in significant amounts has to be assured. Even with that, recent data puts into question the net effectiveness of wetlands in removing nitrogen compounds and some form of phosphates. Periodic sediment removal is also necessary to maintain the proper distribution of growth zones and of water movement within the wetland.

Physical Site Suitability

A perennial base flow is needed to sustain a wetland, and should be determined using a water budget analysis. Loamy soils are needed in wetland bottom to permit plants to take root. Infiltration through a wetland bottom cannot be relied upon because the bottom is either covered by soils of low permeability or because the groundwater is higher than the wetland's bottom. Wetland bottom channels also require a near zero longitudinal slope; drop structures are used to create and maintain a flat grade.

Pollutant Removal

Removal efficiencies of constructed wetlands vary significantly. Primary variables influencing removal efficiencies include design, influent concentrations, hydrology, soils, climate, and maintenance. With periodic sediment removal and plant harvesting, expected removal efficiencies for sediments, organic matter, and metals can be moderate to high; for phosphorous, low to moderate; and for nitrogen, zero to low. Pollutants are removed primarily through sedimentation and entrapment, with some of the removal occurring through biological uptake by vegetation and microorganisms. Without a continuous dry-weather base flow, salts and algae can concentrate in the water column and can be released into the receiving water in higher levels at the beginning of a storm event as they are washed out.

Harvesting aquatic plants and periodic removal of sediment also removes nutrients and pollutants associated with the sediment. Researchers still do not agree that routine aquatic plant harvesting affects pollutant removals. Until research documents these effects, periodic harvesting for the general upkeep of wetland, and not routine harvesting of aquatic plants, is recommended.

Cold Weather Considerations

Constructed wetland channels may be used in cold climate; however, the functions of the wetland vegetation for aesthetics and pollutant removal can be limited by the shortened growing season. Snow accumulation during winter months may reduce available channel conveyance capacity in early spring.

Design Considerations

Wetlands can be set into a drainageway to form a wetland bottom channel as shown in **Figure 8.39**. An analysis of the water budget is needed so that the inflow of water throughout the year is sufficient to meet all the projected losses (such as evaporation, evapotranspiration, and seepage). An insufficient base flow could cause the wetland bottom channel to dry out and die.

Design Procedure and Criteria

The following steps outline the Constructed Wetlands Channel design procedure. Refer to **Figure 8.35** for design components.

1. Design Discharge — Determine the 2-year peak flow rate in the wetland channel *without* reducing it for any upstream ponding or flood routing effects.

2. Channel Geometry — Define the newly-built channel's geometry to pass the design 2-year flow rate at 2.0 feet per second with a channel depth between 2.0 to 4.0 feet. The channel cross-section should be trapezoidal with side slopes of 4:1 (Horizontal/Vertical) or flatter. Bottom width shall be no less than 8.0 feet.

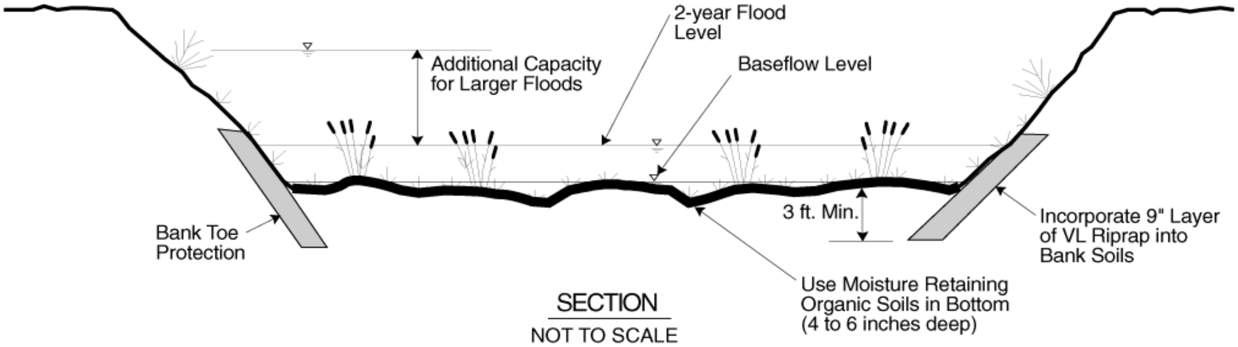
3. Longitudinal Slope — Set the longitudinal slope using Manning's equation and a Manning's roughness coefficient of n=0.03, for the 2-year flow rate. If the desired longitudinal slope cannot be satisfied with existing terrain, grade control checks or small drop structures must be incorporated to provide desired slope.

4. Final Channel Capacity — Calculate the final (or mature) channel capacity during a 2-year flood using a Manning's roughness coefficient of n=0.08 and the same geometry and slope used when initially designing the channel with n=0.03. The channel shall also provide enough capacity to contain the flow during a 100-year flood while maintaining one foot of free-board. Adjustment of the channel capacity may be done by increasing the bottom width of the channel. Minimum bottom width shall be 8 feet.

5. Drop Structures — Drop structures should be designed to satisfy the drop structure criteria of the *Major Drainage* chapter in Volume 1 of the *USDCM.*

6. Vegetation — Vegetate the channel bottom and side slopes to provide solid entrapment and biological nutrient uptake. Cover the channel bottom with loamy soils upon which cattails, sedges, and reeds should be established. Side slopes should be planted with native or irrigated turf grasses.

7. Maintenance Access — Provide access for maintenance along the channel length. Maximum grades for maintenance vehicles should be 10 percent and provide a solid driving surface.



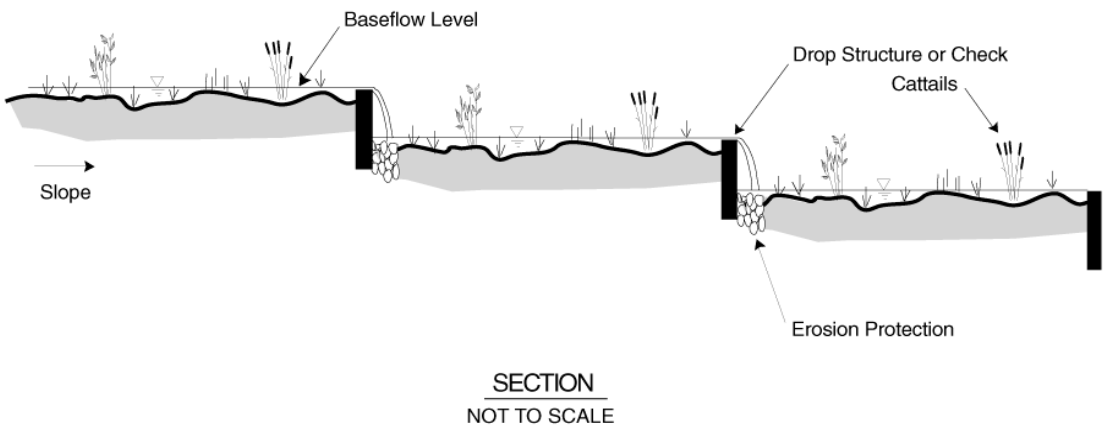


Figure 8.39 Constructed Wetland Channel Typical Plan and Profile

Maintenance

Table 8.11 provides maintenance recommendations for constructed wetland channels.

Table 8.11 Maintenance Recommendations for Constructed Wetland Channels

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Mow occasionally to limit unwanted vegetation. Maintain irrigated turf grass at 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from the channel.	Routine – Including just before annual summer storm seasons (that is following snowmelt), following significant rainfall events, and in fall prior to snow cover.

Required Action	Maintenance Objective	Frequency of Action
Sediment removal	Remove accumulated sediment and muck along with wetland vegetation growing on top of it. Re-establish growth zone depths and revegetate with original wetland species.	Non-routine – Every 10 to 20 years as needed by inspection if no construction activities take place in the tributary watershed. More often if they do.
Aquatic plant harvesting	Cut and remove plants growing in wetland (such as cattails and reeds) to remove nutrients permanently with manual work or specialized machinery.	Non-routine until further evidence indicates such action would provide significant nutrient removal. In the meantime, perform this task once every 5 years or less frequently as needed to clean the wetland zone out.
Inspections	Observe inlet and outlet works for operability. Verify the structural integrity of all structural elements, slopes, and embankments.	Routine – At least once a year, preferably once during one rainfall event resulting in runoff.

8.5.2 Street BMPs/Sediment Traps

Figure 8.40 Bioretention planters within the street rights-of-way to help treat and store stormwater runoff, as well as provide traffic calming. *The City of Portland, Department of Environmental Services*

Description

Street BMPs and sediment traps refer to BMPs described in this manual that are designed and constructed within the street Right-of-Way. The in-street treatment options range from bioretention areas or planters, grassed swales, grass buffers, underground sedimentation vaults, and permeable pavers (not to be used where streets are sanded),

Street BMPs and sediment traps will provide important pretreatment of urban runoff, and are designed primarily for sediment/sand removal. In-street sediment traps can be utilized in the City of Aspen to greatly reduce the sediment transport to the Roaring Fork River, especially where streets are sanded in the winter.

Street BMPs may not satisfy WQCV requirements. WQCV BMPs are recommended areas, in a regional or sub-regional facility for removal of other pollutants and fine sediment.

General Application

Street BMPs and sediment traps are appropriate for streets in new developments, or retro-fitted within existing street rights-of-way in residential areas and commercial areas of Aspen, where street widths tend to be wider. In-street BMPs can also be used along busy streets as a “traffic calming” strategy. In-street sediment traps and BMPs should be constructed along existing flow lines (curb and gutter), and upstream of existing inlets in order to maximize the benefits of sediment removal. Geotechnical issues should be carefully considered prior to locating in-street BMPs. Additionally, street BMP’s should not negatively impact vehicular traffic lanes, bicycles and pedestrian sidewalks within the City, and therefore should be carefully planned with appropriate City agencies.

Advantages/Disadvantages

The City of Aspen’s high land values and current zoning regulations encourage full coverage development-- lot line to lot line. This equates to nearly 90%-100% imperviousness of sites within ultra-urban areas, resulting in very little available land for stormwater treatment and storage. The primary advantage of in-street BMPs and sediment traps are that they utilize City rights-of-way and can be combined with other City initiatives such as street beautification through tree and groundcover plantings, as well as traffic calming through the use of planted medians and “bulb outs”.

The primary disadvantages of in-street BMP’s and sediment traps are that they are highly visible and will require careful design as well as frequent maintenance to uphold their water quality function and aesthetic appearance. Additionally, street BMPs may serve multiple owners because they are located outside of property lines, within City rights-of-way or private access easements, which may be an advantage. However, a special district may need to be established in order to fund and maintain the BMPs.

Design Considerations, Procedure and Criteria

Refer to appropriate Runoff Reduction BMP’s and Structural BMP figures, procedures and criteria located throughout the manual for the design and development of in-street BMP’s. The basins of In-street sediment traps should be constructed with a permeable hard surface so that sediments can be easily removed with small equipment, or a shovel, without doing permanent damage to the BMP.

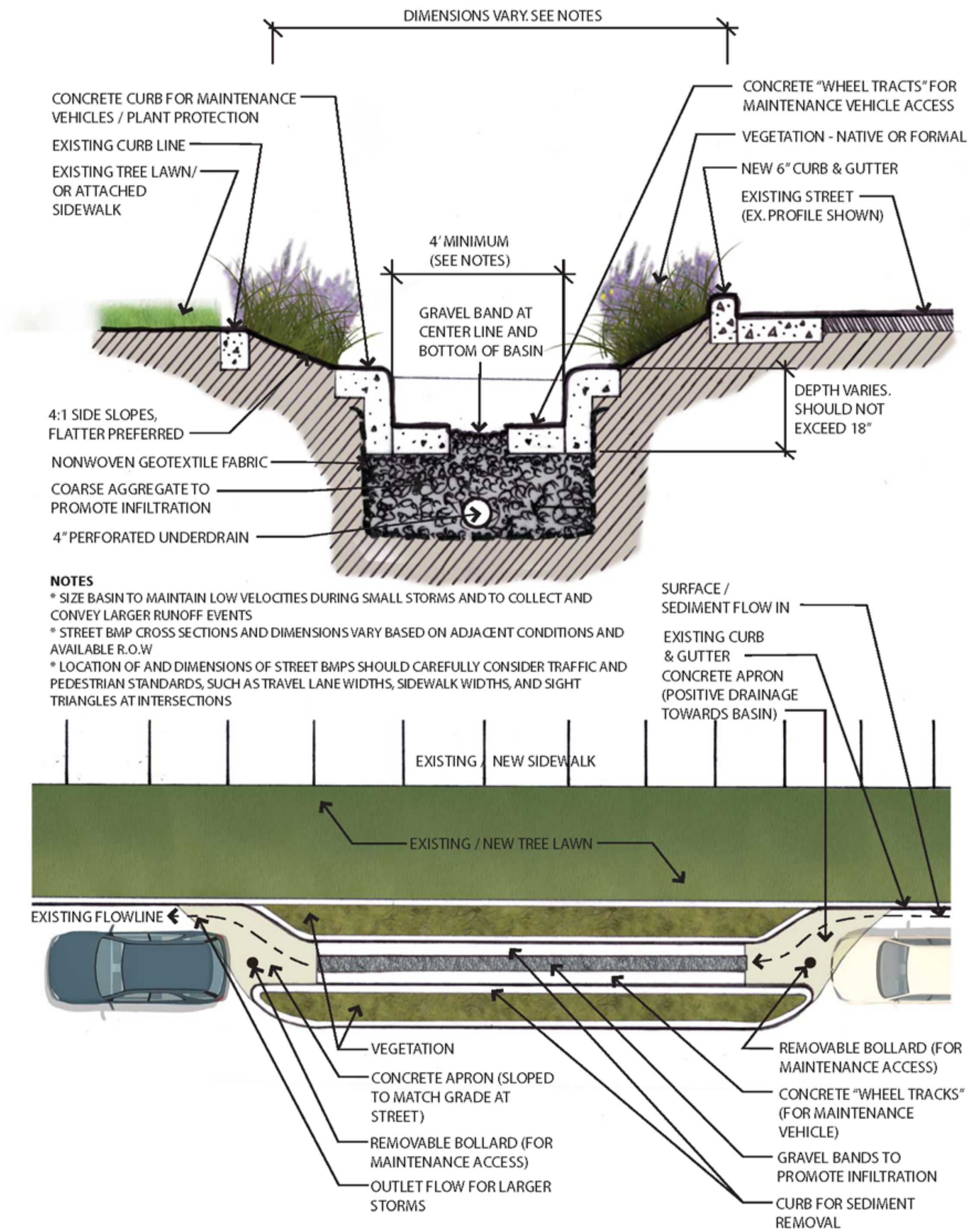


Figure 8.41 In-street Sediment Trap Conceptual Design Sketch - Plan and Section-Residential Street Application

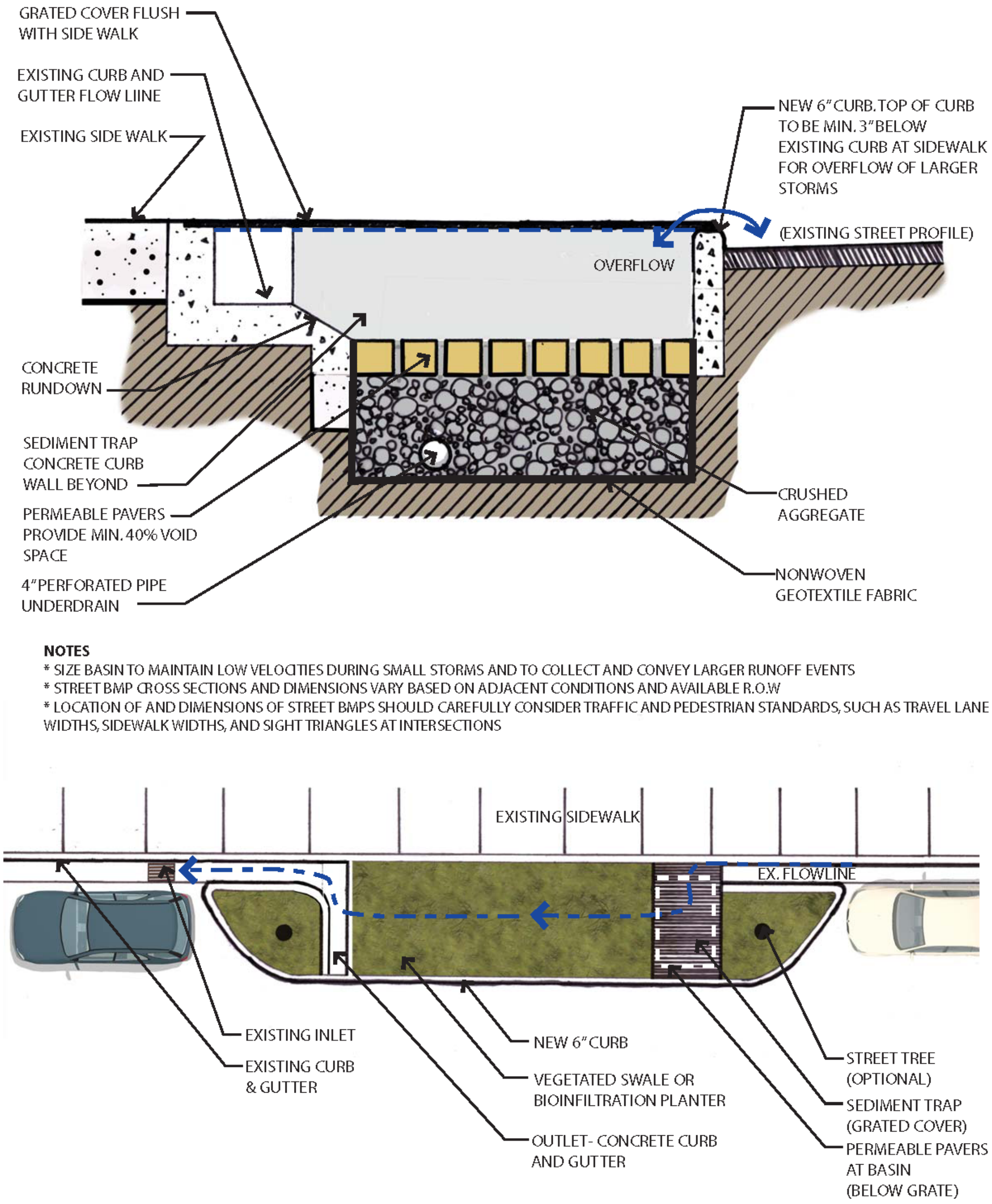


Figure 8.42 In-street Sediment Trap Conceptual Design Sketch- Plan and Section- Urban/ Commercial Street Application

Figures 8.43 and 8.44 Parking Examples

Some parking stalls in Aspen's commercial core could be replaced with in-street BMP planters and sediment traps in order to manage sediment transport, provide water quality treatment, and add attractive plantings and street trees in the Downtown.

8.5.3 Storage Volume BMPs

Storage volume BMPs are designed to provide the WQCV determined using the methods described in **Section 8.4**. These BMPs include bioretention (BR) (also known as porous landscape detention [PLD]), extended detention basins (EBDs), and constructed wetland basins (CWBs). These BMPs function by capturing runoff and releasing it over an extended period of time (typically 12 hours for Aspen). This allows time for sedimentation, and in the case of BR and CWBs, contact time with vegetation for biological treatment.

8.5.3.1 Bioretention and Rain Gardens

Figure 8.45 Bioretention planters can be used to treat stormwater runoff from the building site and roof, as well as being attractive planting areas or flower gardens

Figure 8.46 This larger Bioretention area manages stormwater runoff for a medium density residential neighborhood. The forebay sediment trap (in the foreground) is located at the outlet of the storm sewer to trap settlement larger

Figure 8.47 Rain gardens are used to collect and filter stormwater runoff. As seen in the examples above they can be planted in a variety of areas with a wide variety of plant life from flowers and grasses to trees.

Description

Bioretention is a depressed landscape area with soils, typically Hydrologic Soil Group (HSG) A or B (sand to loam) that promotes filtration and infiltration of runoff. Bioretention areas (without underdrains) can significantly reduce runoff volume through infiltration, reducing flooding and erosion in downstream receiving waters.

General Application

Typical areas for implementation of bioretention include parking islands, medians, landscape buffers, courtyards, and planters. Geotechnical and foundation issues must be carefully considered when locating bioretention facilities and designing underdrains and linings.

Advantages/Disadvantages

A primary advantage of bioretention is making it possible to provide *WQCV* on a site while reducing the impact on developable land. It works well with irrigated bluegrass, whereas experience has shown that conditions in the bottom of extended detention basins (EDBs) become too wet for bluegrass. Bioretention provides a natural moisture source for vegetation, enabling “green areas” to exist with reduced irrigation.

The primary disadvantage of bioretention is a potential for clogging if a moderate to high level of silts and clays is allowed to flow into the facility. Also, this BMP should not be placed close to building foundations or other areas when expansive soils are present, although an underdrain and impermeable liner can ameliorate some of this concern.

Physical Site Suitability

If an underdrain system is incorporated into this BMP, bioretention is suited for about any site regardless of in-situ soil type. If sandy soils are present, the facility can be installed without an underdrain (infiltration option); granular sub-soils are not a requirement. This BMP has a flat surface area, and may be more difficult to incorporate it into steeply sloping terrain.

Pollutant Removal

Although not tested to date in the Denver area, the amount of pollutant removed by this BMP should be significant and should equal or exceed the removal rates provided by sand filters, extended detention basins, or wetland basins. In addition to settling, bioretention provides for filtering, adsorption, and biological uptake of constituents in stormwater. In addition, because it provides for some infiltration and evaporation, volume of runoff is also reduced, which translates into a reduced pollutant load leaving the site.

Cold Weather Considerations

Bioretention areas will perform most effectively in late-spring and summer months when the ground is not frozen and vegetation is healthy. Bioretention areas should not be installed in areas that are sanded or that receive runoff from adjacent sanded areas unless pretreatment for sediment removal is provided. Even if pretreatment is provided, heavy sediment loads may result in sediment accumulation in bioretention areas, reducing infiltration capacity and potentially impacting vegetation. Designers should consider operation of bioretention facilities in late-winter, early-spring melting conditions when infiltration capacity may be limited by frozen ground. Under these circumstances, the designer should provide a path for runoff to flow out of the bioretention area and into the drainage system without causing flooding. Bioretention areas may be used for snow storage; however, spring maintenance should be expected given sediment loads in stockpiled snow.

Design Considerations

Figure 8.43 shows a typical cross-section for a bioretention area. When implemented using multiple small installations on a site, it is increasingly important to accurately account for each upstream drainage area tributary to each bioretention site to make sure that each facility is properly sized, individual bioretention sites intercept runoff from their respective tributary areas, and that all portions of the development site are directed to a bioretention area.

The designer needs to decide early on if infiltration is possible or allowed at the bioretention site as that will affect the design cross-section and whether underdrains will be needed. Considerable savings can be achieved if the site is suitable for infiltration, sites that typically have NRCS Soil Types A, B or C. The best way to determine if the site is suitable for bioretention without underdrains is to perform a standard individual percolation tests or infiltration tests at a depth equal to the bottom of the bioretention area. The test shall be performed or supervised by a licensed professional engineer. If the engineer certifies that the site has a percolation rate of less than 60 minutes per inch, underdrains and the supporting gravel and geotextile fabric layers may be eliminated.

A wide variety of plant types are possible, ranging from native grasses, groundcovers, flowers, and shrubs. Turf grass is discouraged because of the difficulty of maintenance. Trees should not be included in porous landscape detention areas (roots decrease storage volume and make maintenance difficult). Dense shrub plantings may become difficult to maintain, and should be limited to edges not prone to sediment build-up. Rock mulches (especially in high sediment areas) are discouraged because they limit the available pervious surface and are difficult to remove sediment from. The use of long fiber shredded wood mulch is encouraged because of a higher level of perviousness. It is important to account for each upstream drainage area in order to ensure that bioretention is properly sized and stormwater is directed to it.

Design Procedure and Criteria

1. Basin Storage Volume — Determine WQCV for the bioretention area using the procedure described in Section 8.4. The WQCV should be calculated for the area tributary to the bioretention area.

2. Surface Area and Maximum WQCV Depth — Calculate the minimum required **flat** surface area of the bioretention area as follows:

$$Flat\ Surface\ Area = \frac{Design\ Volume\ in\ ft^3}{d}$$

in which,

d = *WQCV* depth (12-inch maximum) of the bioretention basin, ft.

3. Sand/Topsoil/Organic Media — Provide, as a minimum, an 18-inch layer of well mixed sand and soil (70% sand and 30% combination of topsoil and large organic matter by volume as shown in **Figure 8.43**. Less than 5% of the media can pass the 200 sieve and the media must infiltrate at least 2 inches/hour. Maintain top surface flat. If sideslopes need to be steeper than 3:1 use vertical walls. Media shall be delivered fully mixed in a drum mixer. On-site mixing of piles shall not be allowed.

4. Granular Sub-base and Underdrains — Granular material shall have all fractured faces and meet the technical requirements of AASHTO #3 or #4 aggregate (CDOT 703, #3 or #4).

   For NRCS Type D soils, or when standard percolation tests show percolation drawdown rates exceeding 60 minutes per inch, or when potential for groundwater contamination exist, install an 8-inch layer of granular base with underdrains and an impermeable liner under it. For

Type C soils, retain the underdrain system and utilize an impermeable liner if percolation rates prove it necessary. When underdrains are not needed, the 8-inch layer of gravel may be eliminated. Use a control orifice sized to drain the pore volume to empty each cell in approximately 12-hours.

5. Impermeable Membrane

When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil, or heavier, liner on the bottom and sides of the basin. If vertical walls are permeable or of stacked blocks, extend the impermeable liner behind the walls.

Wrap all liners to top of the bioretention basin and attach firmly with staples to the soil vertical wall using staples or concrete anchors. Provide sufficient slack so that the liners are not stretched when rock and sand are placed. If tears are seen or discovered, repair them as recommended by manufacturer with no less than 18 inches of overlap on all sides of the tear.

See **Appendix E** for general criteria regarding planting and selected plant species applicable for BMPs.

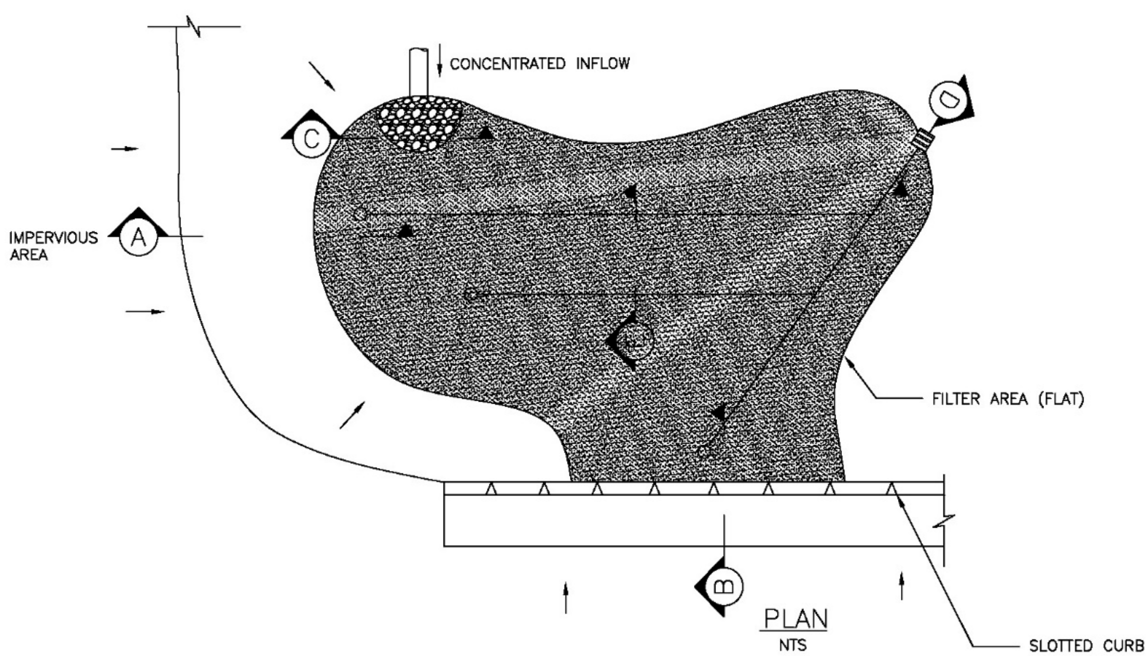
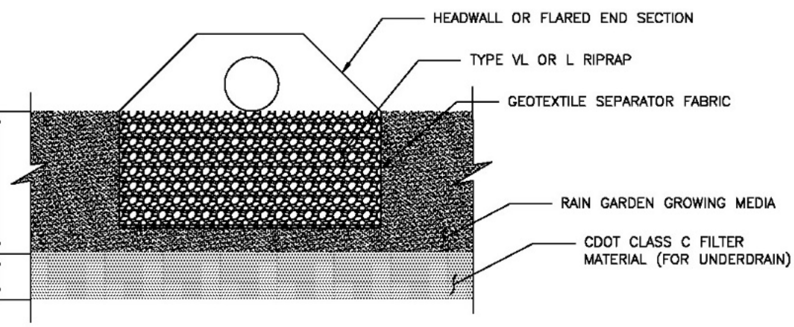
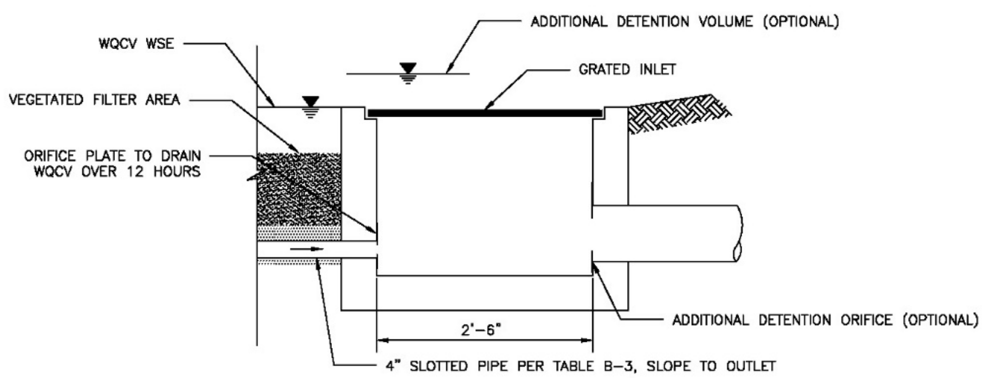


Figure 8.48 Typical Bioretention Section



SECTION C
NTS



SECTION D
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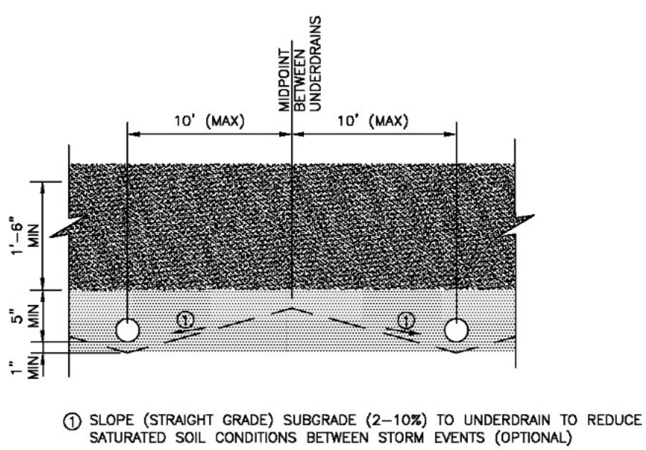

SECTION E
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Figure 8.49 Bioretention Cross Sections

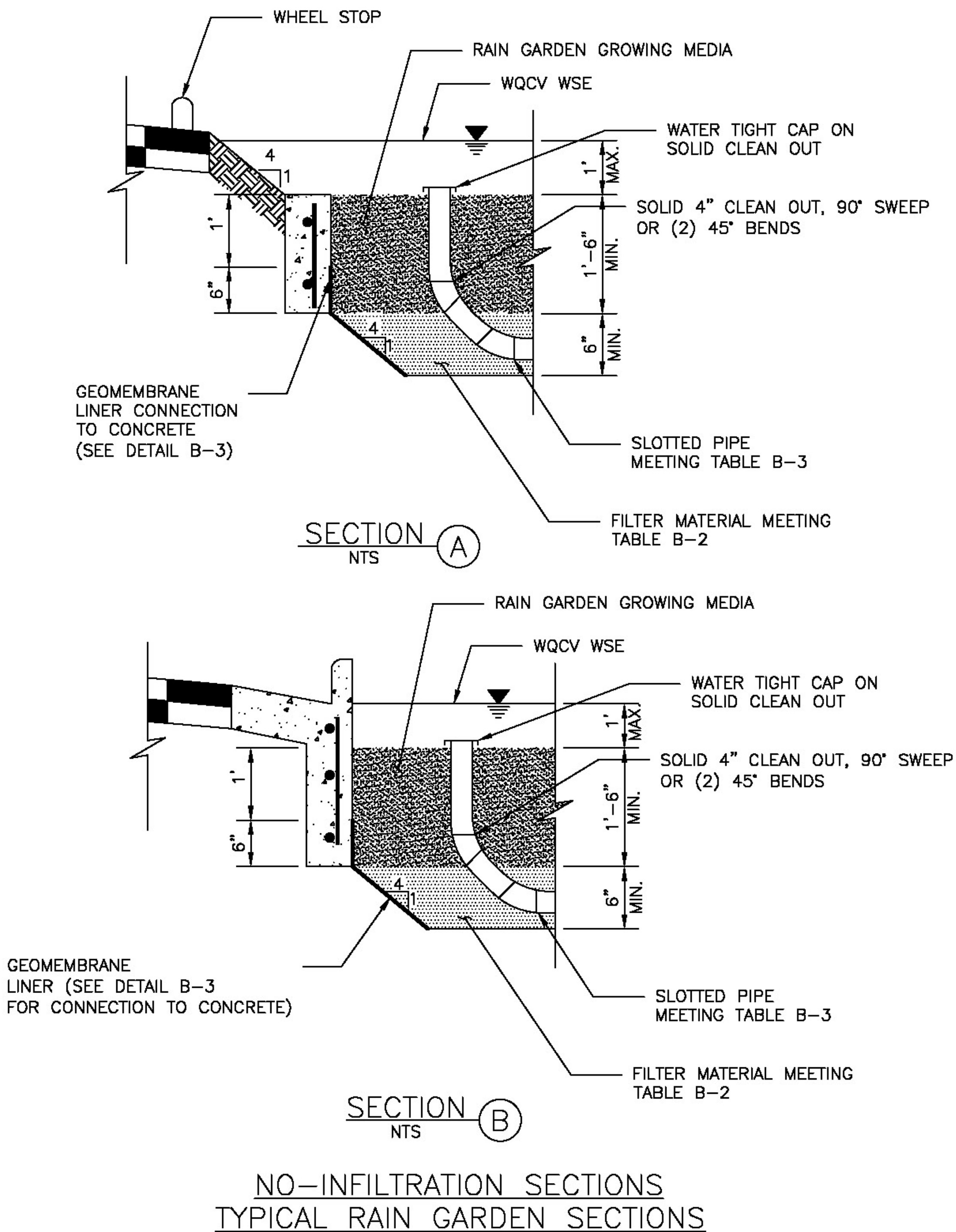


Figure 8.50 No Infiltration Sections

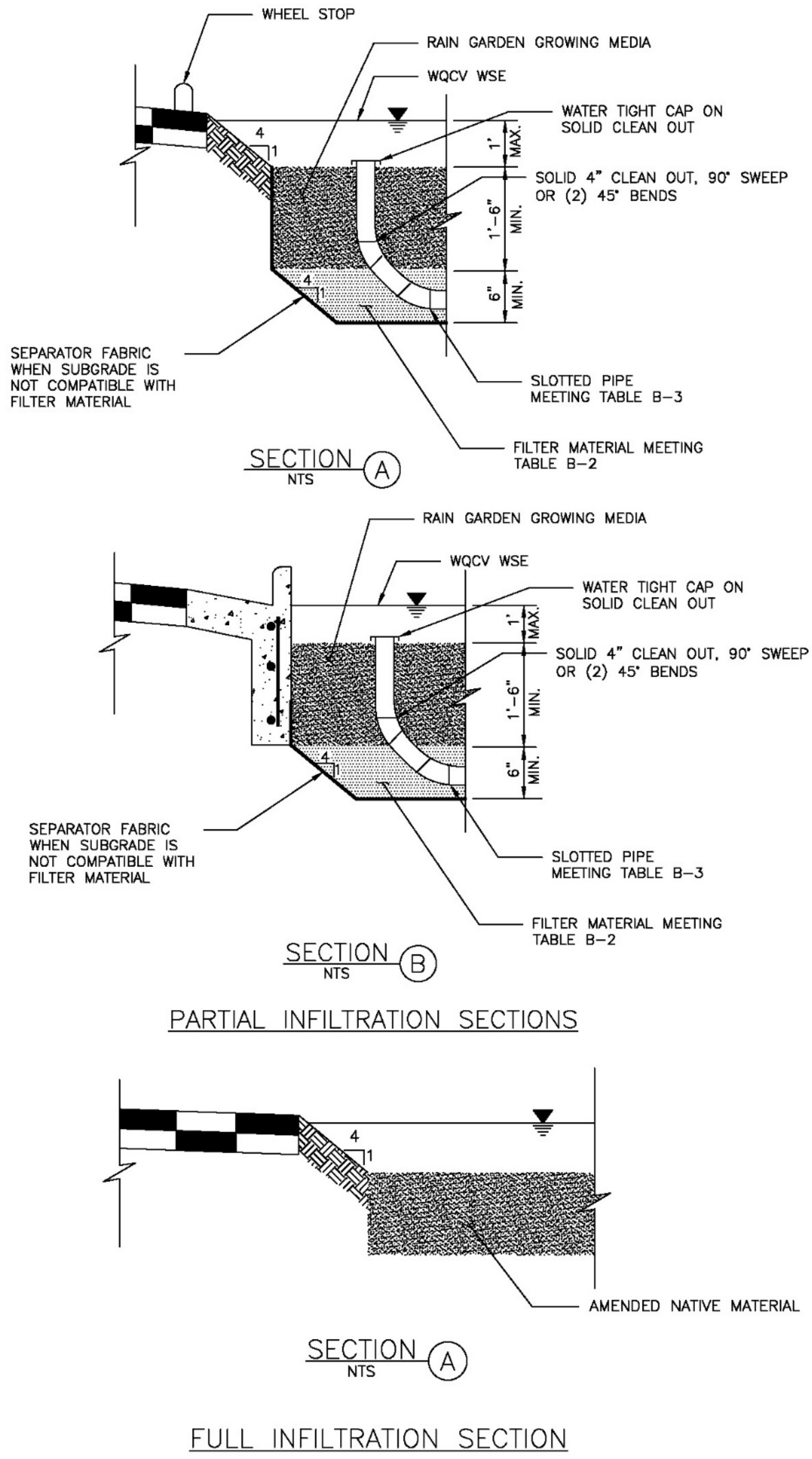


Figure 8.51 Full Infiltration Sections

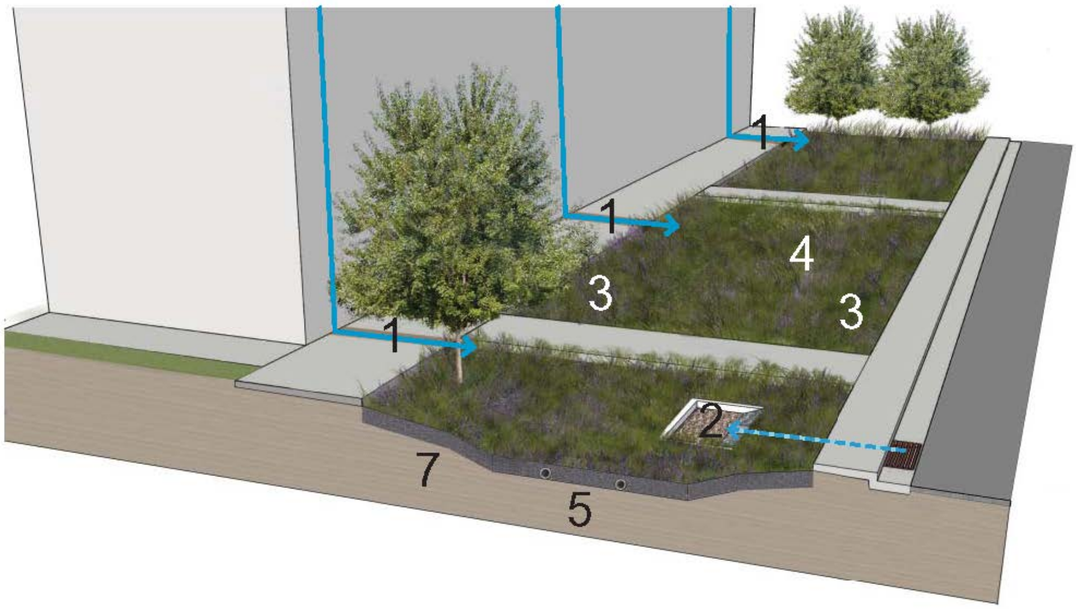


Figure 8.52 Typical Bioretention Design Sketch

1: Inlet: Roof downspouts are directed towards Bioretention Planter. Provide chases (with grated covers) in highly used pedestrian areas or where stormwater runoff crosses sidewalks.

2: Erosion Protection: Include a forebay or rock rundown, where storm sewers daylight into Bioretention areas, to reduce the likelihood of erosion and trap larger sediments.

3: Slopes: Relatively flat bottom with a 6-12 inch deep WQCV zone. Sides may include up to a 4:1 slope, flatter preferred.

4: Vegetation: Varies depending on site context. See **Appendix E** for vegetation types applicable to Aspen.

5: Underdrain/Liner: Underdrain is required when underlying soils have insufficient infiltration capacity. Underdrain and liner are recommended where geotechnical concerns exist. Refer to **Figure 8.43** for Bioretention Typical Section

6: Outlet/Overflow: Provide overflow above WQCV for larger storm events. (Not shown in sketch)

7: Infiltration Matrix: Provide infiltration media in accordance with design requirements shown in UDFCD Volume 3.

Figures 8.53 and 8.54 Planters, such as these shown in Downtown Aspen, could be utilized as biofiltration planters to treat and manage stormwater quality in dense urban environments where space for stormwater management is limited.

Maintenance

Sediment build-up may require periodic removal of sediments and plants when clogging reduces infiltration capacity to unacceptable levels. Access to facility must be provided to enable maintenance operations. Plant materials in areas prone to sediment build-up should be limited to grasses and groundcovers tolerant of periodic wet-dry cycles.

Table 8.12 Maintenance Recommendations for Bioretention

Required Action	Maintenance Objectives	Frequency
Inspections	Inspect detention area to determine if the sandy growth media is allowing acceptable infiltration.	Routine – Annual inspection of hydraulic performance.
Lawn mowing and vegetative care	Occasional mowing of grasses and weed removal to limit unwanted vegetation. Maintain irrigated turf grass as 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from detention area to minimize clogging of the sand media.	Routine – Depending on aesthetic requirements.
Landscaping removal and replacement	The sandy loam turf and landscaping layer will clog with time as materials accumulate on it. This layer will need to be removed and replaced to rehabilitate infiltration rates, along with all turf and other vegetation growing on the surface.	Every 5 to 15 years, depending on infiltration rates needed to drain the WQCV in 12-hours or less. May need to do it more frequently if exfiltration rates are too low to achieve this goal.

8.5.3.2 Pervious Pavement Detention

Description

Pervious pavement detention (PPD) takes advantage of the storage available in the sub-base layer of the pervious pavement to provide WQCV and potentially detention volume. Pervious pavement criteria in **Section 8.5.1.4** should be followed for PPD, in addition to the following:

1. The maximum sub-base porosity for determination of storage volume is 30 percent. The storage volume can be calculated by multiplying the depth of the sub-base by 0.30.

2. For WQCV applications, the captured runoff should be designed to infiltrate into the underlying soils or, if an underdrain is used, to be released over a period of 12 hours. This can be accomplished by restricting the underdrain with an orifice to provide the controlled release.

3. For detention applications, the captured runoff should be designed to infiltrate into the underlying soils or, if an underdrain is used, to be released at rates in accordance with the allowable release rates in the Detention Chapter of this Manual.

8.5.3.3 Extended Detention Basin

Figure 8.55 Typical Extended Detention Basins are normally designed at the outlet of storm sewers—"end of pipe". EDB's can manage large volumes of stormwater runoff utilizing a single BMP facility. This EDB has steep side slopes and a deep ponding depth and therefore limits the range plant species that can survive in this environment.

Figure 8.56 This Extended Detention Basin is spread out over the length of the parking lot, has minimal side slopes, and a shallow ponding depth. This design criteria allows this basin to utilize a greater plant species diversity than that of **Figure 8.55**

Description

An extended detention basin (EDB) is a sedimentation basin designed to totally drain dry sometime after stormwater runoff ends. It is an adaptation of a detention basin used for flood control. The primary difference is in the outlet design. The EDB uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal. The EDB's drain time for the brim-full water quality capture volume (i.e., time to fully evacuate the design capture volume) of 12 hours is recommended to remove a significant portion of fine particulate pollutants found in urban stormwater runoff while taking into consideration freeze-thaw cycles common in Aspen. Soluble pollutant removal can be somewhat enhanced by providing a small wetland marsh or ponding area in the basin's bottom to promote biological uptake. The basins are considered to be "dry" because they are designed not to have a significant permanent pool of water remaining between storm runoff events. However, EDB may develop wetland vegetation and sometimes shallow pools in the bottom portions of the facilities.

General Application

An EDB can be used to enhance stormwater runoff quality and reduce peak stormwater runoff rates. If these basins are constructed early in the development cycle, they can also be used to trap sediment from construction activities within the tributary drainage area. The accumulated sediment, however, will need to be removed after upstream land disturbances cease and before the basin is placed into final long-term use. Also, an EDB can sometimes be retrofitted into existing flood control detention basins.

EDBs can be used to improve the quality of urban runoff from roads, parking lots, residential neighborhoods, commercial areas, and industrial sites and are generally used for regional or follow-up treatment. They can also be used as an onsite BMP and work well in conjunction with other BMPs, such as upstream onsite source controls and downstream infiltration/filtration basins or wetland channels. If desired, a flood routing detention volume can be provided above the WQCV of the basin.

Advantages/Disadvantages

An EDB can be designed to provide other benefits such as recreation and open space opportunities in addition to reducing peak runoff rates and improving water quality. They are effective in removing particulate matter and the associate heavy metals and other pollutants. As with other BMPs, safety issues need to be addressed through proper design.

Physical Site Suitability

Normally, the land required for an EDB is approximately 0.5 to 2.0 percent of the total tributary development area. In high groundwater areas depth to seasonally high groundwater with 2-3 feet of pond bottom, consider the use of retention ponds (RP) instead in order to avoid many of the problems that can occur when the EDB’s bottom is located below the seasonal high water table. Soil maps should be consulted, and soil borings may be needed to establish design geotechnical parameters.

P*ollutant Removal*

Removal of suspended solids and metals can be moderate to high, and removal of nutrients is low to moderate. The removal of nutrients can be improved when a small shallow pool or wetland is included as part of the basin's bottom or the basin is followed by BMPs more efficient at removing soluble pollutants, such as a filtration system, constructed wetlands or wetland channels.

The major factor controlling the degree of pollutant removal is the emptying time provided by the outlet. The rate and degree of removal will also depend on influent particle sizes. Metals, oil and grease, and some nutrients have a close affinity for suspended sediment and will be removed partially through sedimentation.

Cold Weather Considerations

Since the EDB does not have a large permanent pool, freezing concerns are less pronounced than with some types of BMPs. Nonetheless, freezing of the outlet is a possibility during extended duration events such as spring runoff or mid-winter melts when nighttime temperatures drop below freezing. The outlet should be designed so that it can be accessed and ice cleaned off if necessary. Siting the pond so that the outlet has favorable solar exposure, when feasible, may also help. Snow accumulation in the pond bottom over the course of the winter may reduce available storage volume in the spring.

Design Considerations

Whenever desirable and feasible, incorporate the EDB within a larger flood control basin. Also, whenever possible try to provide within the basin for other urban uses such as passive recreation, and wildlife habitat. If multiple uses are being contemplated, consider the multiple-stage detention basin to limit inundation of passive recreational areas to one or two occurrences a year. Generally, the area within the WQCV is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas. These are best located above the WQCV pool level.

Figure 8.49 shows a representative layout of an EDB. Although flood control storage can be accomplished by providing a storage volume above the water quality storage, how best to accomplish this is not included in this discussion. Whether or not flood storage is provided, all embankments should be protected from catastrophic failure when runoff exceeds the design event. The State Engineer's regulatory requirements for larger dam embankments and storage volumes must be followed whenever regulatory height and/or volume thresholds are exceeded. Below those thresholds, the engineer should design the embankment-spillway-outlet system so that catastrophic failure will not occur.

Perforated outlet and trash rack configurations from Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual should be followed.

Although the soil types beneath the pond seldom prevent the use of this BMP, they should be considered during design. Any potential exfiltration capacity should be considered a short-term characteristic and ignored in the design of the WQCV because exfiltration will decrease over time as the soils clog with fine sediment and as the groundwater beneath the basin develops a mound that surfaces into the basin.

High groundwater should not preclude the use of an EDB. Groundwater, however, should be considered during design and construction, and the outlet design must account for any upstream base flows that enter the basin or that may result from groundwater surfacing within the basin itself.

Stable, all weather access to critical elements of the pond, such as the inlet, outlet, spillway, and sediment collection areas must be provided for maintenance purposes.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for an EDB to detain and treat the WQCV. Refer to Chapter 5 to determine proper sizing for both WQCV and detention volume.

1. Basin Storage Volume — Provide a storage volume equal to 130 percent of the WQCV calculated according to the procedures in **Section 8.4**. The additional 30 percent of storage volume provides for sediment accumulation and the resultant loss in storage volume.

2. Outlet Works — The Outlet Works are to be designed to release the WQCV (i.e., not the “Design Volume”) over a 12-hour period. Use the fewest number of perforation columns possible to maximize the perforation hole diameter. This helps to reduce clogging problems.

3. Trash Rack — Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Size the rack so as not to interfere with the hydraulic capacity of the outlet.

4. Basin Shape — Shape the pond whenever possible with a gradual expansion from the inlet and a gradual contraction toward the outlet, thereby minimizing short circuiting. It is best to have a basin length to width ratio between 2:1 to 3:1. To achieve this, it may be necessary to modify the inlet and outlet points through the use of pipes, swales or channels to accomplish this.

   Always maximize the distance between the inlet and the outlet.

5. Two-Stage Design — A two-stage design with a pool that fills often with frequently occurring runoff minimizes standing water and sediment deposition in the remainder of the basin. The two stages are as follows:

   A. Top Stage: The top stage should be 2 or more feet deep with its bottom sloped at 1 to 2 percent toward the low flow channel.

   B. Bottom Stage: The active surcharge storage volume of the bottom stage should be 1.0 to 2 feet deep below the bottom of the top stage and store no less than 3.0 percent of the WQCV.

      Provide a permanent micro-pool below the active storage volume of the lower stage in front of the outlet. The pool should be ½ the depth of the top stage depth described above, or 2.5 feet, whichever results in the larger depth.

6. Low-Flow Channel — Conveys low flows from the forebay to the bottom stage. Erosion protection should be provided where the low-flow channel enters the bottom stage. Lining the low flow channel with concrete is recommended. Otherwise line its sides with buried Type VL riprap and bottom with concrete. Make it at least 6-inches deep if concrete lined sides and 9-inches if buried riprap sides are used. At a minimum provide capacity equal to twice the release capacity at the upstream forebay outlet.

7. Basin Side Slopes — Basin side slopes should be stable and gentle to facilitate maintenance and access. Side slopes should be no steeper than 4:1 and the use of flatter slopes is recommended; the flatter, the better and safer.

8. Dam Embankment — The embankment should be designed not to fail during a 100-year <u>and larger storms</u>. Embankment slopes should be no steeper than 3:1, preferably 4:1 or flatter, and planted with turf forming grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to at least 95 percent of their maximum density according to ASTM D 698-70 (Modified Proctor). Spillway structures and overflows should be designed in accordance with local drainage criteria and should consider UDFCD drop-structure design guidelines.

9. Vegetation	Bottom vegetation provides erosion control and sediment entrapment. Pond bottom, berms, and side sloping areas may be planted with native grasses or with irrigated turf, depending on the local setting.
10. Access	All weather stable access to the bottom, forebay, and outlet works area shall be provided for maintenance vehicles. Grades should not exceed 10 percent, and a solid driving surface of gravel, rock, concrete, or gravel stabilized turf should be provided.
11. Inlet	Dissipate flow energy at pond's inflow point(s) to limit erosion and promote particle sedimentation
12. Forebay Design	Provides an opportunity for larger particles to settle out in the inlet in an area that has a solid surface bottom to facilitate mechanical sediment removal. A rock berm should be constructed between the forebay and the main EDB. The forebay volume of the permanent pool should be about 5 percent of the design WQCV. A pipe through the berm to convey water to the main body of the EDB should be offset from the inflow streamline to prevent short circuiting and should be sized to drain the forebay volume in 5 minutes. The floor of the forebay should be concrete or grouted boulder lined to define sediment removal limits.
13. Flood Storage	Combining the water quality facility with a flood control facility is recommended. The 5-year, 10-year, 100-year, or other floods may be detained above the WQCV.
14. Multiple Uses	Whenever desirable and feasible, incorporate the EDB within a larger flood control basin. Also, whenever possible, try to provide for other urban uses such as active or passive recreation, and wildlife habitat. If multiple uses are being contemplated, use the multiple-stage detention basin to limit inundation of passive recreational areas to one or two occurrences a year. Generally, the area within the WQCV is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas. These are best located above the WQCV level.

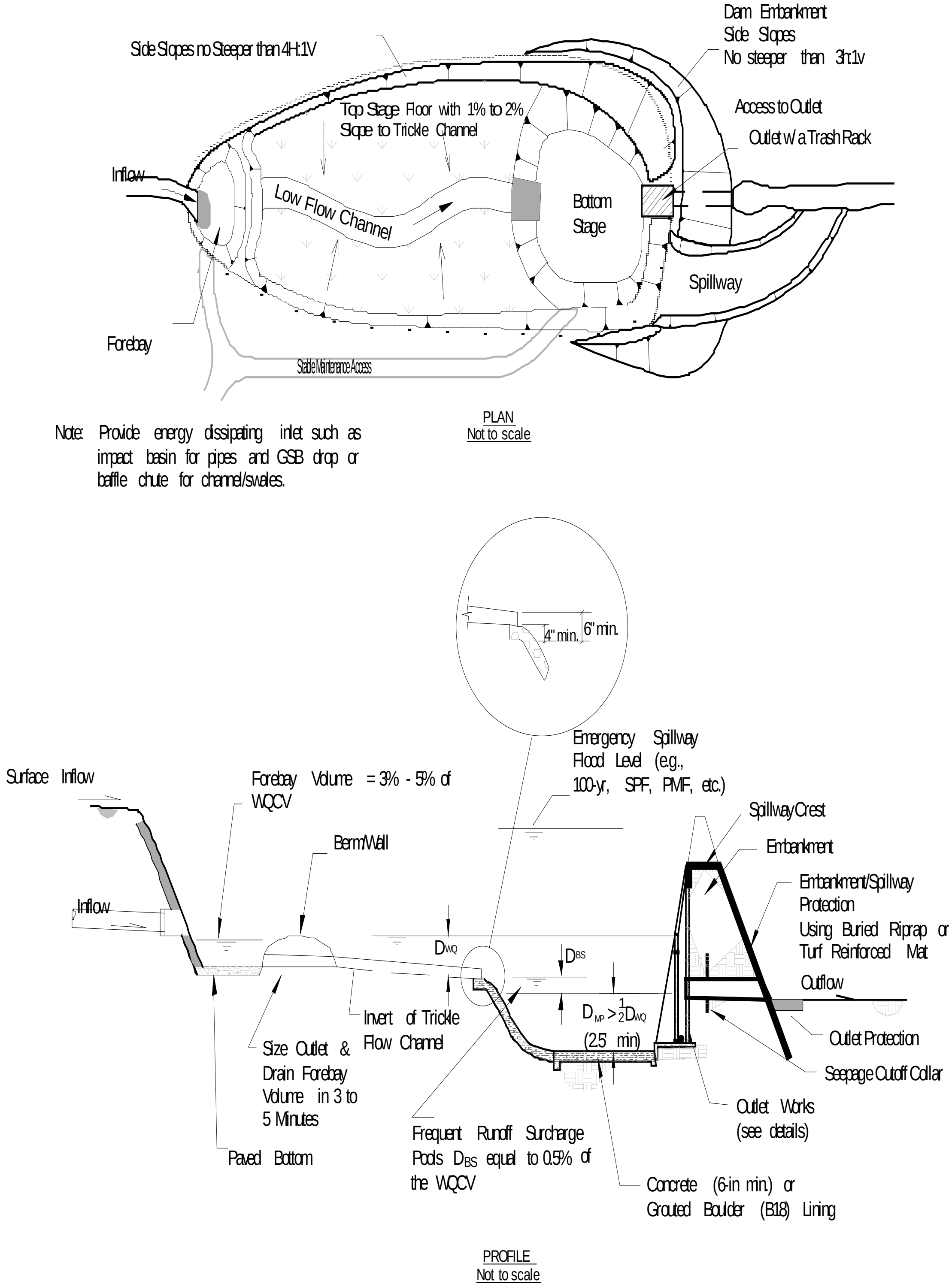


Figure 8.57 Extended Detention Basin Typical Plan and Profile

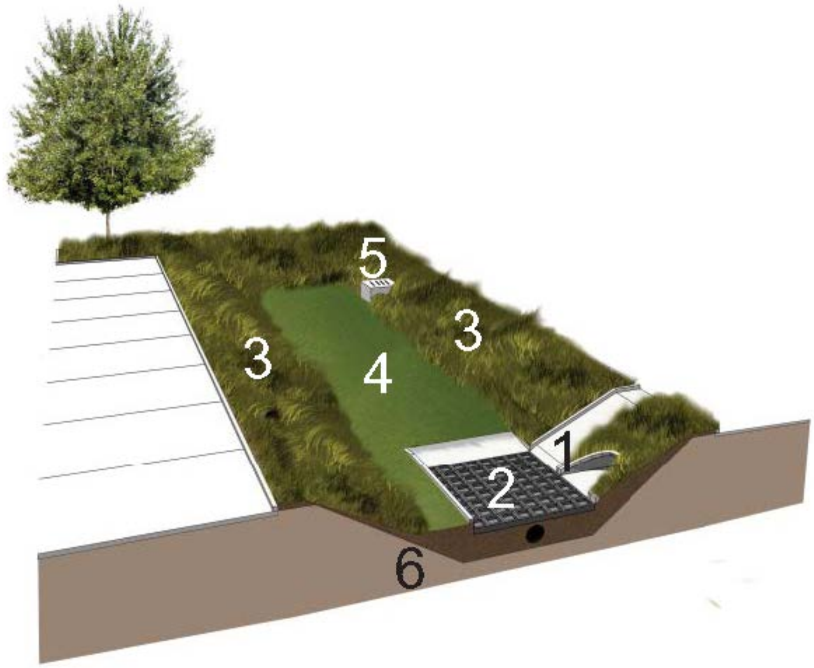


Figure 8.58 Extended Detention Basin Design Sketch

1: Inlet: Dissipate energy at outfalls to prevent erosion and sediment re-suspension.

2: Sediment Trap: Provide forebay for erosion protection and settlement for large particulates in runoff. Provide a pervious hard bottom and access ramp to allow equipment access.

3: Slopes: Side slopes are generally 4:1 or flatter for safety and maintenance.

4: Vegetation: Bottom can consist of turf grass if a longitudinal slope is present. For flat ponds, or deep ponds provide a gravel bottom. Side slopes can be planted with native and riparian species. To minimize landscape damage, avoid trees and shrubs in the bottom of the basin where significant sediment deposition is anticipated

5: Outlet/Overflow: Locate an outlet in less visible or screened areas. On larger facilities, locate a micro-pool, trash rack,and emergency spillway in less visible areas

6: Infiltration Matrix: Native soils in all but sand filter basins, which are to be designed with a sand layer and underdrain system in accordance with UDFCD Manual; Volume 3.

Maintenance

Extended detention basins have low to moderate maintenance requirements. Routine and non-routine maintenance is necessary to assure performance, enhance aesthetics, and protect structural integrity. The dry basins can result in nuisance complaints if not properly designed or maintained. Bio-degradable pesticides may be required to limit insect problems. Frequent debris removal and grass-mowing can reduce aesthetic complaints. If a shallow wetland or marshy area is included, mosquito breeding and nuisance odors could occur if the water becomes stagnant. Access to critical elements of the pond (inlet, outlet, spillway, and sediment collection areas) must be provided. The basic elements of the maintenance requirements are presented in **Table 8.13**

Table 8.13 Extended Detention Basin Maintenance Considerations

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Occasional mowing to limit unwanted vegetation. Maintain irrigated turf grass as 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from the entire pond to minimize outlet clogging and improve aesthetics.	Routine – Following spring runoff and following significant rainfall events.
Sediment removal from forebay and micro-pool	Remove accumulated sediment from the forebay and micro-pool. Dewatering of the micro-pool by pumping onto the EDB's bottom grasses and temporary diversion of all base flows will be needed to remove the accumulated sediment from micro-pool's bottom.	Routine – The sediment accumulations forebay and the micro-pool will need to be cleaned out every one to three years. Cleaning of micro-pool is important for mosquito control.

8.5.3.4 Sand Filter Extended Detention Basin

Figure 8.59 Turf grass over a Sand Filter Extended Detention Basin can serve as an informal play area during most of the year.

Description

A sand filter extended detention basin (SFB) is a stormwater filter that consists of a runoff storage zone underlain by a sand bed with an underdrain system. During a storm, accumulated runoff ponds in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The underdrain gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm sewer.

General Application

A SFB is generally suited to offline, onsite configurations where there is no base flow and the sediment load is relatively low.

Advantages/Disadvantages

Primary advantages of SFBs include effective water quality enhancement through settling and filtering. The primary disadvantage is a potential for clogging if a moderate to high level of silts and clays are allowed to flow into the facility. For this reason, it should **not** be put into operation while construction activities are taking place in the tributary catchment. Also, this BMP should not be located close to building foundations or other areas where expansive soils are a concern, although an underdrain and impermeable liner can ameliorate some of this concern.

Physical Site Suitability

Since an underdrain system is incorporated into this BMP, SFB is suited for about any site; presence of sandy sub-soils is not a requirement. This BMP has a relatively flat surface area, so it may be more challenging to incorporate it into steeply sloping terrain.

Pollutant Removal

Although not fully tested to date in the Denver area, the tests on filter vaults in the Denver area and other parts of United States show that the amount of pollutant removed by this BMP should be significant and should at least equal the removal rates by sand filters tested elsewhere.

Cold Weather Considerations

A sand filter will not function when the ground is frozen; therefore, it is important to have an overflow path. Storage volume may be diminished in the spring due to snow accumulation. Sand filters will clog quickly if exposed to moderate to high loads of sediments, so sand filters should not be used to treat areas that are sanded.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for an SFB.

1.	Basin Storage Volume	Provide a storage volume equal to 130 percent of the *WQCV* calculated using the method described in Section 8.4
2.	Basin Depth/Design	Maximum depth for the *Design Volume* shall be 3 feet.
3.	Filter's Surface Area	Calculate the minimum sand filter area (A_s) of the basin's bottom using: $A_s = 2V/9$, where V = detention volume
4.	Sand Media	Provide, as a minimum, an 18-inch layer of clean C-33 sand as shown in Figure 8.60. Maintain top surface flat. If side slopes need to be steeper than 3:1 (4:1 or flatter preferred), use vertical walls.
5.	Granular Base and Underdrains	Granular material shall have all fractured faces and meet the technical requirements of AASHTO #3, #4 or #67 aggregate (CDOT 703, #3, 4 or #67).
6.	Impermeable Membrane	When expansive or NRCS Type D soils are present, or when standard percolation tests show percolation drawdown rates exceeding 60 minutes per inch, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin. If vertical walls are permeable or of stacked blocks, extend the impermeable liner behind the walls. Wrap impermeable liners to top of the SFB basin and attach firmly with staples to the soil vertical wall using staples or concrete anchors.

Provide sufficient slack so that the liners are not stretched when rock and sand are placed. If tears are seen or discovered, repair them as recommended by manufacturer with no less than 18 inches of overlap on all sides of the tear.

7. Outlet Works — When underdrains are needed, the outlet works consists of 4" perforated HDPE pipe to convey water to the overflow outlet structure. Space perforated pipe on 20 foot centers or less. At the outlet of the HDPE pipe into the box, install an orifice sized to empty the WQCV above the sand in no less than 12 hours.

Provided an overflow outlet pipe out of the overflow structure to convey flows away from the filter basin when the runoff volume exceeds the *WQCV* at rates required by local jurisdiction to control the flood detention, typically the 10- and the 100-year storm.

8. Inlet Works — Provide an energy dissipating outlet for all inlet points into the SFB. Use an impact basin for pipes and a baffle chute or grouted sloping boulder drop if a channel or swale is used. Fill all rock voids with filter sand.

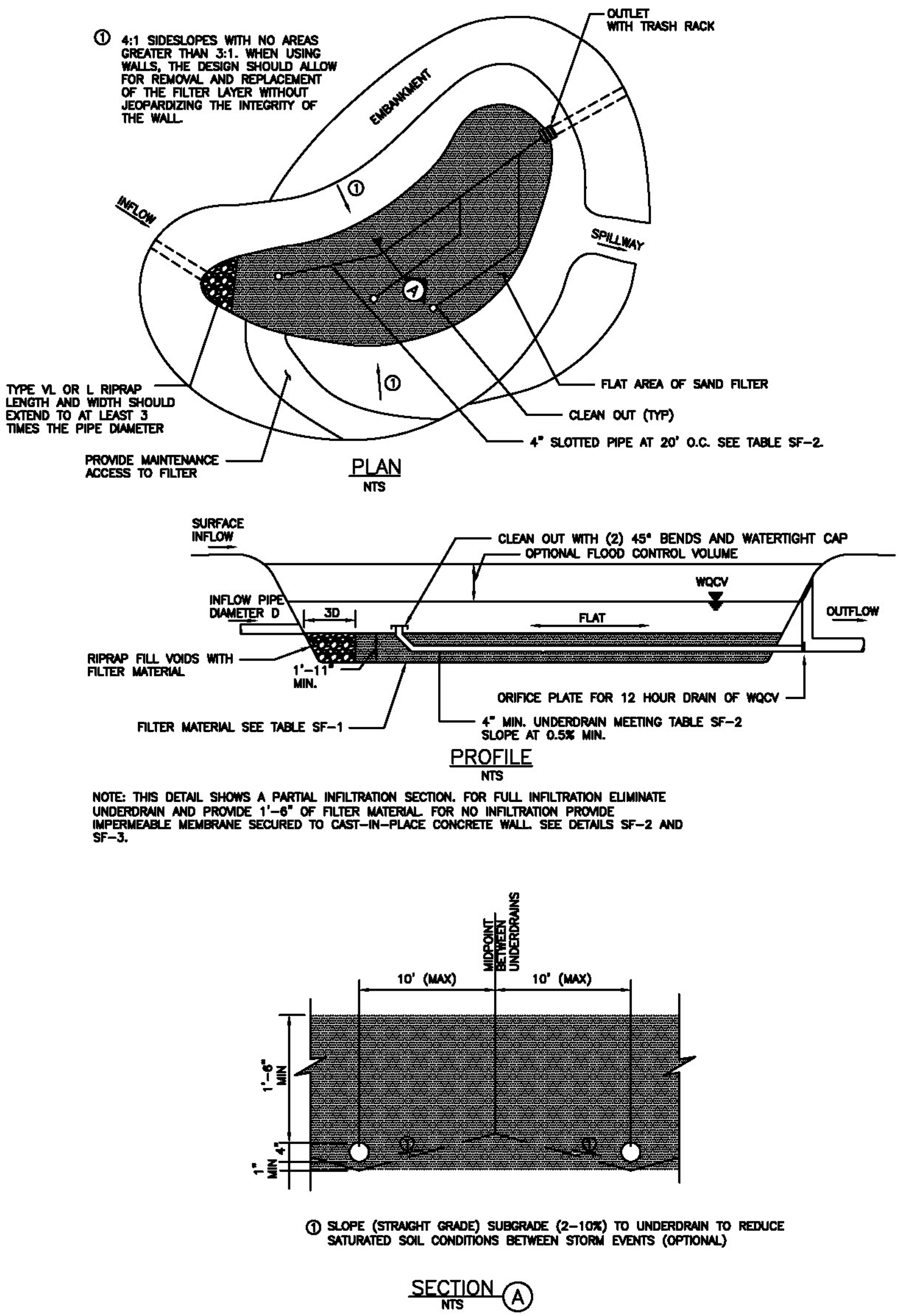


Figure 8.60 Sand Filter Typical Plan and Profile

Maintenance

Table 8.14 provides maintenance recommendations for SFBs.

Table 8.14 Sand Filter Extended Detention Basin Maintenance Recommendations

Required Action	Maintenance Objectives	Frequency
Debris and litter removal	Remove debris and litter from detention area to minimize clogging of the sand media.	Routine – Depending on aesthetic requirements.
Inspections	Inspect detention area to determine if the sand media is allowing acceptable infiltration. Also inspect the underdrain outlet if one is present, including the orifice plate to make sure it is there and in operating condition.	Routine – Every one to two years inspect for hydraulic performance. If possible, schedule these inspections within 24 hours after a significant rainfall.
Scarify filter surface	Scarify top 3 inches by raking the filter's surface.	Once per year or when needed to promote drainage.
Sand filter removal	Remove the top 3 inches of sand from the sand filter. After a second removal, backfill with 6 inches of new sand to return the sand depth to 18 inches. Minimum sand depth is 15 inches.	If no construction activities take place in the tributary watershed, every 2 to 5 years depending on observed drain times, namely when it takes more than 40 hours to empty 3-foot deep pool. Otherwise more often.

8.5.3.5 Modular Suspended Pavement System

Description

Modular suspended pavement systems (MSPS) provide support and rigidity for paved areas while allowing underneath soils to remain uncompact. A MSPS is a series of modular units or "cells" that are assembled together to create an interconnected skeletal matrix. This subgrade matrix supports concrete, asphalt, or pavers as well as pedestrian and traffic loads. Each cell frame is filled with uncompacted soil. Trees are planted in tree grates or planting strips adjacent to the system. Tree roots are free to move through the cell system without being impeded by dense, compacted soil which is required for traditional pavement subsoil. A healthy tree root network supports healthy, large tree growth. In addition to healthy tree growth, MSPS's can be utilized for stormwater management through a treatment train approach. Through interception, absorption, evapotranspiration and infiltration the system treats stormwater runoff. Stormwater runoff from impervious surfaces enters the MSPS through perforated pipes or permeable pavers. The uncompact soil absorbs the runoff which is then utilized by the adjacent trees. What is not picked up by tree roots infiltrates into deeper subsoils helping to replenish the water table.

General Application

MSPS are utilized to enhance stormwater runoff by treating a portion of the WQCV. A treatment train approach must be applied with MSPS as this BMP is not capable of treating large sediment loads without clogging. Pretreatment is required for the use of MSPS. The MSPS system is in place as a volume storage BMP to contain runoff and promote infiltration. MSPS as a standalone BMP is not applicable for sediment pollutant removal.

Traditional trees surrounded by pavement tend to have a lifespan of approximately 13 years. This is due to the fact that urban trees in tree grates have less than 1/10th of the rooting volume necessary for trees to thrive. With a lifespan of only 13 years the trees die before they can provide significant ecological benefits. Trees planted with sufficient uncompacted soil tend to live upwards of 50 years. This time period allows trees to grow and mature, providing more ecological benefit to the surrounding area.

Advantages/Disadvantages

The advantage of a MSPS system is to treat stormwater runoff while promoting healthy tree growth. The system can be installed in urban areas where pervious area is limited as it resides underneath sidewalks, patios, and roads, thus requiring no additional area. MSPS's have the potential to treat runoff from streets via curb cuts and gutter inlets. Another advantage is tree shade has been correlated with better pavement performance and reduced maintenance.

The disadvantages of MSPS's are if not properly installed or maintained, runoff may not infiltrate causing issues with odor and mosquitoes. MSPS are not effective in high pollutant areas where debris will clog the system and kill the trees and if the system does become clogged it might be difficult and costly to replace. A major disadvantage if fines can easily enter the system and will remain in the system until maintenance is performed. Due to the sediment load constraints MSPS require a pre-filter so as not to clog the system with fines.

Physical Site Suitability

MSPS's are suited for urban areas where impervious area is limited and stormwater management must be done subgrade below pavement. The systems are designed for areas where trees are desired but there is minimal access to uncompacted soils. MSPS's provide an alternative to traditional tree grates which limit root zones and tree growth.

MSPS's can be installed adjacent to streets with curb and gutter. Curb cuts or inlets and perforated pipes provide an access point for street runoff from the gutter to enter the MSPS system. This street runoff is then treated by the system.

MSPS's are utilized is Aspen's downtown area where there is no landscaping strip and where tree grates have traditionally been installed.

Pollutant Removal

Modular suspended pavement systems remove pollutants through soil filtration and plant uptake. Studies show 80% removal of phosphorous, 60% removal of Total Kjeldahl Nitrogen, and 90% removal of heavy metals such as lead, copper, and zinc.

Cold Weather Considerations

The MSPS effectiveness drops significantly during the winter months. When trees go dormant there is little to no water uptake. Without plant uptake the only runoff treatment is accomplished through infiltration. During even colder parts of the year when the ground and system is frozen, there is little infiltration the system effectiveness decreases even more.

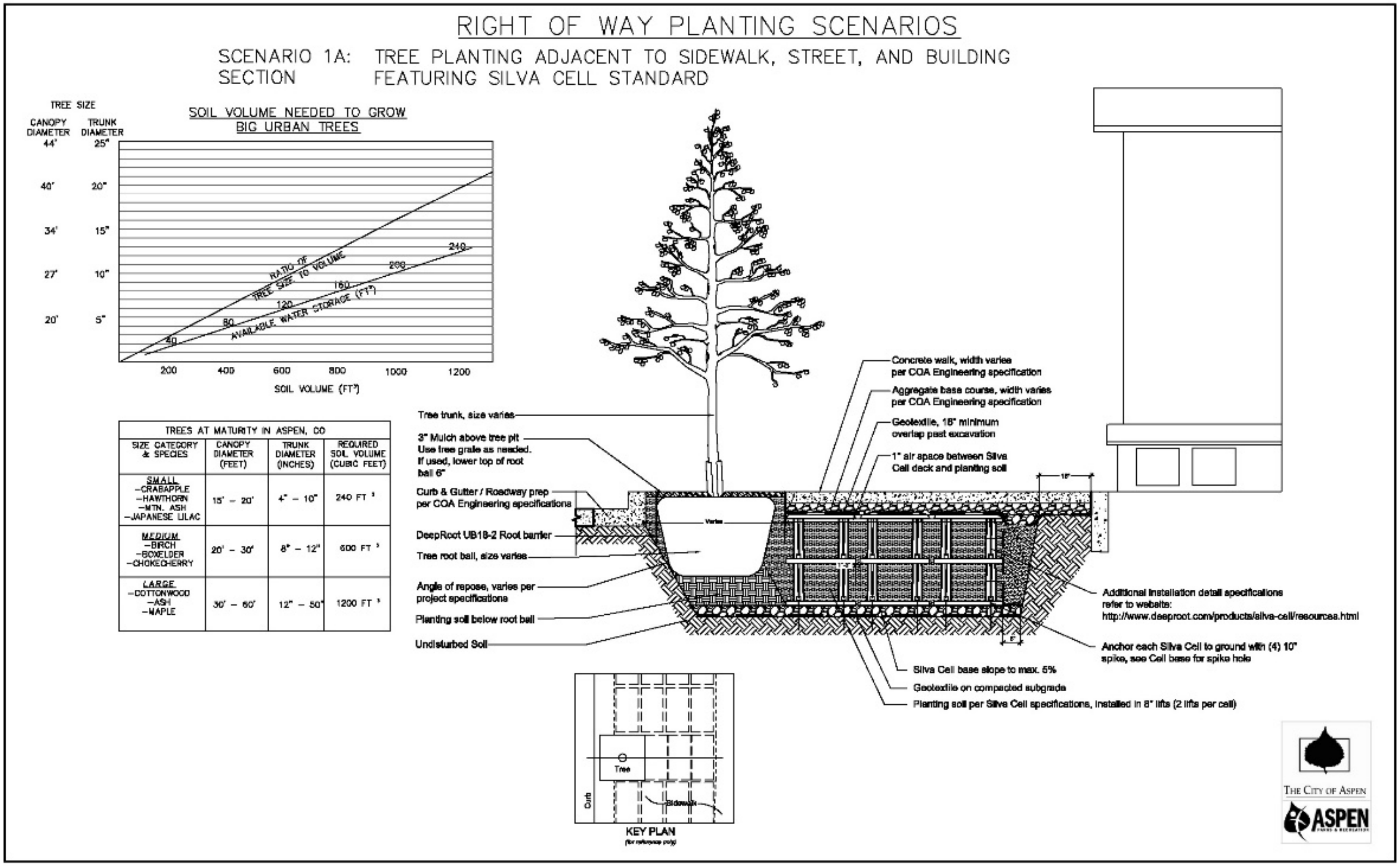
Design Considerations

There are many design considerations and site constraints that should be taken into account for the design of and MSMS system. MSPS's are able to work in conjunction with pervious pavers. Pavers over the system allow runoff to infiltrate over the entire area. If the system is placed in close proximity to a structure, a waterproof liner must be installed along the foundation and extended 10' away from the structure. A perforated underdrain can be placed within the system to distribute runoff throughout. Pipe cleanouts must be provided for any subsurface pipe.

If infiltration rates are low, if the system does not have an outlet, or if the system is located next to a building, a gravel sump pit may be required at the base of the system to provide additional volume area and to draw runoff away from the root zone. If too much water sits in the root zone for an extended period of time there is potential for root rotting.

If a curb inlet is incorporated into the system, and outlet should be provided. This could include tying the system in to another curb inlet further downstream.

A pre-filter is required for all systems with a tributary area high in sediment loading. This includes all streets and gutters. The system shall only be installed in areas where there is no conflict with other utilities. Tree openings should be as large as possible.



TREES AT MATURITY IN ASPEN, CO			
SIZE CATEGORY & SPECIES	CANOPY DIAMETER (FEET)	TRUNK DIAMETER (INCHES)	REQUIRED SOIL VOLUME (CUBIC FEET)
SMALL –CRABAPPLE –HAWTHORN –MTN. ASH –JAPANESE LILAC	15' – 20'	4" – 10"	240 FT³
MEDIUM –BIRCH –BOXELDER –CHOKECHERRY	20' – 30'	8" – 12"	600 FT³
LARGE –COTTONWOOD –ASH –MAPLE	30' – 60'	12" – 50"	1200 FT³

Figure 8.61 Right of Way Planting Scenario 1

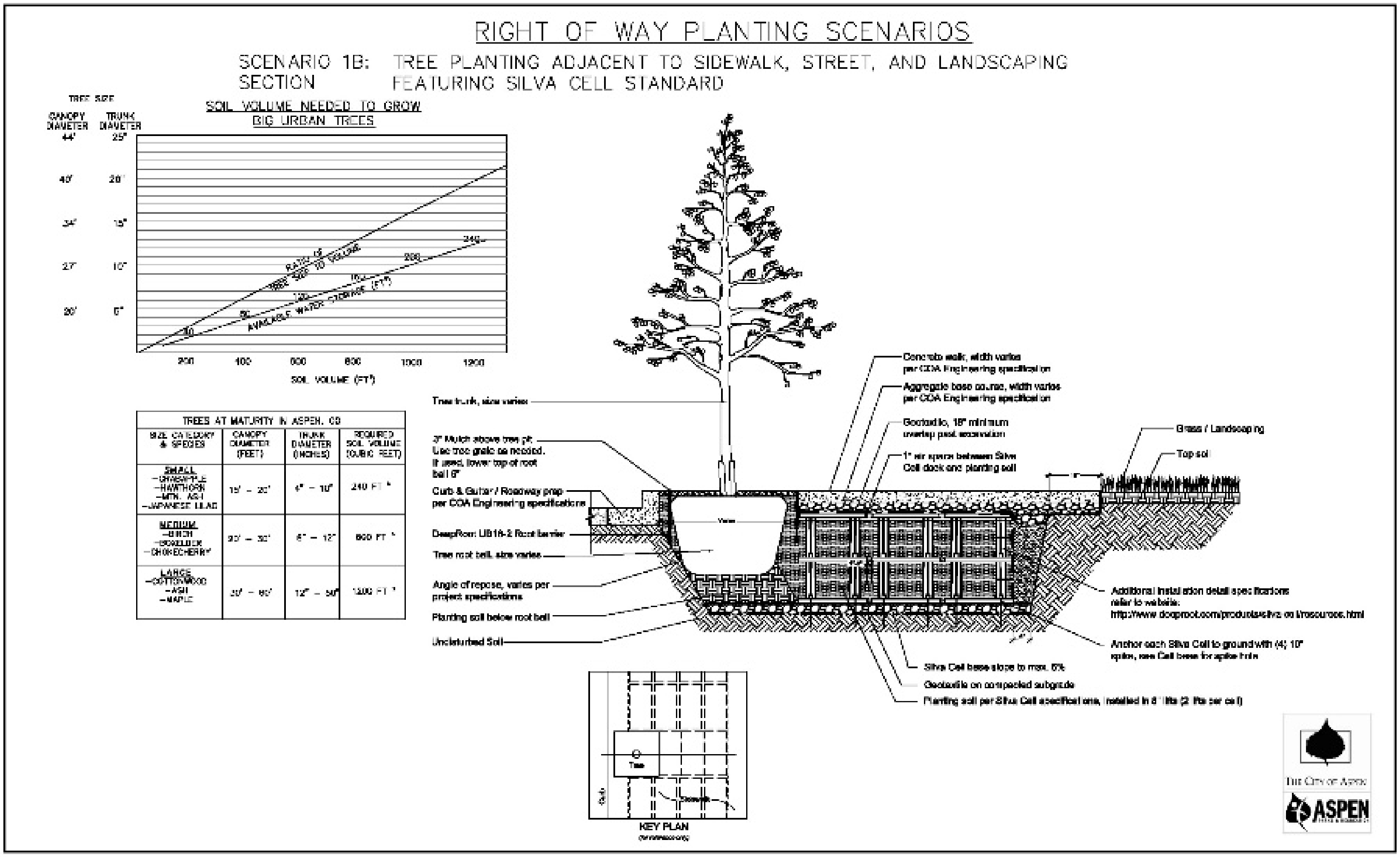


Figure 8.62 Right of Way Planting Scenario 1B

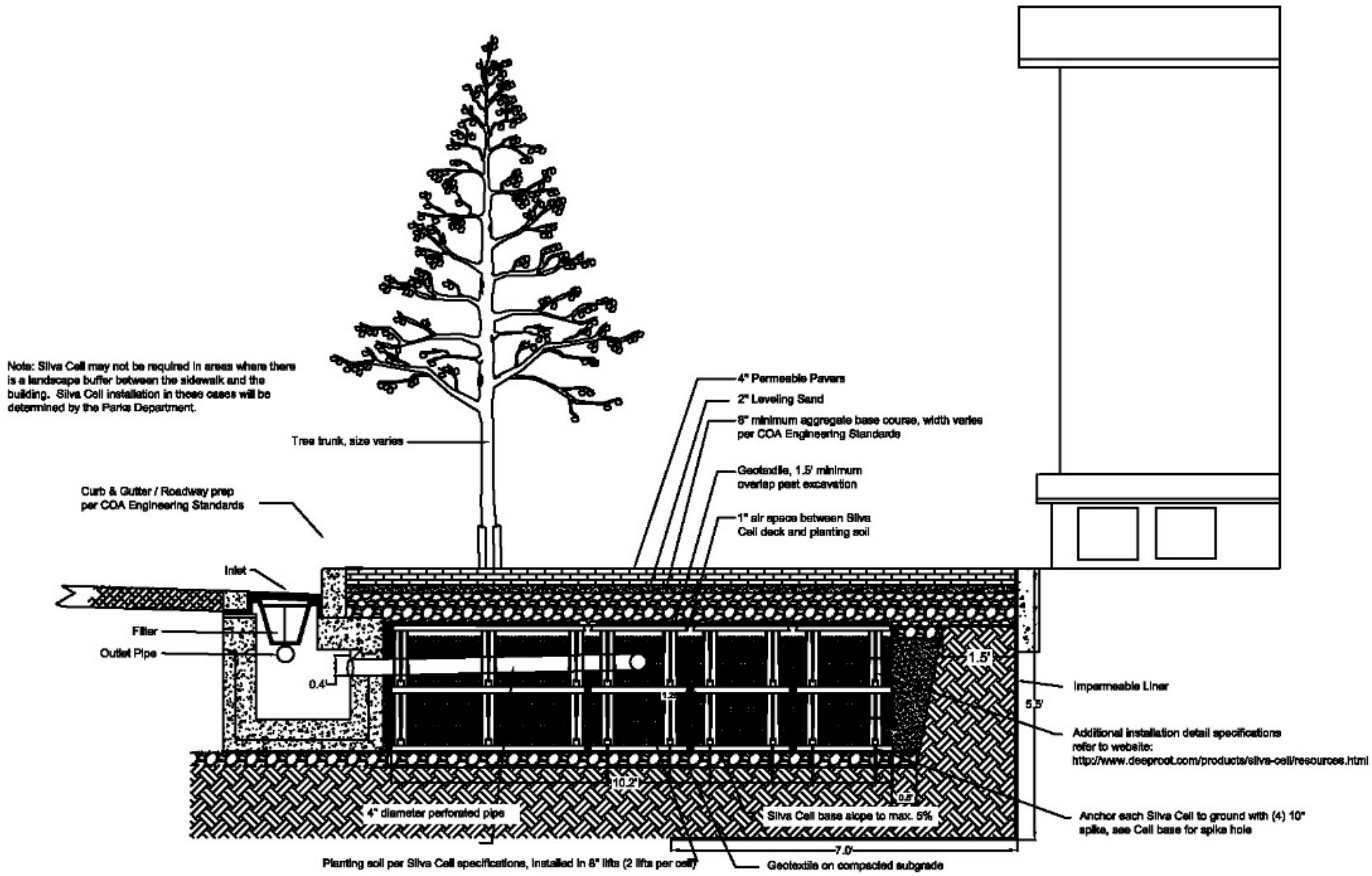


Figure 8.63 MSPS with Inlet

Design Procedure and Criteria

1. Basin Storage Volume - Determine WQCV for tributary area using the procedure described in Section 8.4.
2. System Volume - Determine according to manufacturer's specs the available volume in each MSPS cell. Ensure there are enough MSPS cells to provided adequate volume for the WQCV. Each cell holds 10 cf of soil and able to hold 2 cf of runoff within the void space.
3. Tree placement - Determine the number of trees for the proposed sight. 1,000 cf of soil is recommended for canopy trees while 600 cf is recommended for understory trees. Trees are able to share volume space. It is cost effective to link tree to each other or other soil volumes.
4. Vertical Dimension – MSPS come in a series of cells that can be stacked on top of each other up to three levels. During the design process determine the depth of the system and how many cell levels will be installed. Keep in mind the location of nearby utilities.
5. Structure waterproofing – An impermeable liner must be installed along any foundations of structures within 10' of the MSPS system.
6. Cell Placement – Determine the cell placement. Due to surrounding constraints the proposed plan must show the dimensions and placement of each individual cell in order to avoid spacing conflicts during construction. This also must be done to determine the number of cells to be purchased. It is not adequate to call out MSPS over an overall area.
7. System Uptake – Determine how runoff will enter the system, through modified curb cuts, inlets, piping or pervious pavers. Due to snow plowing operations traditional curb cuts and chases are discouraged within the COA and are not an allowable means to direct street runoff into a MSPS. Modified curb cuts and inlets should be discussed with the COA Engineering Department. Potential designs include smaller and/or reinforced curb openings.
8. Street Runoff Treatment – If runoff treatment for the adjacent street is to be incorporated into the system provide either a modified curb cut or an inlet box and outlet point for the MSPS system. Determine the WQCV of the street tributary basin. Determine the runoff volume that will be treated by the MSPS system and how much runoff will bypass the system. Inlets with a pretreatment filter are the recommended method to direct street runoff into the MSPS system. Direct runoff from the gutter toward curb cuts by placing diagonal cuts within the flowline.
9. Pipe placement– Determine if an underdrain will be utilized to spread runoff throughout the system. If an underdrain is utilized provide a pipe cleanout.
10. Determine if a gravel sump will be necessary beneath the MSPS system. If infiltration rates are low, if the system does not have an outlet, or if the system is located next to a building, a gravel sump pit may be required at the base of the system to provide additional volume area and to draw runoff away from the root zone. If too much water sits in the root zone for an extended period of time there is potential for root rotting.

Maintenance

Any underdrains must be periodically cleaned by way of the pipe clean out.

Tree grates connected to street gutters via modified curb cuts should be monitored and maintained. Any accumulated sediment and debris should be removed periodically and cleaned out after any big storm events. At least once a year the top layer of soil should be scarified and every few years removed and replaced.

If it is observed that the system is not draining and the soil remains wet for extended periods of time the system may need to be replaced. Excavate down to the existing bottom elevation and scrape the bottom layer to remove any fines in the system.

8.5.3.6 Constructed Wetland Basin

Figure 8.64 Large wetlands can provide regional stormwater treatment and detention as well as create valued habitat. The forebay and pond, shown here, dissipates stormwater velocities and allows larger particles to settle

Figure 8.65 A small wetland pond can be an added amenity to a development.

Description

A constructed wetlands basin (CWB) is a shallow retention pond (RP), which requires a perennial base flow to permit the growth of rushes, willows, cattails, and reeds to slow down runoff and allow time for sedimentation, filtering, and biological uptake. It is a sedimentation basin and a form of a treatment plant.

A CWB differ from "natural" wetlands as they are totally human artifacts that are built to enhance stormwater quality. Sometimes small wetlands that exist along ephemeral drainageways on Colorado's high plains could be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

Current regulations intended to protect natural wetlands recognize a separate classification of wetlands constructed for a water quality treatment. Such wetlands generally are not allowed on receiving waters and cannot be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality treatment, such as the CWB, is separate from the disturbance of a natural wetland. Nevertheless, the U.S. Army Corps of Engineers has established maximum areas that can be maintained under a nationwide permit. Thus, any activity that disturbs a constructed wetland should be first cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

General Application

A CWB can be used as a follow-up structural BMP in a watershed or as a stand-alone onsite facility if the owner provides sufficient water to sustain the wetland. Flood control storage can be provided above the CWB's water quality capture volume (WQCV) pool to act as a multiuse facility.

Advantages/Disadvantages

A CWB offers several potential advantages, such as natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. It can also provide an effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles. In other words, it offers yet another effective structural BMP for larger tributary catchments.

The primary drawback of the CWB is the need for a continuous base flow to ensure viable wetland growth. In addition, silt and scum can accumulate and unless properly designed and built, can be flushed out during larger storms. In addition, in order to maintain a healthy wetland growth, the surcharge depth for WQCV above the permanent water surface cannot exceed 2 feet.

Along with routine good housekeeping maintenance, occasional "mucking out" will be required when sediment accumulations become too large and affect performance. Periodic sediment removal is also needed for proper distribution of growth zones and of water movement within the wetland.

Physical Site Suitability

A perennial base flow is needed to sustain a wetland, and should be determined using a water budget analysis. Loamy soils are needed in a wetland bottom to permit plants to take root. Exfiltration through a wetland bottom cannot be relied upon because the bottom is either covered by soils of low permeability or because the groundwater is higher than the wetland's bottom. Also, wetland basins require a near-zero longitudinal slope, which can be provided using embankments.

Pollutant Removal

Primary variables influencing removal efficiencies include design, influent concentrations, hydrology, soils, climate, and maintenance. With periodic sediment removal and routine maintenance, removal efficiencies for sediments, organic matter, and metals can be moderate to high; for phosphorous, low to high; and for nitrogen, zero to moderate. Pollutants are removed primarily through sedimentation and entrapment, with some of the removal occurring through biological uptake by vegetation and microorganisms. Without a continuous dry-weather base flow, salts and algae can concentrate in the water column and can be released into the receiving water in higher levels at the beginning of a storm event as they are washed out.

Researchers still do not agree whether routine aquatic plant harvesting affects pollutant removals significantly. Until research demonstrates and quantifies these effects, periodic harvesting for the general upkeep of wetland, and not routine harvesting of aquatic plants, is recommended.

Cold Weather Considerations

Primary cold weather considerations for constructed wetlands are similar to those noted for EDBs. In addition, the shorter growing season in cold climates like Aspen mean a shorter window for biological benefits of these BMPs. Care should be taken in timing the planting of constructed wetlands basins so that plant establishment is successful.

Design Considerations

Figure 8.66 illustrates an idealized CWB. An analysis of the water budget is needed to show the net inflow of water is sufficient to meet all the projected losses (such as evaporation, evapotranspiration, and seepage for each season of operation). Insufficient inflow can cause the wetland to become saline or to die off.

Design Procedure and Criteria

The following steps outline the design procedure for a CWB.

1. Basin Surcharge Storage Volume — Calculate the WQCV based on the guidance provided in **Section 8.4**.

2. Wetland Pond Depth and Volume — The volume of the permanent wetland pool shall be no less than 75% of the WQCV found in Step 1.

   Proper distribution of wetland habitat is needed to establish a diverse ecology. Distribute pond area in accordance with the following:

Components	Percent of Permanent Pool Surface Area	Water Design Depth
Forebay, outlet and free water surface areas	30% to 50%	2 to 4 feet deep
Wetland zones with emergent vegetation	50% to 70%	6 to 12 inches deep*
*One-third to one-half of this zone should be 6 inches deep.		

3. Depth of Surcharge WQCV — The surcharge depth of the WQCV above the permanent pool's water surface shall not exceed 2.0 feet.

4. Outlet Works — Provide outlet works that limit WQCV depth to 2 feet or less. Use a water quality outlet that is capable of releasing the WQCV in no less than a 12-hour period. Refer to the Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual for schematics pertaining to structure geometry; grates, trash racks, and screens; outlet type: orifice plate or perforated riser pipe; cutoff collar size and location; and all other necessary components.

5. Trash Rack — Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Size the rack so as not to interfere with the hydraulic capacity of the outlet. Refer to the Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual for trash rack criteria.

6. Basin Use — Determine if flood storage or other uses will be provided for above the wetland surcharge storage or in an upstream facility. Design for combined uses when they are to be provided for.

7. Basin Shape — Shape the pond with a gradual expansion from the inlet and a gradual contraction to the outlet, thereby limiting short circuiting. Try to achieve a basin length to width ratio between 2:1 to 4:1. It may be necessary to modify the inlet and outlet point through the use of pipes, swales, or channels, to accomplish this. Always maximize the distance between the inlet and outlet.

8. Basin Side Slopes — Basin side slopes are to be gentle and stable to facilitate maintenance and access. Side slopes should be no steeper than 4:1, preferably 5:1 or flatter.

9. Base Flow — A net influx of water must be available throughout the year that exceeds all of the losses. The following equation and parameters can be used to estimate the net quantity of base flow available at a site:

$$Q_{net} = Q_{Inflow} - Q_{Evap} - Q_{Seepage} - Q_{E.T.}$$

Where:

Q_{Net} = Net quantity of base flow (acre-ft/year)

Q_{Inflow} = Estimated base flow (acre-ft/year) (Estimate by seasonal measurements and/or comparison to similar watersheds)

Q_{Evap} = Loss attributed to evaporation less the precipitation (acre-ft/year) (Computed for average water surface)

$Q_{Seepage}$ = Loss (or gain) attributed to seepage to groundwater (acre-ft/year)

$Q_{E.T.}$ = Loss attributed to plant evapotranspiration (computed for average plant area above water surface, not including the water surface)

10. Inlet/Outlet Protection — Provide a means to dissipate flow energy entering the basin to limit sediment resuspension. Outlets should be placed in an outlet bay that is at least 3 feet deep. The outlet should be protected from clogging by a skimmer shield that starts at the bottom of the permanent pool and extends above the maximum capture volume depth.

11. Forebay Design — Provide the opportunity for larger particles to settle out in an area that has a solid driving surface bottom for vehicles to facilitate sediment removal. The forebay volume of the permanent pool should be 5 to 10 percent of the design water quality capture volume.

12. Vegetation — Refer to **Appendix E** for general planting criteria and plant species specific to Aspen and BMPs

13. Maintenance Access — Provide vehicle access to the forebay and outlet area for maintenance and removal of bottom sediments. Maximum grades should not exceed 10 percent, and a stabilized, all-weather driving surface needs to be provided. Provide a concrete or grouted boulder lined bottom and side-slopes under water in the forebay area to define sediment removal limits and permit heavy equipment to operate within them.

Maintenance

Table 8.15 provides maintenance recommendations for CWBs.

Table 8.15 Maintenance Recommendations for Constructed Wetlands Basin

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Mow occasionally to limit unwanted vegetation. Maintain irrigated turf grass at 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from entire pond to minimize outlet clogging and aesthetics. Include removal of floatable material from the pond's surface.	Routine – Including just before annual storm seasons (that is, in April and May) and following significant rainfall events.
Sediment removal	Remove accumulated sediment and muck along with much of the wetland growth. Re-establish growth zone depths and spatial distribution. Revegetate with original wetland species.	Non-routine – Every 10 to 20 years as needed by inspection if no construction activities take place in the tributary watershed. More often if they do. Expect to clean out forebay every 1 to 5 years.
Aquatic plant harvesting	Cut and remove plants growing in wetland (such as cattails and reeds) to remove nutrients permanently with manual work or specialized machinery.	Non-routine until further evidence indicates such action would provide significant nutrient removal. In the meantime, perform this task once every 5 years or less frequently as needed to clean the wetland zone out.
Inspections	Observe inlet and outlet works for operability. Verify the structural integrity of all structural elements, slopes, and embankments.	Routine – At least once a year, preferably once during one rainfall event resulting in runoff.

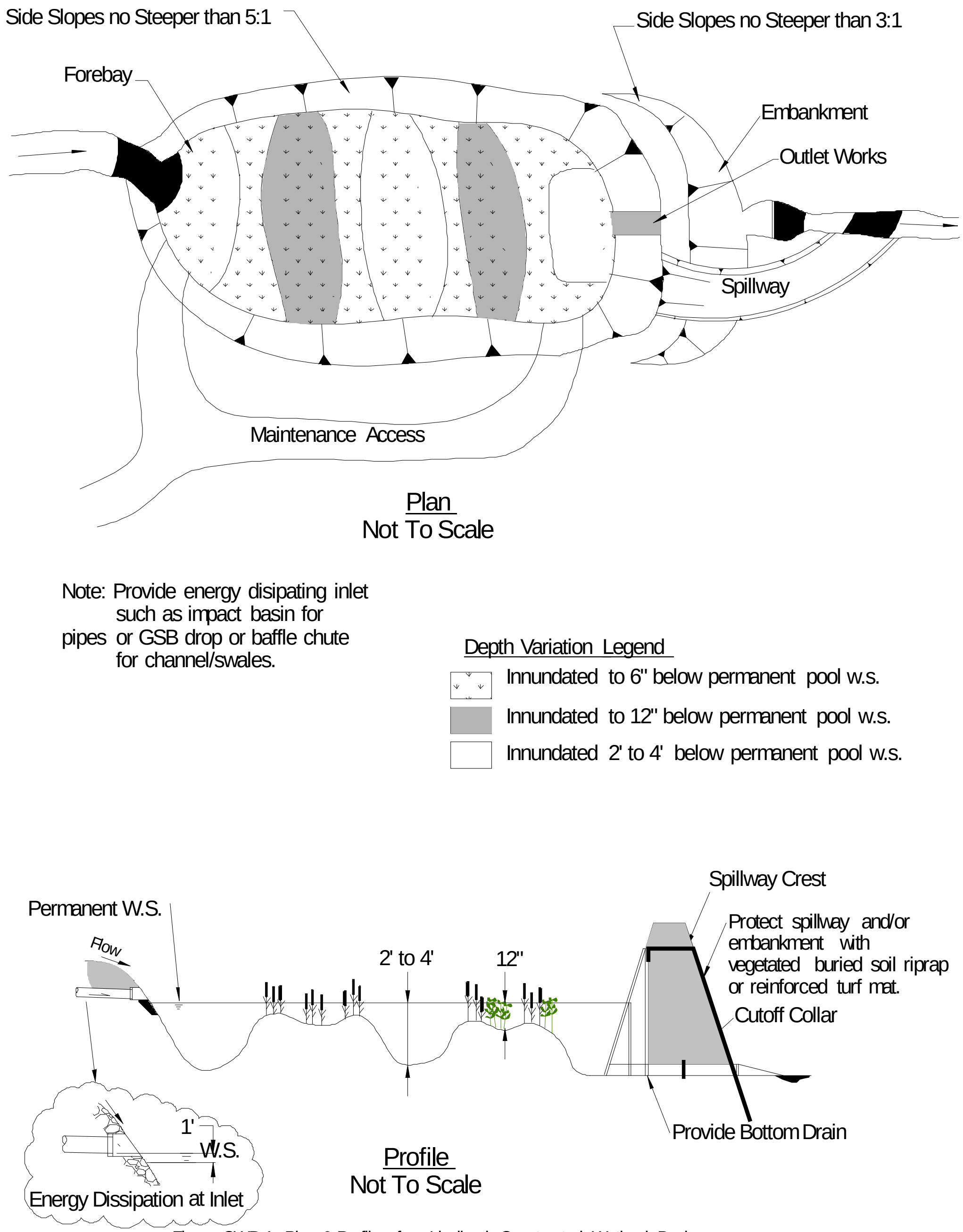


Figure CWB-1 Plan & Profile of an Idealized Constructed Wetland Basin

Figure 8.66 Constructed Wetland Basin – Plan and Cross-Section

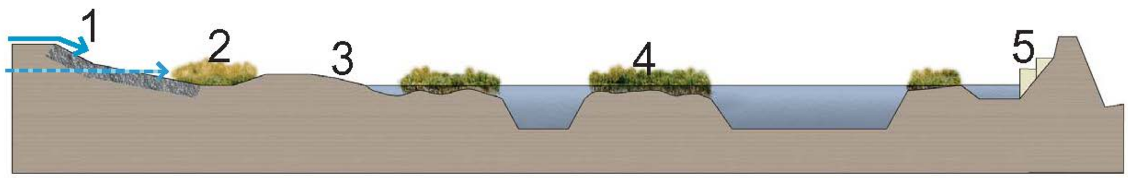


Figure 8.67 Typical Constructed Wetland Basin Design Sketch

1: Inlet: Dissipate energy at inlets to prevent erosion and sediment re-suspension.

2: Sediment Trap: Provide a sediment forebay to remove larger sediment particles. Provide access for routine maintenance

3: Slopes: Side slopes are generally 4:1 or flatter for safety and maintenance. Provide a safety bench slope at 10:1 to a depth of 18” below normal water level for ponds.

4: Vegetation: Should consist of native grasses, rushes, willows, cattails and reeds. Refer to Appendix E for a list of appropriate plant species.

5: Outlet/Overflow: Provide a micropool, outlet structure, and overflow weir designed to withstand necessary flow velocities.

6: Infiltration Matrix: Infiltration through pond areas is not appropriate; requires soils with low permeability. In areas with permeable soils, and impervious linear may be necessary to retain stormwater

8.5.4 Sub-surface BMPs

The general policy of the City of Aspen is that subsurface BMPs are acceptable as long as they meet the City’s water quality criteria of 80th percentile treatment and > 90 percent removal of particles 60 microns and larger. Subsurface BMPs designed and sized in accordance with methods above for volume-based BMPs will be presumed to meet this objective. Inspection and maintenance for sub-surface BMPs must be rigorous (minimum yearly requirement) with reporting to City.

For proprietary BMPs, design engineers and/or manufacturers must provide actual field data to substantiate performance if they do not meet the volume and drain time requirements in this Chapter.

8.5.4.1 Subsurface Sedimentation/Filtration Vaults

Subsurface sedimentation/filtration vaults that meet the criteria in Section 8.4 for the WQCV and allowable drain time may be used for water quality treatment in Aspen provided that they are inspected and maintained yearly at a minimum. Because underground systems may be pumped and because historically, there have been problems with re-suspension of sediments in underground vault systems, a multi-chambered treatment approach is required. Biological/vegetation based BMPs are not feasible underground, limiting options for storage-based BMPs to extended detention and sand-filtration. Because of the potential to pump out or scour bottom sediments, sand-filtration is the primary recommended non-proprietary underground treatment method for the City of Aspen.

At a minimum, an underground sand filter shall meet the following requirements:

1. A pretreatment chamber for removal of course sediments with a volume equivalent to 0.30 times the WQCV calculated according to Section 8.4 must be provided. This must be separated from the sand filter chamber by baffling.

2. The sand filter chamber shall have a surcharge (i.e. above the filter media) volume equivalent to the WQCV.

3. Material specifications, depth and area parameters shall be the same as for an above ground sand filter basin (**Section 8.5.3.4**).

4. Where discharges from the BMP will be pumped, a separate outlet chamber is required from which the water passing through the filter layer can be pumped. The outlet pump shall be sized to discharge at a rate not to exceed the WQCV/12 hours.

5. If detention storage is also provided underground, it shall be in a separate vault. A diversion shall be sized so that flows in excess of the WQCV are diverted to the detention chamber and the underground sand filter is not surcharges (in terms of depth or hydraulic grade line) beyond the WQCV maximum elevation.

6. Maintenance access must be provided to each chamber. Access must be sufficient to allow complete removal of the filter material, if necessary.

Figure 8.68 illustrates a typical underground sand filter.

Table 8.16 provides maintenance requirements for underground sand filters.

Table 8.16 Underground Sand Filter Maintenance Requirements

Required Action	Maintenance Objective	Frequency of Action
Inspection	Monitor water level and accumulation of sediments in chambers.	Quarterly and following all rainfall events >0.25 inches.
Scarify filter surface	Scarify top 3 inches by raking the filter's surface.	Once per year or when needed to promote drainage.
Sand filter removal	Remove the top 3 inches of sand from the sand filter. After a second removal, backfill with 6 inches of new sand to return the sand depth to 18 inches. Minimum sand depth is 15 inches.	If no construction activities take place in the tributary watershed, every 2 to 5 years depending on observed drain times, namely when it takes more than 12 hours to empty 3-foot deep pool. Otherwise more often.

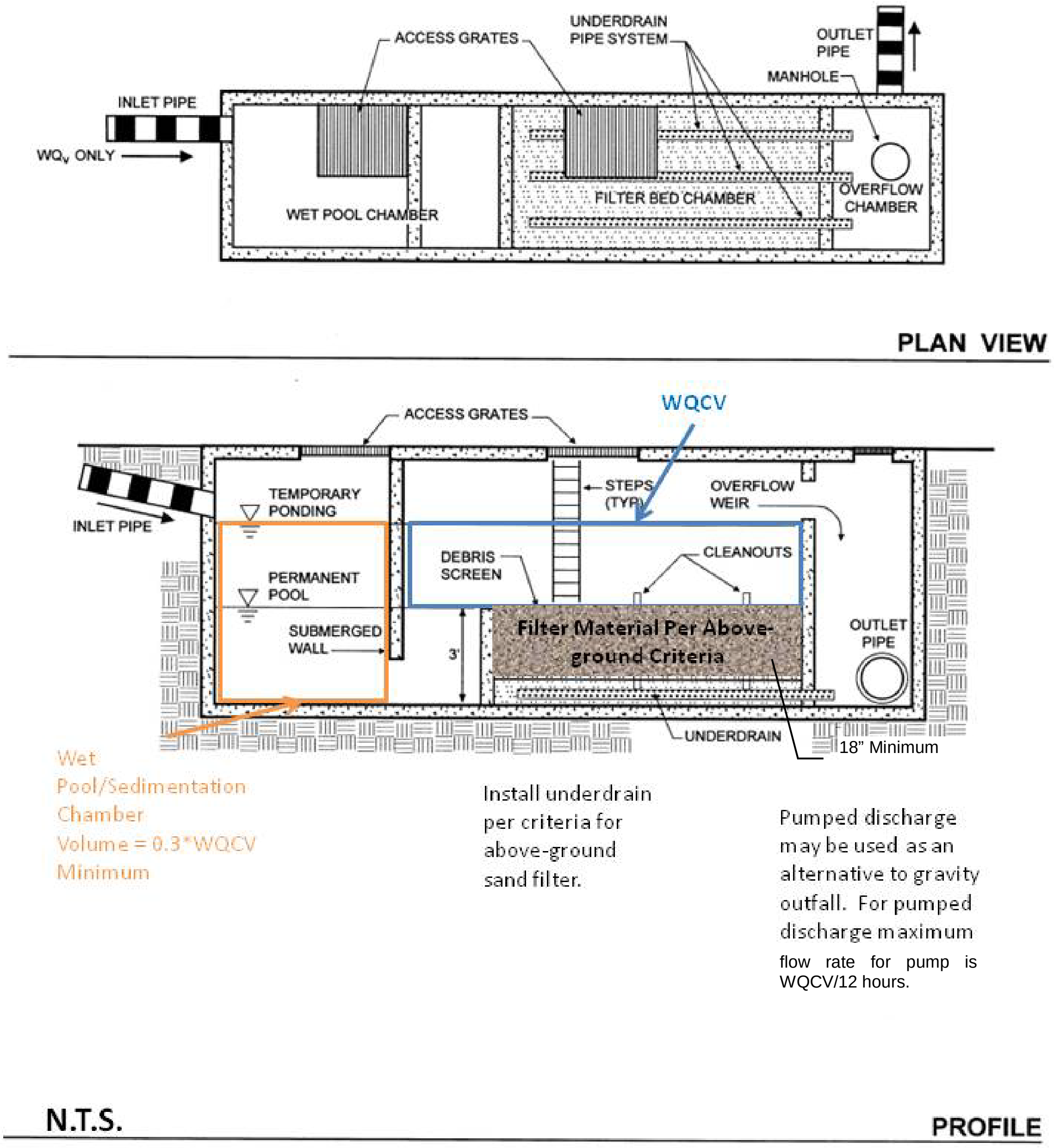


Figure 8.68 Typical plan and Profile for Underground Sand Filter (Source: Center for Watershed Protection with modifications)

8.5.4.2 Dry Wells

Description

Dry wells may be used to collect, detain, and percolate runoff for individual residences and for commercial development for which a standard detention pond or discharge to the City's stormwater collection system is infeasible. The applicant will need to provide evidence of such infeasibility to the City Engineer for review. Dry wells typically collect runoff from the entire impervious area of a new development. Therefore, the dry well is a type of storm management practice that can satisfy the goal of maintaining the predevelopment runoff characteristics of a drainage basin. However, dry wells may also create groundwater contamination problem. Dry wells cannot be used in conjunction with certain land uses and activities that may produce soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some polycyclic aromatic hydrocarbons.

General Application

Dry wells should be considered a BMP of last resort. In areas where other BMPs are infeasible, dry wells may be considered. They are not appropriate for treating runoff containing moderate to high levels of sediment. They may be acceptable for treatment of runoff from roofs, and un-sanded sidewalks drives and pedestrian areas.

Advantages/Disadvantages

In general, dry wells have the following advantages:

- Dry well facilities have an ability to capture surface water runoff and filter it through the ground.
- Dry well facilities will improve or increase ground water recharge capacity.
- Dry well facilities will reduce thermal impacts on fisheries.
- Dry well facilities will augment low flow stream conditions.

The disadvantages of dry wells are well known include the following:

- Since dry wells rely on infiltration into the surrounding soils, clogging can be a major problem. As a dry well or the surrounding soils becomes clogged, the dry well will exhibit decreased ability to infiltrate water. Signs of reduced infiltration include longer periods of standing water in the well and overflow from the well from smaller than expected events. Sediment loads to dry wells should be closely managed since this is the primary cause of clogging. Runoff with sediment concentrations that are moderate to high should be excluded from dry wells (for example, runoff from landscape areas, roads and/or areas with ground disturbance.

- Because of the potential for clogging over time, conservative criteria must be used for sizing of dry wells. **When sizing a drywell to capture WQCV, the volume must be calculated at 1.5 times the WQCV**. **If a drywell is to be utilized for detention in addition to water quality, the entire runoff volume of the design storm shall be captured.** Refer to the Design Procedure and Criteria for proper drywell detention sizing

- Frequent inspection and maintenance are necessary to maintain performance and to preemptively detect changes in performance.

- Dry wells may not be used in areas that receive runoff from areas with pollutants that have the potential to contaminate groundwater including many dissolved constituents.

Physical Site Suitability

Dry wells remain a viable treatment option in Aspen in areas where soils have high infiltration capacity. Restrictions on use of dry wells include the following:

- Dry wells may not be used if seasonal high groundwater is less than 5 feet below the bottom of the well.
- Dry wells may not be used in areas where sanding occurs.
- Suitable sources of runoff for dry wells include roofs, residential lots, un-sanded drives and sidewalks.
- Pre-treatment for sediment removal is required (see Street BMPs in **Section 8.5.2**).
- Dry wells are not applicable in areas where pollutant loadings have potential for groundwater contamination. Dry wells are considered Class V Injection Wells under the Environmental Protection Agency Underground Injection Control Program. Appropriate permitting, which typically includes providing documentation of the dry well location and characteristics, is the responsibility of the applicant proposing the dry well.
- Dry wells may not be used where the infiltration surface is on top of fill.
- Dry wells must be located at least 10 feet from building foundations. The design engineer shall evaluate potential impacts of infiltrated runoff on nearby foundations even when spacing from the foundation is greater than 10 feet.
- Use of a dry well is limited to areas with soils with minimum percolation rate of 3 inches per hour. Slower percolating soils are not suitable or practical for drywell systems.

Pollutant Removal

Performance data for dry wells is not widely available. There have been instances of documented groundwater contamination when runoff with soluble pollutants has been directed to dry wells. A properly designed and maintained dry well, sited with due attention to underlying soils and groundwater, can be a very effective runoff reduction BMP.

Cold Weather Considerations

Dry wells will not infiltrate runoff as designed if the surrounding ground is frozen; therefore, it is essential that the infiltration portion of the dry well be located below the frost line. In addition, dry wells have the potential to introduce very cold air into the underground chamber in the winter, creating the potential for freezing underground water and sewer lines if adequate separation is not provided.

Design Considerations

Figure 8.57 shows a typical dry well. Dry wells must be a minimum of 10 feet deep and the water level from the design storm runoff must not rise above 6 inches below the ground surface. The bottom section of the well casing, conventionally known as the barrel section, is perforated concrete wall surrounded by gravel backfill and filter fabric. A percolation or hydraulic conductivity test must be submitted to the City showing that the soil will drain the runoff volume in 24 hours.

The expected fluctuation in ground water levels must also be submitted to show that a normal rise in ground water will not impede the infiltration of runoff through the dry well.

Overflow pipes may be incorporated into a drywell detention design. The lot or property must be graded to allow possible overflows to drain to a local conveyance facility without crossing adjacent properties or damaging property.

Runoff from vehicular areas must be pretreated before entering drywell.

Drywells are not permitted in parking lots, garages, or interior drains.

Design Procedure and Criteria

1. Dry Well Volume

   *Note: The COA will permit the void space of gravel up to 2' surrounding a drywell to count towards drywell volume. Gravel which is installed beyond 2' of the drywell shall not be counted as additional drywell volume.

   Water Quality Capture Volume:

   Drywells designed to capture and treat the WQCV of a tributary area should use the WQCV times a factor of safety of 1.5.

   Detention Volume:

   A drywell without a controlled outlet, utilized for detention, must capture the entire storm runoff volume. The design storm runoff volume shall be conservatively estimated by multiplying the one hour design storm depth by the total impervious area tributary to the drywell.

   A drywell with a controlled outlet shall use the FAA method as described in Chapter 5 to determine the required detention volume. Drywells without controlled outlet flow rates shall not utilize the FAA method.

2. Minimum Diameter

   The minimum dry well diameter is whatever is deemed necessary by the design engineer to allow for maintenance of the drywell.

3. Minimum Depth

   The percolation zone of the dry well must be below the maximum freezing depth of the surrounding soil.

4. Percolation Area

   The minimum percolation rate for soils surrounding the dry well is 3 inches per hour. If, based on evaluation of hydraulic conductivity data by a Registered Professional Engineer, the percolation rate around or beneath a proposed drywell is believed to be less than 3 inches per hour, a dry well is not a suitable BMP. The bottom section of the well casing, conventionally known as the barrel section, is perforated (1-inch diameter holes) concrete wall surrounded by gravel backfill.

   Area shall be calculated using the following equation:

   $AP = (Vr)/(K)(43,200)$

   Where:

   AP = Total area of the sides of the percolation area, square feet

Vr = Runoff volume, cubic feet
K = Hydraulic conductivity of soil, feet/second based off the most conservative percolation or hydraulic conductivity test results provided by a certified geotechnical engineer.

The above equation is a rearranged Darcy Equation for groundwater flow assuming a 24-hour drain time, a hydraulic gradient of 1.0 and a 50% clogging factor. Since the bottom of the dry wells must be constructed 5 feet above the maximum ground water elevation, the hydraulic gradient (I) can be assumed to equal 1. In addition, the soil around the dry well may clog with time. Therefore, it is important to reduce the value of hydraulic conductivity with a safety factor. The hydraulic conductivity shall be determined by a Registered Professional Engineer.

5. Structural Backfill — ¾-inch screened rock shall be provided to transition from the dry well to the surrounding native soil. The minimum thickness of this layer shall be 18-inches surrounding the dry well. The COA will permit the void space of gravel up to 2' surrounding a drywell to count towards drywell volume. Gravel which is installed beyond 2' of the drywell shall not be counted as additional drywell volume.

6. Dry Well Bottom — The bottom of the dry well shall be considered impervious due to likely clogging from sediment accumulation over time.

Maintenance

Dry wells must be inspected and maintained yearly to remove sediment and debris that is washed into them. A maintenance plan shall be submitted to the City in the Drainage Report describing the maintenance schedule that will be undertaken by the owners of the new residence or building. Minimum inspection and maintenance requirements include the following:

- Inspect dry wells as annually and after every storm exceeding 0.5 inches.
- Dispose of sediment, debris/trash, and any other waste material removed from a dry well at suitable disposal sites and in compliance with local, state, and federal waste regulations.
- Routinely evaluate the drain-down time of the dry well to ensure the maximum time of 24 hours is not being exceeded. If drain-down times are exceeding the maximum, drain the dry well via pumping and clean out the percolation area (the percolation barrel may be jetted to remove sediment accumulated in perforations). Consider drilling additional perforations in the barrel. If slow drainage persists, the system may need to be replaced.

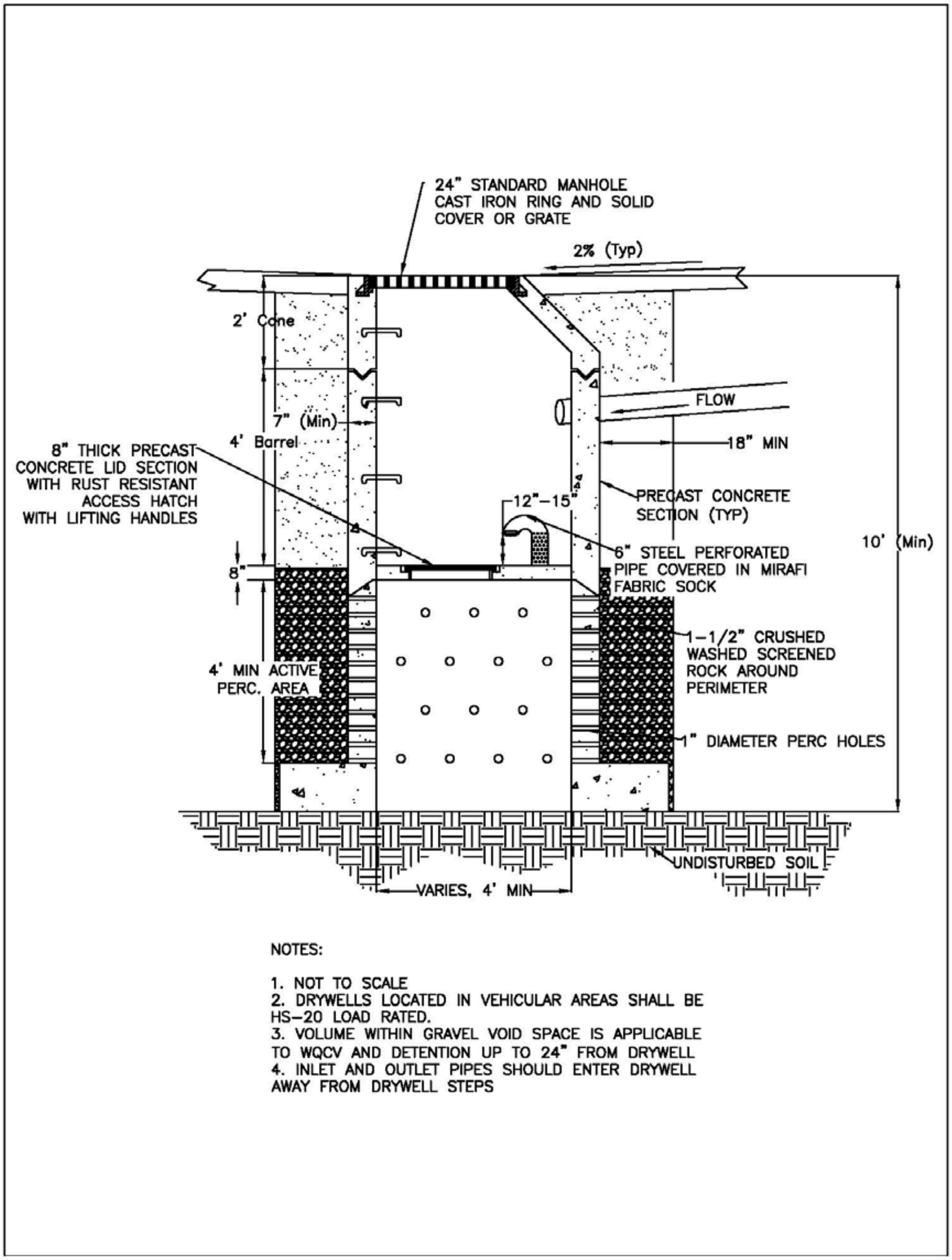
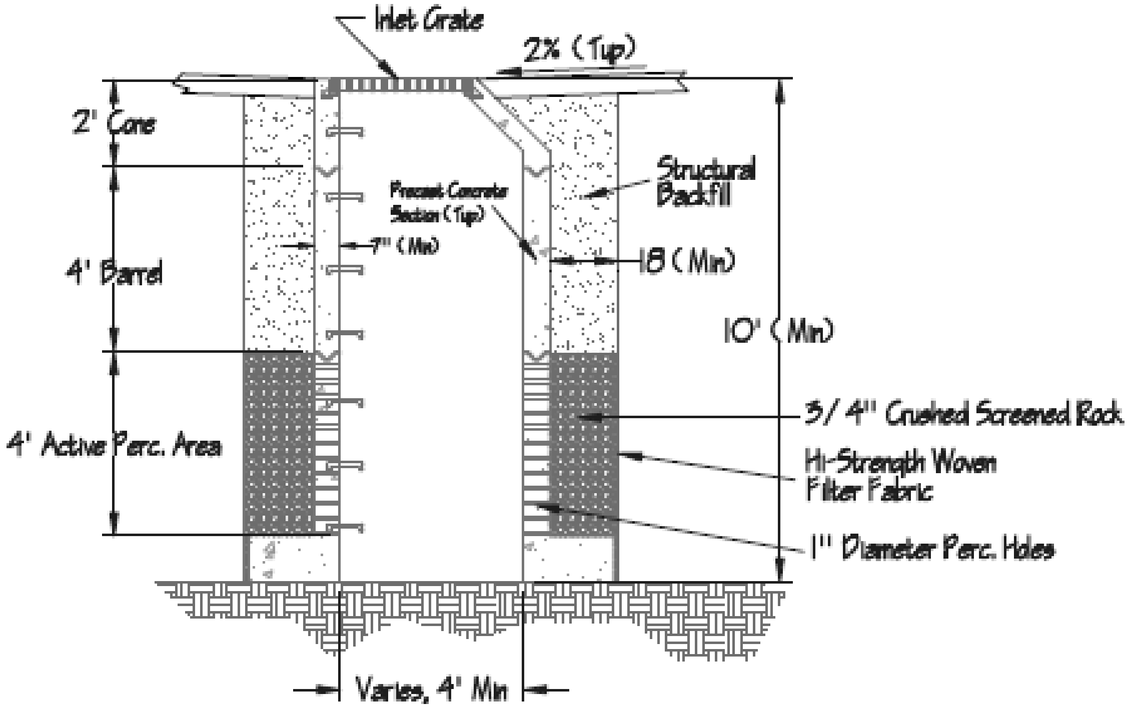


Figure 8.69 Typical WQCV Dry Well



Notes:

1. Drywell design is to be considered when other drainage options prove unfeasible.
2. Drywell diameter and depth must be based on professional hydraulic calculations (taking into account runoff volume and the surrounding soil's percolation rate).
3. Drywells may not be placed in City ROW or in City Easements.
4. Drywells must be cleaned periodically and as often as necessary to keep them performing at maximum capacity.
5. $\frac{3}{4}$" screened rock (wrapped in woven filter geotextile) is required to transition from drywell to native fill.

Figure 8.70 Typical "Detention Only" Dry Well

8.5.4.3 Proprietary Underground Treatment Devices

Proprietary underground treatment devices are allowable in Aspen as long as they meet the treatment objectives described in **Section 8.4** (90 percent removal of total suspended solids 60 microns and coarser for 80 percent of runoff events on an annual basis). It is the responsibility of the applicant to provide documentation that the BMP will meet this criterion. The City reserves the right to not accept any proprietary BMP proposed.

Documentation of performance must meet the following criteria:

1. Testing must consist of field data collected in substantial compliance with the Technology Acceptance and Reciprocity Partnership (TARP). Laboratory studies will not be considered. Information on the TARP program can be found in several locations on the internet including http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/.

2. Data collected in environments similar to Aspen (i.e. high-mountain, cold climates). Data from other climates may be considered; however, the City may deem data collected in dissimilar locations (e.g. Florida) unacceptable.

Many studies have been conducted over the past decade to document the performance of proprietary BMPs. Sources of data that may be used to support using a proprietary BMP include the following:

- International Stormwater BMP Database (www.bmpdatabase.org).

- University of Massachusetts Amherst Stormwater Technologies Clearinghouse (www.mastep.net).

Other data sources may also be acceptable, provided they meet the documentation criteria above.

Maintenance of any underground BMP, proprietary or not, is of utmost importance. For proprietary BMPs, manufacturers' recommended maintenance shall be followed. Where frequency of inspection and maintenance activities vary from the requirements described above for dry wells, the stricter (more frequent) schedule shall be followed.

8.6 References

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Appendix A - Submittal Checklists

1. **Conceptual Review Submittal Checklist**
2. **Landscape and Grading Permit Requirements and Checklist**
3. **Sufficiency Review Checklist**
4. **Minor Grading and Drainage Report and Plan Review Checklist**
5. **Major Grading and Drainage Report and Plan Review Checklist**
6. **Soils Report Checklist**
7. **Public Improvements Checklist**
8. **As-Built Survey Checklist**
9. **Maintenance Agreement**

Conceptual Design Checklist

THE CITY OF ASPEN

CITY OF ASPEN ENGINEERING DEPARTMENT

GRADING AND DRAINAGE REQUIREMENTS FOR CONCEPTUAL DESIGN

DRAINAGE **REPORT** SHALL INCLUDE:

General

- □ Description of the existing site, including common location, topography, land use, ground cover, soil type, drainage pattern, and receiving system.
- □ Description of the proposed project, including changes to land use, topography, ground cover, soil type, drainage pattern and receiving system.
- □ Discussion of any previous drainage studies (i.e., project master plans) for the site that influence or are influenced by the drainage design and the mitigation plan for any negative impacts.
- □ Discussion of the drainage impact of site constraints such as streets, utilities, existing structures, and development or site plan.
- □ Describe the downstream stormwater system – size, material, condition (if known), etc.
- □ Identification of all irrigation facilities and waterways within the watershed that will influence or be influenced by the site drainage.
- □ Discussion of floodplains, wetlands, environmentally sensitive areas, geologic hazard areas (steep slopes or mudflow hazard areas) located within the site.
- □ Discussion of easements and tracts for drainage purposes, including the conditions and limitations for use.

Drainage Basins and Sub-basins

- □ Describe existing and proposed sub-basins, including ground cover, acreage, soil type, and location and method of discharge.
- □ Delineate and reference sub-basins on a map with contours. Each drainage basin should be labeled with its area (in acres), runoff coefficient (C), and Q (cfs).
- □ Discuss offsite drainage patterns and impact on site under existing basin conditions and fully-developed basin conditions.
- □ Discuss pre-developed (historic) and post-developed drainage flow rates at specified point locations (should match labeled locations on plan).

Low Impact Site Design

- □ Describe what efforts have been made to reduce runoff and increase infiltration (e.g. reduce impervious area, disconnect impervious area, route runoff via landscape rather than hard infrastructure).

Hydrologic Criteria

- □ Identify runoff calculation method. Discussion and justification of other criteria or calculation methods used that are not presented in or referenced by the criteria.
- □ Identify the area, storm frequency, rainfall intensity, time of concentration, runoff coefficients, and adjustments for each sub-basin.
- □ Calculate runoff prior to the project.

- □ Calculate the post development runoff flows for each sub-basin and compare these flows to pre-development flows. Determine post development flow prior to inclusion of detention. Flow should be calculated for each location that runoff leaves the site. A map showing all drainage basins should be labeled with basin area (in acres), runoff coefficient (C), and Q (cfs).
- □ Provide calculations of the WQCV, minor event (5-yr for drywell, 5- or 10-year for storm system and detention) and major storm runoff (100yr) at specific design points.

Hydraulic Criteria

- □ Identify flow capacity of drainage facilities.
- □ Calculate culvert sizes with capacities and area of contribution.
- □ Calculate storm sewer capacity including capacity of next two downstream drainage structures.
- □ Calculate gutter capacity.
- □ Calculate storm inlet capacity.
- □ Provide open channel size.
- □ Provide volumes and release rates for detention storage facilities.

Proposed Facilities

- □ Describe proposed better site design practices (BMPs) used to treat the water quality capture volume, detention methods and outlet design with protection techniques.
- □ Provide sizing calculations and approximate locations, with drainage basins, of BMPs used to treat the water quality capture volume.

GRADING AND DRAINAGE **PLANS** SHALL INCLUDE

- □ Vicinity map with north arrow and scale.
- □ Drawings must be 24" x 36" in size.
- □ Scale of 1"=10’ to 1"=40’ or plan must be provided in sufficient detail and clarity to identify drainage flows entering and leaving the development and general drainage patterns.
- □ Benchmark and tie to the City of Aspen Survey.
- □ Name of the subdivision or project.
- □ Property map and parcel number.
- □ Date of preparation, scale, and symbol designating true north.
- □ Legend to define map symbols.
- □ Existing and proposed contours at 1-foot maximum intervals. In terrain where the slope exceeds 15%, the maximum interval is 10 feet. The contours shall extend a minimum of 100 feet beyond the property lines. **Additional topography can be obtained from the City of Aspen GIS Department. The two foot contours are acceptable.**
- □ Overall drainage area boundary and drainage sub-area boundaries for all basins on and off site.
- □ Location, elevation, and FIRM rate code for all existing floodplains within 100’ of property.
- □ Indicate the top of slope and delineate the 15’ no-touch setback.
- □ Property lines and easements with purposes noted.

- □ Existing and proposed drainage facilities and structures, roadside ditches, drainage ways, gutter flow directions, and culverts. All pertinent information such as material, size, shape, slope, and location shall also be included.
- □ Existing and proposed building footprints, streets, indicating ROW width, flow line width, curb type, sidewalk, and approximate slopes.
- □ Proposed landscaping (berms, planters, shrub beds, trees, etc.).
- □ Irrigation ditches, major drainage ways, 100-year floodplains, top of slope and 15-ft no-touch setback, environmentally sensitive areas, and geologic hazard areas.
- □ Proposed type of street flow (i.e., vertical or combination curb and gutter), roadside ditch, gutter, slope and flow directions, and cross pans.
- □ Proposed locations of storm sewers and open drainage ways, including inlets, manholes, culverts, and other appurtenances, (i.e. riprap protection). (allowable manhole spacing = 400 feet)
- □ Proposed outfall point for runoff from the developed area and facilities to convey flows to the final outfall point without damage to downstream properties.
- □ Flow path leaving the development through the downstream properties ending at a major drainage way.
- □ Location and (if known) elevations of all existing and proposed utilities affected by or affecting the drainage design.
- □ Routing of offsite drainage flow through the development.
- □ Summary Runoff Table.
- □ Discussion of easements and tracts for drainage purposes, including the conditions and limitations for use.
- □ Drywell locations (if any) - Minimum 10 feet deep, and 10 feet from property line, and 10 feet from foundation

THE CITY OF ASPEN

Landscape / Grading Permit Requirements

You do not need to apply for a Landscape/Grading Permit if **ALL** of the following exemptions are met:

- Not a Historic Property
- Not Removing Any Trees
- Not Working in the Floodplain or Stream Margin
- Not Working in the Smuggler Mountain Superfund Site
- Not Working in the 8040 Greenline Review Area
- Not Hardscaping in the Setbacks

AND

  - Less than 200sq.ft. of work

OR

  - Less than 1000sq.ft. of total Landscaping that does not include hardscape, or a change in grade or drainage pattern

Definition of Terms:

- **Hardscape** – in the practice of landscaping, refers to hard surfaced areas like decks, patios, walkways, and pools where the soil is no longer exposed to the surface. Hardscape also include other permanent features such as retaining walls and fire pits.
- **Landscape/Softscape** – any activity that modifies the visible features of an area of land. In the case for a landscape and grading permit, it alters features that are planted.
- **Change in Grade** – or "grading" occurs when soil material is disturbed on a site to establish a certain level, shape, or slope. In the case for a landscape and grading permit, the addition of mulch up to 4 inches is not considered "grading."

Submittal Requirements:

- Site Plan
- CMP

In Addition:

<u>If Plan Contains Less than 1000sq.ft. of Grading or Hardscaping:</u>

- See Minor Grading/Drainage Submittal Requirement Checklist

<u>If Plan Contains 1000sq.ft. or More of Grading or Hardscaping:</u>

- See Major Grading/Drainage Submittal Requirement Checklist

<u>If Plan Contains Exterior Lighting:</u>

- Site Lighting Plan
- Individual Specification for each fixture
- Comcheck Energy Audit – **For Commercial Projects Only**

<u>If Plans Contain Exterior Energy Uses (Snowmelt, Pools, and Spas):</u>

- 2009 IECC REMP Worksheet
- The Site Plan must include locations of proposed snowmelt, spas, and/or pools. It must show individual snowmelt area square footages, and total square footage requested.
  Note: Snowmelt proposed in a Right of Way (ROW) will require a separate zone, a ROW permit and a permanent encroachment license. Snowmelt may not drain to the ROW.

<u>If Plans Contain a Firepit:</u>

- Spec Sheet for Appliance

<u>If Plans Contain Hardscape in The Setback:</u>

- Structural Details Showing Improvement Height Above and Below Grade

Landscape and Grading Checklist

CITY OF ASPEN ENGINEERING DEPARTMENT

LANDSCAPE AND GRADING

PERMIT CHECKLIST

THE CITY OF ASPEN

If the project will increase or disturb any impervious area (this includes adding hard surface patios, walkways, etc.) < 200SF, or disturb > ? SF of pervious area (this includes pervious pavers, flowerbeds, etc.), or does not include the repair snowmelt then an analysis of stormwater runoff via a Grading and Drainage Plan and Report are not required, unless determined by the Development Engineer to be unnecessary. Two copies of the information is required for Sufficiency Review. Three copies will be required for Building Permit Application.

NOTE: A Design Professional is not required for preparation or submittal of a Landscape and Grading permit.

LANDSCAPE AND GRADING NARRATIVE SHALL INCLUDE:

- □ Area of impervious increase or disturbance.
- □ Area of land disturbance.
- □ Description of the existing site, including common location, topography, land use, ground cover, soil type (if known), drainage pattern (if known).
- □ Description of the proposed project, including changes to land use, topography, ground cover, soil type, drainage pattern (if known).
- □ Discussion of any drainage issues (if known).

LANDSCAPE AND GRADING PLAN (Sketch Plan) SHALL INCLUDE:

The following should be provided on at least 8.5”x11” paper (24”x36” preferred).

- □ The address of the project.
- □ Date of preparation, scale, and symbol designating true north.
- □ Property lines, streets, and waterways (swales, irrigation ditches, streams, etc.).
- □ Boundary lines of project area including disturbance area, construction access, materials storage, etc.
- □ Sketch of proposed work, including calculation of disturbed area.
- □ Drainage direction (with arrows), drainage facilities on site, existing and proposed (if known).
- □ Erosion and sediment control measures plan. Erosion must be controlled, sediment cannot be allowed to leave the site, and disturbed areas must be stabilized prior to completion.

- ☐ Start and finish dates.

THE CITY OF ASPEN

Sufficiency Checklist

CITY OF ASPEN ENGINEERING DEPARTMENT

SUFFICIENCY REVIEW REQUIREMENTS

If the project will increase impervious area (this includes enlarging a driveway, adding hard surface patios, increasing the footprint of the house, etc.), disturb >200SF of exterior area (this includes grading, even if a structure or hard surface isn't added), or add or repair snowmelt then an engineering review will be required as part of the Building Permit or Landscape and Grading Permit Application review process. All permit applications that must receive an engineering review are required to schedule and participate in a Pre-Application Meeting with the Development Engineer. The sufficiency checklist below and any necessary supporting documents should be completed prior to this meeting, as they will be reviewed during the meeting. **The Development Engineer's signature on this checklist is required in order to submit a Building Permit Application.**

Project Address: ____

Project Common Location/Common Name:____

Parcel ID Number: ____

Owner and Phone Number: ____

Contact and Phone Number and e-mail address: ____

1. **How much land will be disturbed? _________ acres = __________sq.ft.**
   If one acre or more is disturbed, a CDPHE Construction General Permit is required.
   Yes, Notice of Coverage has been included in the CMP. _________
   No, A statement that Notice of Coverage is not required has been included in the CMP._________

2. **How much impervious area will be disturbed? _________ sq.ft. Added? _________ sq.ft.**

3. **What is the estimated total impervious area of the site (not just the addition)?_________sq.ft.**

4. **What type of permit is being sought (Building or Landscape/Grading)?__________________**

5. **What sub-basin (see Secion 1.5 of URMP) is the project located within? __________________**

6. **What level of project is this – Minor or Major?_______________________________________**
   In general, the project is considered "Minor" if 200 – 1000 sq ft of disturbance/work and "Major" if > 1000 sq ft of disturbance/work.

The following information is required for the engineer's review. Please indicate if these documents have been completed and are attached. If any of these documents are not applicable, please provide an explanation in the space provided.

	Included	N/A
7. Minor Grading and Drainage Plan and Report	☐	☐
8. Major Grading and Drainage Plan and Report	☐	☐
9. Compliant City of Aspen Survey	☐	☐
10. Soils Report	☐	☐
11. Excavation Stabilization Plan	☐	☐
12. Construction Management Plan (CMP)	☐	☐
13. Public Improvement Requirements	☐	☐
14. Floodplain Development Requirements	☐	☐
15. Mudflow Analysis	☐	☐

I hereby declare the engineering information submitted in this sufficiency review for this project is sufficient for City of Aspen Building Permit Application submittal.

______________________________ __________________

Applicant's Signature **Date**

______________________________ __________________

City of Aspen Development Engineer's Signature **Date**

Minor Project

THE CITY OF ASPEN

CITY OF ASPEN ENGINEERING DEPARTMENT

GRADING AND DRAINAGE REQUIREMENTS FOR MINOR DESIGN

If the project will increase impervious area (this includes changing a gravel driveway to hard surface, adding hard surface patios, increasing the footprint of the house, etc.), disturb >200SF of land (this includes grading, even if a structure or hard surface is not added, as well as "scrape and replace"), or add or repair snowmelt then an analysis of stormwater runoff via a Grading and Drainage Plan and Report are required, unless determined by the Development Engineer to be unnecessary. "Minor" projects include those that add or disturb 200 – 1000 sq.ft. of soil or impervious area. One copy of the Report and one copy of the Plans is required for Sufficiency Review. Three copies of each will be required for Building Permit Application.

NOTE: A Professional Engineer is not required for preparation or submittal of a plan and report for a minor project.

REFERENCE: Use the Introduction and Chapter 8 of the Urban Runoff Management Plan to design for a minor project.

DRAINAGE REPORT (Narrative) SHALL INCLUDE:

The following should be included in a bound, narrative report.

- □ Description of the existing site, including common location, topography, land use, ground cover, soil type (if known), drainage pattern, and receiving system.
- □ Description of the proposed project, including changes to land use, topography, ground cover, soil type, drainage pattern and receiving system.
- □ Discussion of any drainage issues.
- □ Discussion of drainage basins and drainage alterations, including increases in flow, changes in direction, outfalls, etc. Note: Snowmelt cannot drain to the right-of-way.
- □ Description of downstream stormwater conveyance system – hard infrastructure (Minor (hard)) or "green" infrastructure (Minor (green)).

  - Minor (green) – Description of water quality improvements. Improvements must be made for at least the project area. Describe what efforts have been made to reduce runoff and increase infiltration (e.g. reduce impervious area, disconnect impervious area, route runoff via landscape rather than hard infrastructure).

  - Minor (hard) – Calculations to determine the WQCV and design a BMP that can treat that volume.

GRADING AND DRAINAGE PLAN (Sketch Plan) SHALL INCLUDE:

The following should be provided on at least 8.5"x11" paper (24"x36" preferred).

- □ Name of the subdivision or project, property map and parcel number.
- □ Date of preparation, scale, and symbol designating true north.
- □ Property lines, streets, and waterways (swales, irrigation ditches, streams, etc.).

- □ Boundary lines of project area including disturbance area, construction access, materials storage, etc.
- □ Sketch of proposed work (on topographic map if possible), including calculation of disturbed area.
- □ Drainage direction (with arrows), drainage facilities on site, existing and proposed.
- □ Location and size of BMP to treat WQCV (for Minor (hard) projects only).
- □ Erosion and sediment control measures and revegetation plan. Erosion must be controlled, sediment cannot be allowed to leave the site, and disturbed areas must be stabilized prior to completion.
- □ Start and finish dates.

Major Project

THE CITY OF ASPEN

CITY OF ASPEN ENGINEERING DEPARTMENT

GRADING AND DRAINAGE REQUIREMENTS FOR MAJOR DESIGN

If the project will increase impervious area by more than 1000 SF or 50% of the existing site imperviousness (this includes changing a gravel driveway to hard surface, adding hard surface patios, increasing the footprint of the house, etc.), disturb >1000 SF of land (this includes grading, even if a structure or hard surface is not added, as well as "scrape and replace"), or add or repair snowmelt then an analysis of stormwater runoff via a Grading and Drainage Plan and Report are required, unless determined by the Development Engineer to be unnecessary. The Plan and Report must be signed and stamped by a Colorado Professional Engineer. One copy of the Report and one copy of the Plans set is required for Sufficiency Review. Three copies of each will be required for Building Permit Application.

DRAINAGE REPORT SHALL INCLUDE:

General

- □ Signature, date, and stamp of a Colorado Professional Engineer.
- □ Description of the existing site, including common location, topography, land use, ground cover, soil type, drainage pattern, and receiving system.
- □ Description of the proposed project, including changes to land use, topography, ground cover, soil type, drainage pattern and receiving system.
- □ Discussion of any previous drainage studies (i.e., project master plans) for the site that influence or are influenced by the drainage design and the mitigation plan for any negative impacts.
- □ Discussion of the effects of adjacent drainage issues.
- □ Reference to major drainage way planning studies such as flood hazard delineation reports, master plans, and flood insurance rate maps.
- □ Discussion of the drainage impact of site constraints such as streets, utilities, existing structures, and development or site plan.
- □ Identification of all irrigation facilities and waterways within the watershed that will influence or be influenced by the site drainage.
- □ Discussion of easements and tracts for drainage purposes, including the conditions and limitations for use.
- □ Report must include printed copies of the input and output files for all computer models used for the analysis and design.
- □ Reference plan drawings as needed.

Drainage Basins and Sub-basins

- □ Describe existing and proposed sub-basins, including ground cover, acreage, soil type, and location and method of discharge.
- □ Delineate and reference sub-basins on a map with contours. Each drainage basin should be labeled with its area (in acres), runoff coefficient (C), and Q (cfs).
- □ Discuss offsite drainage patterns and impact on site under existing basin conditions and fully-developed basin conditions.
- □ Discuss pre-developed/historic and post-developed drainage flow rates at specified point locations (should match labeled locations on plan).

Low Impact Site Design

- □ Describe what efforts have been made to reduce runoff and increase infiltration (e.g. reduce impervious area, disconnect impervious area, route runoff via landscape rather than hard infrastructure).

Hydrologic Criteria

- □ Identify design storm recurrence intervals.
- □ Identify design rainfall.
- □ Identify runoff calculation method.
- □ Identify detention discharge and storage calculation method.
- □ Discussion and justification of other criteria or calculation methods used that are not presented in or referenced by the criteria.
- □ Identify the area, storm frequency, rainfall intensity, time of concentration, runoff coefficients, and adjustments for each sub-basin.
- □ Calculate existing runoff or historic runoff as appropriate. Refer to Section 5.2 of the URMP.
- □ Calculate the post development runoff flows for each sub-basin and compare these flows to pre-development flows. Post development flows must not exceed pre-development flows. Determine post development flow prior to inclusion of detention. Flow should be calculated for each location that runoff leaves the site. Each drainage basin should be labeled with its area (in acres), runoff coefficient (C), and Q (cfs).
- □ Provide calculations of the WQCV, minor event (5-yr for drywell, 5- or 10-year for storm system and detention) and major storm runoff (100yr) at specific design points.
- □ Hydrographs at critical design points.

Hydraulic Criteria

- □ Identify the hydraulic design point for closed systems tied to the City's existing collection system.
- □ Identify flow capacity of drainage facilities.
- □ Calculate culvert sizes with capacities and area of contribution.
- □ Calculate storm sewer capacity including capacity of next two downstream drainage structures (max velocity 20 ft/sec, HGL 12 inches below ground , EGL below ground, minimum velocity of 5 ft/sec at half full conduit flow).
- □ Calculate gutter capacity (max velocity 10 ft/sec, allowable spread = 4 feet minor storm, 12-inch depth at flow line for major storm, n=.016 for street, n=.025 for grass)
- □ Calculate storm inlet capacity (clogging factor = 50%).
- □ Provide open channel design and calculations.
- □ Check and/or channel drop design.
- □ Calculate the downstream/outfall system capacity to the major drainage way system.

Proposed Facilities

- □ Describe proposed better site design practices (BMPs) used to treat the water quality capture volume, detention methods and outlet design with protection techniques.
- □ Provide sizing calculations and approximate locations, with drainage basins, of BMPs used to treat the water quality capture volume.
- □ Provide volumes and release rates for detention storage facilities and information on outlet works.

- □ Discussion of easements and tracts for drainage purposes, including the conditions and limitations for use.
- □ Discussion of the off-site drainage facilities needed for the conveyance of minor and major flows to the major drainage way.
- □ Provide a separate section of the report that includes a narrative of the **Operation and Maintenance** requirements of the proposed on site drainage improvements. Include a description of access for maintenance operations, maintenance schedule, and contact information for party responsible for maintenance.

<u>GRADING AND DRAINAGE PLANS SHALL INCLUDE:</u>

- □ Signature, date, and stamp of Colorado Professional Engineer on each plan sheet.
- □ Vicinity map with north arrow and scale.
- □ Drawings must be 24" x 36" in size.
- □ Scale of 1"=10’ to 1"=40’ or plan must be provided in sufficient detail and clarity to identify drainage flows entering and leaving the development and general drainage patterns.
- □ Benchmark and tie to the City of Aspen Survey.
- □ Name of the subdivision or project, property map and parcel number.
- □ Date of preparation, scale, and symbol designating true north.
- □ Legend to define map symbols.
- □ Property lines and easements with purposes noted.
- □ Existing and proposed contours at 1-foot maximum intervals. In terrain where the slope exceeds 15%, the maximum interval is 10 feet. The contours shall extend a minimum of 100 feet beyond the property lines. **Additional topography can be obtained from the City of Aspen GIS Department.**
- □ Overall drainage area boundary and drainage sub-area boundaries for all basins on and off site.
- □ Location, elevation, and FIRM rate code for all existing floodplains within 100’ of property.
- □ All major drainage ways for which the 100-year floodplain and floodway have been defined shall have the 100-year floodplain and floodway delineated on the plans. This also applies to detention basins.
- □ Indicate the top of slope of the Roaring Fork River and its tributaries (Hunter Creek, Castle Creek, and Maroon Creek) and delineate the 15’ no-touch setback.
- □ Existing building footprints, streets, utility locations and elevations, ROW width, flow line width, curb type, sidewalk, approximate slopes, drainage facilities and structures, irrigation ditches, roadside ditches, drainage ways, gutter flow directions, and culverts. All pertinent information such as material, size, shape, slope, and location shall also be included.
- □ Proposed building footprints, streets, utility locations and elevations, ROW width, flow line width, curb type, sidewalk, approximate slopes, drainage facilities and structures, irrigation ditches, roadside ditches, drainage ways, gutter flow directions, and culverts. All pertinent information such as material, size, shape, slope, and location shall also be included.
- □ Proposed type of street flow (i.e., vertical or combination curb and gutter), roadside ditch, gutter, slope and flow directions, and cross pans.
- □ Proposed storm sewers and open drainage ways, including inlets, manholes, culverts, and other appurtenances, (i.e. riprap protection, allowable manhole spacing = 400 ft).

- □ **Proposed landscaping (berms, planters, shrub beds, trees, etc.). Overlay the actual landscape plan onto the proposed grading and drainage plan.**
- □ Profile views for all subsurface drainage facilities showing their size, slope, lengths, design storm hydraulic grade lines (major and minor), energy grade lines, cover, details of structures and/or City Standard details, and relationship with existing utilities. (18 vertical clearance for storm from water lines, 5 foot horizontal from any utility, 7 feet below ground surface, 2 % slope minimum, 18 inch min for main, 15 inch min for lateral).
- □ Cross-sectional views of all open channels, including irrigation ditches, trickle channels, spillway structures, etc., as necessary. These views shall include applicable easement/property line/ROW boundaries and water surface elevations such as the 100-year storm depth, 2-year storm depth, major storm (100-year) freeboard, and irrigation operating level.
- □ Finished floor and grade at foundation elevations of all buildings. In residential developments also provide lot corner elevations and any grade break elevations critical to the grading concept. Show positive drainage away from structures as required by Building Code (IRC – R401.3 and IBC – 1805.3.4).
- □ Spot elevations critical to describe drainage features and their functions (e.g. inlets, cross pans, spillways, inlets/outlets of manholes, culverts, and storm sewers).
- □ Proposed outfall point for runoff from the developed area and facilities to convey flows to the final outfall point without damage to downstream properties.
- □ Routing and accumulation of flows at various critical points for the initial and major storm runoffs listed on the drawing.
- □ Routing of offsite drainage flow through the development.
- □ Flow path leaving the development through the downstream properties ending at a major drainage way.
- □ Summary Runoff Table.
- □ Natural hazards: The designation of all areas that constitute natural hazard areas including but not limited to snow slide, avalanche, mudslide, and rockslide. Show areas with slopes from 30% to 40% and areas with slopes greater than 40%. Areas with slopes from 30% to 40% and areas with slopes greater than 40% will require a slope stability study performed by the Colorado Geological Survey (800-945-0451).
- □ Civil details of dry wells, outlet structures, foundation drain sumps, custom design, etc.
- □ Erosion prevention and sediment control measures for all phases of construction, including areas of revegetation.
- □ Profile views for all subsurface drainage facilities showing their size, slope, lengths, design storm hydraulic grade lines (major and minor), cover, details of structures and/or City Standard details, and relationship with existing utilities. (18 vertical clearance for storm from water lines, 5 foot horizontal from any utility, 7 feet below ground surface, 2 % slope minimum, 18 inch min for main, 15 inch min for lateral).
- □ Cross-sectional views of all open channels, including irrigation ditches, trickle channels, spillway structures, etc., as necessary. These views shall include applicable easement/property line/ROW boundaries and water surface elevations such as the 5 or 10-year storm depth, major storm 100-year, and irrigation operating level.

Checklist C

THE CITY OF ASPEN

CITY OF ASPEN ENGINEERING DEPARTMENT

SOILS REPORT REQUIREMENTS

If a project disturbs more than 200 square feet of exterior area a Soils Report must be submitted to the Engineering Department. The following are minimum requirements for all Soils Reports:

SOILS REPORT SHALL INCLUDE:

- □ Signature, date, and stamp of Colorado Professional Geotechnical Engineer.
- □ Description of the existing site, including common location, land use, and soil type.
- □ Description of the proposed project, including changes to land use, grade, ground cover, drainage pattern and receiving system.
- □ Discussion of any previous soil studies for the site.
- □ Soil type, determined by analyses of borings performed on project site.
- □ Percolation rates, determined by a percolation test or observation of soil type performed on project site.
- □ Hydraulic conductivity. Include testing method, location and depth of tests.

Checklist E

THE CITY OF ASPEN

CITY OF ASPEN ENGINEERING DEPARTMENT

PUBLIC IMPROVEMENT REQUIREMENTS

In accordance with the City's Sidewalk, Curb and Gutter Master Plan, property owners are required to install and maintain sidewalk, curb and gutter along the street frontage adjacent to their properties. Properties within certain areas of the City are not required to install sidewalk, curb and gutter. These locations are shown on the "Sidewalk Free Zones" and the "No Curb and Gutter Zones" maps dated February 22, 2002. These maps are kept in the City Engineering Department. Call the Engineering Department at 920-5080 to find out if sidewalk or curb and gutter are required for a property.

Sidewalk, curb and gutter does not need to be installed as part of the project if (i) the property is outside of the City's sidewalk, curb and gutter zones, and (ii) the cost of installing sidewalk, curb, and gutter exceeds 50% of the project cost excluding the cost of the sidewalk curb and gutter. [For example, the project would not need to install sidewalk, curb and gutter if the project cost is $20,000 and the cost to install sidewalk curb and gutter is more than $10,000.]

General

- □ Provide a drainage study that delineates the drainage sub-basin, runoff flows, and the flow capacity of the curb and gutter.
- □ Landscaping in the landscape island (between the curb and sidewalk) needs to be coordinated with the City Parks Department. (phone: 920-5120 or 429-2035)
- □ Public improvements including pavement, sidewalk, curb and gutter plans must be stamped by a Colorado licensed professional engineer.
- □ If no curb and gutter exists on the adjacent properties, the curb and gutter needs to be designed for the adjacent property. (This is necessary in order to ensure that the location and elevation of the new curb and gutter is coordinated with the future curb and gutter on adjacent properties.

Site Plan

- □ Existing utilities and structure with appropriate stationing including: Waterline, valves, hydrants, sanitary sewer line, manholes, storm drainage facilities, telephone line including junction and control box, gas, electric, cable, fiber optic, floodways and plains, driveway locations, street lights, curb and gutter, traffic signal poles and controllers, pavement edges, trees
- □ Show the location of the sidewalk, curb and gutter on the site plan and grading plan, spot elevations in the gutter flow line every 10 feet, and the extent of new pavement.
- □ Station and elevation of all curb returns, horizontal PCs, PTs etc existing and proposed. Also at high or low point for all curbs , at inlets (including invert and 100 foot maximum intervals along the streets.
- □ Curb return radius, existing and proposed.
- □ Pedestrian access ramp locations
- □ Complete horizontal curve data (radius angle, length and tangent)
- □ All crown lines were departing from the normal cross sections (transitions to existing roadways) with appropriate transition stating elevation.

Profile

- □ All design elevations, at centerline, flow line, pipe inverts. Including water lines larger than 4 inch diameter, all distribution or collection lines under pressure and gravity lines with 6 inch or larger diameter.
- □ Existing and proposed grade, drawn and labeled
- □ Centerline stations continuous for the entire length of the street or project, with centerline stationing of all intersection streets.
- □ Existing utilities particularly where crossed, with grades and elevations
- □ Station and elevation of grade breaks, existing and proposed.
- □ Proposed vertical curves with VPI, VPC, VPT, high point or low point (not the middle ordinate) stations and elevations
- □ Proposed slope and distance for all tangent lines
- □ Proposed Curb return profiles
- □ Proposed Size, type and structural class of pipe
- □ Proposed Pipe bedding
- □ Station and elevation on all drainage and other proposed utilities
- □ Provide a profile of curb flow line showing both the existing and proposed grade.
- □ Provide cross sections across the sidewalk and/or curb and gutter every 50 feet including cross sections at both ends of the proposed sidewalk, curb and gutter.
- □ Typical Cross section(s), shown for all streets, including profile street width, ROW and cross slope.

Details

- □ The construction plans shall include adequate technical information in text format, complete design details and design calculations for special structures.

Signing and Pavement Marking

- □ A complete signing and marking plan must be submitted as apart of the design documents for review by the Engineering Department All signing and marking design must conform to MUTCD

Design Parameters

- □ Standard City details for sidewalk, curb and gutter, drive ramps, and handicap ramps are available from the City. Minimum width of sidewalk is five feet for residential, 6 feet for high density and multi-family and 8 feet for commercial. Sidewalk cross slope: 2%.
- □ Gutter should be designed to drain with a slope of 0.75% or greater.
- □ If possible, elevation of sidewalk should match the elevation of top of curb. And be placed next to the property lines.
- □ The curb radius at intersections is established in the City's Engineering Standards.

Snow Melt Systems

- □ Snowmelt systems installed within the Rights-of-Way must be maintained by the adjacent property owner. A permanent encroachment permit must be completed.

THE CITY OF ASPEN

CITY OF ASPEN ENGINEERING DEPARTMENT
GRADING AND DRAINAGE CERTIFICATE

All major projects within the City of Aspen require a Grading and Drainage Certificate following final grade, landscaping, and installation of all stormwater quality and quantity control measures for the site. Certificate of Occupancy will not be issued until Grading and Drainage Certificate has been submitted and approved by the Development Engineer. The following are the minimum requirements for a Grading and Drainage Certificate:

GRADING AND DRAINAGE CERTIFICATE SHALL INCLUDE:

- □ As-built survey
- □ A video of the subsurface drainage systems may be necessary. A video of the subsurface drainage system is required if the site drains into the City of Aspen's stormsewer infrastructure and/or if the site discharged pollutants, such as concrete, sediment, or construction debris, during construction.
- □ Maintenance Agreement for stormwater facilities such as detention systems and structural best management practices designed to treat the WQCV.
- □ Elevation Certificate if the site is in the FEMA 100-yr floodplain.
- □ Signature, date, and stamp of Colorado Professional Engineer on each plan sheet.

"I, the undersigned Registered Professional Engineer, certify that I have inspected the as-built survey data for project site: ____ and have concluded that the property will drain adequately in conformance with the drainage plan submitted and approved by the City on date: ____________________."

By: ____ Date: ____________________

PE License No. ________________________

As-Built Survey

- □ Signature, date, and stamp of Colorado Professional Land Surveyor on each plan sheet.
- □ Vicinity map with north arrow and scale.
- □ Drawings must be 24" x 36" in size.
- □ Scale of 1"=10' to 1"=40' or plan must be provided in sufficient detail and clarity to identify drainage flows entering and leaving the development and general drainage patterns.
- □ Benchmark and tie to the City of Aspen Survey.
- □ Name of the subdivision or project.
- □ Property map and parcel number.
- □ Date of preparation, scale, and symbol designating true north.
- □ Legend to define map symbols.
- □ Property lines and easements with purposes noted.

- □ Contours at 1-foot maximum intervals. In terrain where the slope exceeds 15%, the maximum interval is 10 feet.
- □ Drainage facilities and structures, including irrigation ditches, roadside ditches, drainage ways, gutter flow directions, and culverts. All pertinent information such as material, size, shape, slope, and location shall also be included.
- □ Building footprints, streets, utility locations, ROW width, flow line width, curb type, and sidewalks.
- □ Storm sewers and open drainage ways, including inlets, manholes, culverts, and other appurtenances. All pertinent information such as material, size, shape, slope, and location shall also be included.
- □ Cross-sectional views of all open channels, including irrigation ditches, trickle channels, spillway structures, etc., as necessary. These views shall include applicable easement/property line/ROW boundaries.
- □ Finished floor and grade at foundation elevations of all buildings. In residential developments also provide lot corner elevations and any grade break elevations critical to the grading concept. Show positive drainage away from structures as required by Building Code (IRC – R401.3 and IBC – 1805.3.4).
- □ Spot elevations critical to describe drainage features and their functions (e.g. inlets, cross pans, spillways, inlets/outlets of manholes, culverts, and storm sewers).
- □ Location and (if known) elevations of all utilities.

- □ As-Built Survey Certification Statement:

"I, the undersigned Registered Land Surveyor, hereby certify that the elevations, grading and drainage features shown of the property described as:_________________ ___________________________________ were developed from surveying the property on the date of:______________________ and accurately depict the elevations existing during the survey. The elevations may change subsequent to the survey due to subsidence, upheaval, erosion, acts of man or other factors. Therefore, this certificate may not accurately depict elevations, grading and drainage pattern after the date of the survey. Easements are shown per the plat unless noted otherwise. No part of this lot lies within the 100- year floodplain as defined by FEMA, except as noted."

By: Date:

_____________________________ ________ _________________

For and behalf of _____________ PLS seal

STORMWATER BEST MANAGEMENT PRACTICES OPERATIONS AND MAINTENANCE AGREEMENT

City of Aspen, Colorado

THIS AGREEMENT, made and entered into this ___ day of ____________, 20___, by and between (Insert Full Name of Owner)____ hereinafter called the "**Landowner**", and the City of Aspen, Colorado, hereinafter called the "**City**".

WITNESSETH

WHEREAS, the Landowner is the owner of certain real property described as (Pitkin County tax Map/Parcel Identification Number) ____ located at ____and as more fully as follows, to wit:

also known as, ________________________________, hereinafter called the "**Property**"; and

WHEREAS, the Landowner is proceeding to build on and develop the property; and

WHEREAS, the stormwater management BMP Operations and Maintenance Plan for the property identified herein has been approved by the City, herein after called the "**Plan**", which is attached hereto as Appendix A and made part hereof, as approved by the City, provides for management of stormwater within the confines of the Property through the use of stormwater management or Best Management Practices (**BMPs**) facilities; and

WHEREAS, the City and the Landowner, its successors and assigns, agree that the health, safety, and welfare of the residents of City of Aspen, Colorado and the maintenance of water quality require that on-site stormwater management/BMP facilities be constructed and maintained on the Property; and

WHEREAS, the City requires, through implementation of the Plan from the Landowners dated _____________ and attached hereto, that on-site stormwater management/BMPs as shown on the Plan be adequately constructed, operated, and maintained by the Landowner, its successors and assigns.

NOW, THEREFORE, in consideration of the foregoing premises, the mutual covenants contained herein, and the following terms and conditions, the parties hereto agree as follows:

1. Construction of BMP facility by Landowner. The on-site stormwater management/BMP facilities shall be constructed by the Landowner, its successors and assigns, in accordance with the plans and specifications approved by the City and identified in the Plan.

2. Duty of Operation and Maintenance of Facility. The Landowner, its successors and assigns, including any homeowners association, shall adequately operate, inspect, and maintain the stormwater management/BMP facilities as acceptable to the City and in accordance with the specific operation, inspection, and maintenance requirements noted in the Plan. Adequate operation and maintenance is herein defined as good working condition so that these facilities are performing their design functions.

3. Duty of Documentation. The Landowner, its successors and assigns, shall document inspections, maintenance, and repairs performed and provide said documentation to the City or its representatives upon request.

4. Right of Entry on Property. The Landowner, its successors and assigns, hereby grant permission to the City, its authorized agents and employees, to enter upon the Property at reasonable times and upon presentation of proper identification, and to inspect the stormwater management/BMP facilities whenever the City deems necessary. The purpose of inspection is to follow-up on suspected or reported deficiencies, to respond to citizen complaints, and/or to assure safe and proper functioning of the facilities. The City shall provide the Landowner, its successors and assigns, copies of the inspection findings and a directive with timeline to commence with the repairs if necessary.

5. Failure to Maintain. In the event the Landowner, its successors and assigns, fails to construct, operate and maintain the stormwater management/BMP facilities in good working condition acceptable to the City, the City, its authorized agents and employees, may enter upon the Property and take whatever action(s) deemed necessary to correct deficiencies identified in the inspection report and to charge the costs of such construction or repairs to the Landowner. It is expressly understood and agreed that the City is under no obligation to install, construct, or routinely maintain or repair said stormwater management/BMP facilities, and in no event shall this Agreement be construed to impose any such obligation on the City.

6. Reimbursement by Landowner. In the event the City pursuant to this Agreement, performs work of any nature, or expends any funds in performance of said work for labor, use of equipment, supplies, materials, and the like, the Landowner, its successors or assigns, shall reimburse the City upon demand, within thirty (30) days of receipt thereof for all actual costs incurred by the City hereunder.

7. Duty to Inspect by City. The City, its employees or representatives, shall inspect the stormwater management/BMP facilities at a minimum of once every three years to ensure their continued and adequate functioning.

8. Release of City. The Landowner, its executors, administrators, assigns, and other successors in interests, shall release the City, its employees and designated representatives from all damages, accidents, casualties, occurrences, or claims which might arise or be asserted against said City, employees, and representatives from the construction, presence, existence, operative or maintenance of the stormwater management/BMP facilities by the Landowner or City. In the event that a claim is asserted against the City, its elected officials, City Officers or employees, the City shall promptly notify the Landowner and the Landowner shall defend, at its own expense, any suit based on the claim. If any judgment or claims against the City's employees or designated representatives shall be allowed, the Landowner shall pay all costs and expenses regarding said judgment or claim.

9. Recording of Agreement running with the Property. This Agreement shall be recorded in the real property records of Pitkin County, Colorado, and shall constitute a covenant running with the Property or land, and shall be binding on the Landowner, its administrators, executors, assigns, heirs and any other successors in interests, in perpetuity.

IN WITNESS WHEREOF the undersigned have hereunto affixed their signatures as of the date first above written.

LANDOWNER:

By:_________________________________ Print Name: _______________________________

State of Colorado) :ss

County of Pitkin)

The foregoing Agreement was acknowledged before me this _____day of ____________, 20___,

by ____.

____
Notary Public

My Commission Expires: _______________

THE CITY OF ASPEN:

By:_________________________________ Print Name: _______________________________

State of Colorado) :ss

County of Pitkin)

The foregoing Agreement was acknowledged before me this _____day of ____________, 20___,

by ____.

____
Notary Public

My Commission Expires: _______________

Appendix B – Equations and Examples

Purpose

The purpose of this appendix is to provide background equations and example problems for clarity of calculations used throughout the manual. This appendix is divided into sections by referenced chapters in the manual. Topics are differentiated by arrows.

Chapter 2 – Runoff

- **Depth-Duration-Frequency**

The depth-duration-frequency (DDF) data from the NOAA Atlas Volume 3 is summarized in **Table 1**.

Table 1 – Point Rainfall Depth-Duration-Frequency *in* Aspen, Colorado

Period	*5-min*	*10-min*	*15-min*	*30-min*	***1-hr (P1)***	*2-hr*	*3-hr*	*6-hr*	*24-hr*
2-yr	0.18	0.29	0.36	0.50	**0.64**	0.75	0.83	0.98	1.40
5-yr	0.29	0.45	0.57	0.79	**1.00**	1.10	1.17	1.30	1.80
10-yr	0.35	0.54	0.68	0.95	**1.20**	1.30	1.37	1.50	2.00
25-yr	0.41	0.63	0.80	1.11	**1.40**	1.54	1.63	1.80	2.40
50-yr	0.46	0.72	0.91	1.26	**1.60**	1.74	1.83	2.00	2.70
100-yr	0.49	0.76	0.96	1.34	**1.69**	1.87	1.98	2.20	3.05
Notes: **1. Read Volume III for 6-hr and 24-hr rainfall depths**									

Based on the depth and duration data in Table 1, rainfall intensities can be calculated for various frequencies. Rainfall intensity data forms the basis of the Intensity-Duration-Frequency (IDF) curves in Figure 2.1 of Chapter 2.

- **Depth Ratios**

The recommended rainfall distributions, based generally on the Denver design rainfall distribution depth ratios with minor adjustments for Aspen, are provided in **Table 2**. The incremental rainfall depth rations in **Table 2** have been verified to provide reasonable agreement to Aspen's IDF formula **(Equation 2-1)** and are generally consistent with the NOAA Atlas 2 (NOAA 1973). Depth ratios (or percentages) are input parameters for CUHP models. Chapter 2, Tables 2.5 and 2.6, are depths derived using **Table 2** for the 1-hr event in the City of Aspen. For areas outside of the City of Aspen, the percentages in **Table 2** should be used in CUHP to derive depths for those areas.

Table 2 – Incremental Rainfall Depth Ratios for Aspen (Applicable to area <10 sq miles)

Design Rainfall Distributions $P(t)/P_1$ in percent					
Time *minutes*	2-yr	5-yr	10-yr	25/50-yr	100/500-yr
0	0.0	0.0	0.0	0.0	0.0
5	2.0	2.0	2.0	1.3	1.0
10	4.0	3.7	3.7	3.5	3.0
15	8.4	8.7	8.2	5.0	4.6
20	16.0	15.3	15.0	8.0	8.0
25	25.0	25.0	25.0	15.0	14.0
30	14.00	13.0	12.0	25.0	25.0
35	6.3	5.8	5.6	12.0	14.0
40	5.0	4.4	4.3	8.0	8.0
45	3.0	3.6	3.8	5.0	6.2
50	3.0	3.6	3.2	5.0	5.0
55	3.0	3.0	3.2	3.2	4.0
60	3.0	3.0	3.2	3.2	4.0
65	3.0	3.0	3.2	3.2	4.0
70	2.0	3.0	3.2	2.4	2.0
75	2.0	2.5	3.2	2.4	2.0
80	2.0	2.2	2.5	1.8	1.2
85	2.0	2.2	1.9	1.8	1.2
90	2.0	2.2	1.9	1.4	1.2
95	2.0	2.2	1.9	1.4	1.2
100	2.0	1.5	1.9	1.4	1.2
105	2.0	1.5	1.9	1.4	1.2
110	2.0	1.5	1.9	1.4	1.2
115	1.0	1.5	1.7	1.4	1.2
120	1.0	1.3	1.3	1.4	1.2

➢ Extreme Rainfall Events

In addition to evaluation of precipitation for events ranging from the 2- to 100-year events, there may be instances in Aspen when larger events may need to be considered, for example for an impoundment with significant development downstream. In such cases, it may be necessary to evaluate extreme precipitation or the Probable Maximum Precipitation (PMP) event. Two methods are currently used in Colorado:

1. Calculation in accordance with Hydrometeorlogical Report Number 49 (HMR 49) (Hansen et al. 1977). This document was developed for the Colorado River and Great Basin drainage areas.

2. Extreme Precipitation Analysis Tool (EPAT). This is a GIS based methodology developed for the State Engineers Office (SEO).

Either method is acceptable in Aspen when extreme precipitation event analysis is required. Engineers should consult with the Division Engineer to determine if the SEO has a preference prior to conducting analysis. As of the date of this Chapter, both methods are still in use, but the EPAT method is being used more frequently and HMR 49 less frequently.

Chapter 3 – Rainfall

- **Soil Types**

Table 3.2 Soil Types in the Aspen Area

Type A Soils	Type B Soils	Type C Soils	Type D Soils
	Almy	Acree	Ansari
	Ansel	Arle	Camborthids
	Antrobus	Callings	Dollard
	Anvik	Cochetopa	Earsman
	Atencio	Cushool	Fluvaquents
	Azeltine	Fughes	Gypsiorthids
	Brownsto	Gothic	Iyers
	Charcol	Gypsum land	Kilgore
	Coulterg	Irrawaddy	Moyerson
	Curecanti	Jerry	Rentsac
	Dahlquist	Kobar	Rock outcrop
	Dotsero	Kobar, dry	Rock outcrop, shale
	Empedrado	Miracle	Rogert
	Etoe	Moen	Starley
	Evanston	Mord	Starman
	Forelle	Redrob	Tanna
	Forsey	Showalter	Torriorthents
	Goslin	Sligting	
	Grotte	Woodhall	
	Ipson	Woosley	
	Millerlake		
	Mine		
	Monad		
	Morval		
	Mussel		
	Pinelli		
	Skylick		
	Southace		
	Tridell		
	Uracca, moist		
	Vandamore		
	Yamo		
	Yeljack		
	Youga		
	Zillman		

- **Infiltration Rates**

An infiltration rate reflects the ability of the soil medium to absorb water. This parameter is usually given in inch per hour or millimeter per hour. Infiltration rates are described by a decay function with a high rate at the beginning of the event when the soil is dry, and a low rate when the soil becomes saturated.

Table 3 Infiltration Rates for Different Soil Groups (UDFCD 2001)

Soil Type	Initial Rate Inch/hr	Final Rate Inch/hr	Decay Coefficient 1/sec for CUHP	Decay Coefficient 1/hr for SWMM
A	5.0	1.0	0.0007	2.52
B	4.5	0.6	0.0018	6.48
C	3.0	0.5	0.0018	6.48
D	3.0	0.5	0.0018	6.48

Table 3 is recommended for design infiltration rates under the average soil antecedent moisture condition. When the watershed has several different types of soils, the representative infiltration rate can be determined as the area-weighted value.

$$f(t) = f_c + (f_o - f_c)e^{-kt}$$ **(Equation 3-1)**

in which,

f(t) = infiltration rate at elapsed time t (in/hr),

f_o = initial infiltration rate (in/hr),

fc = final infiltration rate (in/hr),

e = natural logarithm base, and

k = decay coefficient (1/sec or 1/hr).

Chapter 4 – Street Drainage System Design

- **Example Calculation of Allowable Street Hydraulic Capacity for a Collector Street**
  A collector street in the City of Aspen has a half-width of 29 feet, including the traffic lane of 11 feet and a parking width of 18 feet. The street cross section in **Figure 4.4** has n = 0.016, W = 2.5 feet, D_s = 2 inches, S_o = 3.0 %, and S_x = 2%. The curb height, H_c, for this street is 6 inches. D_m = 6 inches for minor or 12 inches for a major event To reserve the middle width of 10 feet in one traffic direction, the allowable water spread is reduced to 19 feet for this street.

Solution

According to **Table 4.2**, a collector street shall be designed not to overtop the curb height under a minor storm. Thus, the gutter-full capacity for this street is defined by setting the gutter flow depth equal to the curb height of 6 inches. For this case, $D = D_m = H_c$ = 6.0 inches.

The cross slope across the gutter width is calculated as:

$$S_w = S_x + \frac{D_s}{W} = 0.02 + \frac{2}{12 \times 2.5} = 0.087 \text{ ft/ft,}$$

The gutter-full water spread flow is calculated as:

$$T = \frac{(D_m - D_s)/12}{S_x} = \frac{(6-2)/12}{0.02} = 16.7 \text{ feet}$$

$$T_x = T - W = 16.7 - 2.5 = 14.2 \text{ feet}$$

$$T_s = \frac{D_m}{S_w} = \frac{6}{12 \times 0.087} = 5.74 \text{ feet}$$

$$Q_w = \frac{0.56}{0.016}(0.087)^{1.67}[5.74^{2.67} - (5.74 - 2.5)^{2.67}]\sqrt{0.030} = 8.58 \text{ cfs}$$

$$Q_x = \frac{0.56}{0.016}0.02^{1.67}14.2^{2.67}\sqrt{0.03} = 10.45 \text{ cfs}$$

$$Q_g = Q_w + Q_x = 8.58 + 10.45 = 19.0 \text{ cfs}$$

The available water spread on this street is set to be 19 feet. The spread width capacity is calculated as:

$$T_x = T - W = 19.0 - 2.5 = 16.5 \text{ feet}$$

$$T = \frac{(D_m - D_s)/12}{S_x} = \frac{(D_m - 2)/12}{0.02} = 15.0 \text{ feet. So, } D_m = 5.6 \text{ inches}$$

$$T_s = \frac{D_m}{S_w} = \frac{5.6}{12 \times 0.087} = 5.77 \text{ feet}$$

$$Q_w = \frac{0.56}{0.016}(0.087)^{1.67}[5.77^{2.67} - (5.77 - 2.5)^{2.67}]\sqrt{0.030} = 10.32 \text{ cfs}$$

$$Q_x = \frac{0.56}{0.016}0.02^{1.67}16.5^{2.67}\sqrt{0.03} = 15.7 \text{ cfs}$$

$$Q_m = Q_w + Q_x = 10.32 + 15.7 = 26.0$$

From **Figure 4.5**, the reduction factor for S_o= 3% is 0.75 for a minor storm. The allowable street hydraulic capacity is determined as:

$$Q_a = \min(R \times Q_g, Q_m) = \min(0.75 \times 19.0,\ \ 26.0) = 14.3 \text{ cfs for minor event.}$$

For this case, the allowable street capacity is determined to be 14.3 cfs for a minor event.

Solution for a Major Storm

According to **Table 4.2**, the water depth in a collector gutter can be 12 inches during a major storm event. To calculate the allowable street hydraulic capacity, repeat the above process. The gutter-full capacity is determined to be 44 cfs for a major storm event. The reduction factor in **Figure 4.5** for a major storm is 0.6 for S_0=3%. The allowable street hydraulic capacity is determined as

$$Q_a = \min(R \times Q_g, Q_m) = \min(0.60 \times 44.0,\ \ 26.0) = 26.0 \text{ cfs for major event.}$$

- **Example for Street Design Flow**

Use the Rational method to find the 10-year local design flow to be 10.5 cfs. With a carryover flow of 1.2 cfs (not captured from the upstream inlet), the design flow is calculated as:

$$Q_s = 10.5 + 1.2 = 11.7 \text{ cfs}$$

It takes an iterative process to analyze the design flow in the street section that is described in Section 7.3. For this case, the design flow condition is determined to be: T=13.5 ft, D=0.44 ft, V=6.94 fps, Q_w=6.43 cfs and Q_x=5.32 cfs.

➢ Example for on-Grade Grate

Referring to the Example for Design Flow above, the design flow on the street has: T=13.5 ft, D=0.44 ft, V=6.94 fps, Q_s = 11.7 cfs, Q_w=6.43 cfs and Q_x=5.32 cfs. A typical bar grate has a unit width, W_o, of 1.50 feet and a unit length, L_o, of 2.50 feet. Determine the number of inlet grates in Figure 4.10.a in order to intercept more than 75% of the design flow of 11.7 cfs.

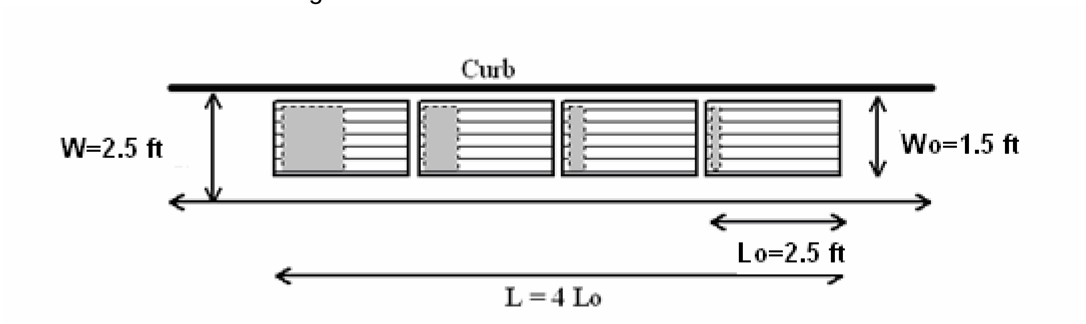


Figure 4.10.a Design Example for On-Grade Grate Inlet

Consider four grates. The total grate length is:

$$L_g = nL_o = 4.0 \times 2.5 = 10.0 \text{ ft}$$

From **Table 4.5**, the clogging factor is 0.23. The effective grate length free from clogging is:

$$L_e = (1 - 0.23) \times 10.0 = 7.7 \; ft$$

$$R_x = \frac{1}{\left(1 + \frac{0.15V^{1.8}}{S_x L_e^{2.3}}\right)} = \frac{1}{1 + \frac{0.15 \times 6.94^{1.8}}{0.02 \times 7.7^{2.3}}} = 0.31$$

The intercepted flow is calculated as:

$$Q_i = Q_w + R_x Q_x = 6.43 + 0.31 \times 5.32 = 8.1 \text{ cfs}$$

Using four units, the interception ratio for this example is: 8.1/11.7 =70% and the carry-over flow is 3.6 cfs for this case.

➢ Example for In-sump Grate

A bar grate inlet in **Figure 4.**6 has a unit length of 2.5 ft and a unit width of 1.5 ft. The steel bars occupy 40% of the grate surface area. Calculate the interception capacity for one bar grate under a water depth of 0.5 foot.

When the inlet operates like a weir, the capacity is determined to be:

$$P_e = 2 \times 1.5 + (1 - 0.5) \times 2.5 = 4.25 \text{ ft}$$

With C_w=3.0, the weir capacity is calculated as:

$$Q_w = 3.0 \times 4.25 \times 0.5^{1.5} = 4.5 \text{ cfs}$$

The net opening area for the grate is calculated as the difference between the grate area and the steel-bar area as:

$$m = 1 - 0.4 = 0.6$$

$$A_e = (1-0.5) \times 0.6 \times 2.5 \times 1.5 = 1.13 \text{ sq feet.}$$

With C_0 =0.65, the interception capacity is calculated as:

$$Q_o = 0.65 \times 1.13 \times \sqrt{64.4 \times 0.5} = 4.2 \text{ cfs}$$

For this case, the weir flow dictates the interception capacity as:

$$Q_i = \min(4.2,\ 4.5) = 4.2 \text{ cfs.}$$

- **Example for On-grade Curb Opening Inlet**

Referring to the Example for Design Flow above, the design flow on the street has: Q_s = 11.7 cfs, Q_w=6.43 cfs and Q_x=5.32 cfs. The curb opening inlet in **Figure 4.10.b** has a length of 5 feet and open height of 4 inches. Considering a clogging factor of 0.12 for a single unit, determine the interception rate for 4 units of curb-opening inlet.

Figure 4.10.b Curb Opening Inlet

For this case, the gutter slope is

$$S_w = S_x + \frac{D_s}{W} = 0.02 + \frac{\left(\frac{2}{12}\right)}{2.5} = 0.087 \text{ ft/ft}$$

The equivalent transverse slope is calculated as:

$$S_e = 0.02 + 0.087 \times \frac{6.43}{11.7} = 0.068 \text{ ft/ft}$$

The required length of the curb opening inlet is:

$$L_t = 0.60 \times 11.70^{0.42} \times 0.03^{0.30} \times \left(\frac{1}{0.016 \times 0.068}\right)^{0.6} = 35.5 \text{ ft}$$

Try four units. The total length of the inlet is:

$L = 5.0 \times 4.0 = 20$ ft

The clogging factor for 4 units of curb-opening inlet is 0.04 from **Table 4.5**. The effective length of the curb opening inlet is:

$L_e = (1 - 0.04) \times 20 = 19.2$ ft

Substituting the effective length into Eq 4-29 yields:

$$Q_i = 11.7 \times \left[1 - \left(1 - \frac{19.2}{35.5}\right)^{1.80}\right] = 8.83 \text{ cfs}$$

This inlet has an interception ratio of 75%. The carry-over flow is 2.87 cfs for this case.

- **Example for in-sump Curb Opening Inlet**

As illustrated in **Figure 4.13**, the 3-ft curb opening inlet with a depression pan is used as the in-sump inlet. The clogging factor for a single curb-opening inlet is 12%. A 3-inch concrete cover is needed to protect to the inlet. The curb height is 6 inches along the street gutter. No overtopping is allowed. Determine the interception capacity.

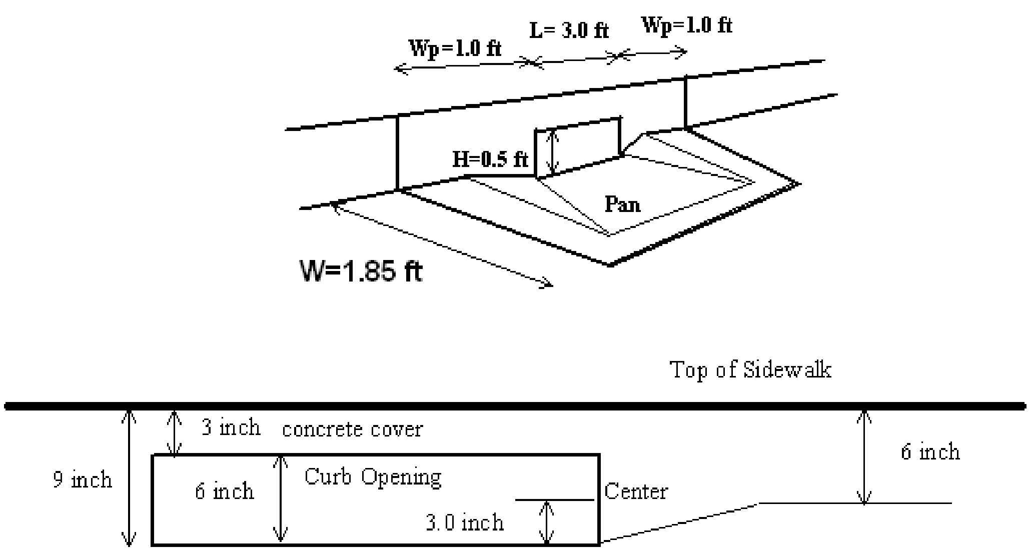


Figure 4.13 Example of Curb Opening Inlet in Sump

Considering the 3-inch concrete cover on top of the 6-inch opening, the water depth is calculated as:

$Y_s = 3 + 6 = 9$ inches

Consider k = 2.0. The effective weir length for the depression pan is:

$P_e = (1 - 0.12) \times (3.0 + 2.0 \times 1.0) + 2 \times 1.85 = 8.10$ ft

The weir flow capacity is estimated as:

$$Q_w = 3.0 \times 8.10 \times (\frac{9}{12})^{1.5} = 15.7 \text{ cfs}$$

The unclogged curb opening area is

$$A = (1 - 0.12) \times 3 \times \frac{6}{12} = 1.32 \text{ sq foot}$$

The center of the curb opening area is 3 inches above the flow line. The orifice flow capacity is estimated as:

$$Q_o = 0.65 \times 1.32 \times \sqrt{2g(9/12 - 3/12)} = 4.87 \text{ cfs}$$

The interception capacity for this curb opening is

$$Q_i = \min(Q_w,\ Q_o) = 4.87 \text{ cfs}$$

- **Example for Circular Sewer**

Design a circular sewer to deliver a discharge of 40 cfs on a slope of 1.0 % with a Manning's roughness coefficient of 0.015.

1. Find the hydraulically required pipe size

$$d = (\frac{0.015 \times 40.0}{0.462\sqrt{0.01}})^{\frac{3}{8}} \times 12 = 31.36 \text{ inches}$$

2. Use a 36-inch circular sewer that has a full flow capacity as

$$Q_f = \frac{1.49}{0.015} \times 0.75^{\frac{2}{3}} \times 7.07 \times \sqrt{0.01} = 57.92 \text{ cfs}$$

3. Determine the design flow condition in the 36-inch pipe.

$$\frac{Q}{Q_f} = \frac{40}{57.92} = 0.69 = \frac{1}{\pi}\left(\frac{1}{\theta}\right)^{\frac{2}{3}}(\theta - \sin\theta\cos\theta)^{\frac{5}{3}}$$

By trial and error, the central angle is found to be 1.79 radians or 102.8 degrees. The flow condition for the design discharge in the 36-inch sewer can be calculated as:

$$Y = \frac{d}{2}(1 - \cos\theta) = \frac{3}{2}(1 - \cos 1.79) = 1.83 \text{ ft}$$

$$A = \frac{d^2}{4}(\theta - \sin\theta\cos\theta) = \frac{3^2}{4}(1.79 - \sin 1.79 \times \cos 1.79) = 4.52 \text{ ft}^2$$

$$V = \frac{Q}{A} = \frac{40.0}{4.52} = 8.85 \text{ fps}$$

$$T = d\sin\theta = 3\sin 1.79 = 2.93 \text{ ft}$$

The above analysis is based on the assumption of normal flow conditions. In fact, a sewer in a system is subject to downstream backwater effects. Under a surcharge condition, the sewer likely becomes full-flowing with a full-flow velocity as:

$$V_f = \frac{40}{3.1416 \times 3.0^2 / 4} = 5.66 \text{ fps}$$

Appendix C - Worksheets

The following worksheets can be used for several common calculations found in the Manual. These worksheet can be downloaded from the City's website: http://www.aspenpitkin.com/Departments/Engineering.

1. **UD Rational**
2. **UD Channels**
3. **UD Inlet**
4. **UD Culvert**
5. **UD Detention**

Appendix D - Floodplain Documents

1. **Floodplain Development Permit**
2. **Elevation Certificate and Instructions**
3. **No-rise Certification and Instructions**

Flood Plain Development Permit
Application Information

Date ____________
Parcel Number ____________ Permit Number ____________
Owner ____________ Telephone ____________
Address ____________
Contractor ____________ Telephone ____________
Address ____________
Project Location/Directions ____________

Project Description

- ______ Single Family Residential
- ______ Multi-Family Residential
- ______ Manufactured (Mobile) Home
- ______ Non-Residential
- ______ New Construction
- ______ Substantial Improvement (>50%)
- ______ Improvement (<50%)
- ______ Rehabilitation
- ______ Channelization
- ______ Fill
- ______ Bridge/Culvert
- ______ Levee

Other/Explanations ____________

Flood Hazard Data

Watercourse Name ____________
The project is proposed in the ____________ Floodway ____________ Floodway Fringe
Base (100-year) flood elevation(s) at the project site ____________
Elevation required for Lowest Floor ____________ / Floodproofing ____________
Source Document / Report / Maps ____________

Proposal Review Checklist

- ______ Site development plans depict the floodway and base flood elevations
- ______ Engineering data is provided for map and floodway revisions
- ______ Floodway certification and data document no increases in flood heights
- ______ Subdivision proposals minimize flood damage and protect utilities
- ______ Lowest floor elevations are above the base (100-year) flood level
- ______ Manufactured (mobile) homes are elevated and adequately anchored
- ______ Non-residential floodproofing designs meet NFIP watertight standards
- ______ Other ____________

Continued on next form.

Flood Plain Development Permit, continued

Permit Action

______ **Permit Approved**: The information submitted for the proposed project was reviewed and is in compliance with approved flood plain management standards (site development plans are on file)

______ **Permit Denied**: The proposed project does not meet approved flood plain management standards (explanation is on file)

______ **Variance Granted**: A variance was granted form the base (100-year) flood elevations established by FEMA consistent with variance requirements of NFIP regulations Part 60.6 (variance action documentation is on file)

____

Flood Plain Administrator's Signature   Date

Comments ______________________________________

____

Development Documentation

______ **Map Revision Data**: Certified documentation by a registered professional engineer of as-built conditions for flood plain alterations were received and submitted to FEMA for a flood insurance map revision.

______ **Fill Certification:** A community official certified the elevation, compaction, slope and slope protection for all fill placed in the flood plain consistent with NFIP regulations Part 65.5 for flood insurance map revisions.

______ **Elevation Certificate**: Certified as-built elevation of the building's lowest floor ________________; floodproofing level ____________. An Elevation Certificate (Part II) completed by a registered professional engineer or land surveyor certifying this elevation is on file

______ **Certificate of Occupancy or Compliance Issued** ________________
Date

FEMA

NATIONAL FLOOD INSURANCE PROGRAM

ELEVATION CERTIFICATE

AND

INSTRUCTIONS

NATIONAL FLOOD INSURANCE PROGRAM
ELEVATION CERTIFICATE

PAPERWORK REDUCTION ACT NOTICE

Public reporting burden for this data collection is estimated to average 3.75 hours per response. The burden estimate includes the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and submitting this form. You are not required to respond to this collection of information unless a valid OMB control number is displayed on this form. Send comments regarding the accuracy of the burden estimate and any suggestions for reducing the burden to: Information Collections Management, Department of Homeland Security, Federal Emergency Management Agency, 500 C Street SW, Washington DC 20472, Paperwork Reduction Project (1660-0008). **NOTE: Do not send your completed form to this address.**

PURPOSE OF THE ELEVATION CERTIFICATE

The Elevation Certificate is an important administrative tool of the National Flood Insurance Program (NFIP). It is to be used to provide elevation information necessary to ensure compliance with community floodplain management ordinances, to determine the proper insurance premium rate, and to support a request for a Letter of Map Amendment (LOMA) or Letter of Map Revision based on fill (LOMR-F).

The Elevation Certificate is required in order to properly rate Post-FIRM buildings, which are buildings constructed after publication of the Flood Insurance Rate Map (FIRM), located in flood insurance Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/AE, AR/A1-A30, AR/AH, and AR/AO. The Elevation Certificate is not required for Pre-FIRM buildings unless the building is being rated under the optional Post-FIRM flood insurance rules.

As part of the agreement for making flood insurance available in a community, the NFIP requires the community to adopt floodplain management regulations that specify minimum requirements for reducing flood losses. One such requirement is for the community to obtain the elevation of the lowest floor (including basement) of all new and substantially improved buildings, and maintain a record of such information. The Elevation Certificate provides a way for a community to document compliance with the community's floodplain management ordinance.

Use of this certificate does not provide a waiver of the flood insurance purchase requirement. Only a LOMA or LOMR-F from the Federal Emergency Management Agency (FEMA) can amend the FIRM and remove the Federal mandate for a lending institution to require the purchase of flood insurance. However, the lending institution has the option of requiring flood insurance even if a LOMA/LOMR-F has been issued by FEMA. The Elevation Certificate may be used to support a LOMA or LOMR-F request. Lowest floor and lowest adjacent grade elevations certified by a surveyor or engineer will be required if the certificate is used to support a LOMA or LOMR-F request. A LOMA or LOMR-F request must be submitted with either a completed FEMA MT-EZ or MT-1 package, whichever is appropriate.

This certificate is used only to certify building elevations. A separate certificate is required for floodproofing. Under the NFIP, non-residential buildings can be floodproofed up to or above the Base Flood Elevation (BFE). A floodproofed building is a building that has been designed and constructed to be watertight (substantially impermeable to floodwaters) below the BFE. Floodproofing of residential buildings is not permitted under the NFIP unless FEMA has granted the community an exception for residential floodproofed basements. The community must adopt standards for design and construction of floodproofed basements before FEMA will grant a basement exception. For both floodproofed non-residential buildings and residential floodproofed basements in communities that have been granted an exception by FEMA, a floodproofing certificate is required.

Additional guidance can be found in FEMA Publication 467-1, Floodplain Management Bulletin: Elevation Certificate, available on FEMA's website at http://www.fema.gov/library/viewRecord.do?id=1727.

U.S. DEPARTMENT OF HOMELAND SECURITY
Federal Emergency Management Agency
National Flood Insurance Program

ELEVATION CERTIFICATE

Important: Read the instructions on pages 1-9.

OMB No. 1660-0008
Expires March 31, 2012

SECTION A - PROPERTY INFORMATION

For Insurance Company Use:
Policy Number
Company NAIC Number

A1. Building Owner's Name

A2. Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No.

City State ZIP Code

A3. Property Description (Lot and Block Numbers, Tax Parcel Number, Legal Description, etc.)

A4. Building Use (e.g., Residential, Non-Residential, Addition, Accessory, etc.) ____

A5. Latitude/Longitude: Lat. ____ Long. ____ Horizontal Datum: ☐ NAD 1927 ☐ NAD 1983

A6. Attach at least 2 photographs of the building if the Certificate is being used to obtain flood insurance.

A7. Building Diagram Number____

A8. For a building with a crawlspace or enclosure(s):
a) Square footage of crawlspace or enclosure(s) ____ sq ft
b) No. of permanent flood openings in the crawlspace or enclosure(s) within 1.0 foot above adjacent grade ____
c) Total net area of flood openings in A8.b ____ sq in
d) Engineered flood openings? ☐ Yes ☐ No

A9. For a building with an attached garage:
a) Square footage of attached garage ____ sq ft
b) No. of permanent flood openings in the attached garage within 1.0 foot above adjacent grade ____
c) Total net area of flood openings in A9.b ____ sq in
d) Engineered flood openings? ☐ Yes ☐ No

SECTION B - FLOOD INSURANCE RATE MAP (FIRM) INFORMATION

B1. NFIP Community Name & Community Number	B2. County Name	B3. State

B4. Map/Panel Number	B5. Suffix	B6. FIRM Index Date	B7. FIRM Panel Effective/Revised Date	B8. Flood Zone(s)	B9. Base Flood Elevation(s) (Zone AO, use base flood depth)

B10. Indicate the source of the Base Flood Elevation (BFE) data or base flood depth entered in Item B9.
☐ FIS Profile ☐ FIRM Community Determined ☐ Other (Describe) ____

B11. Indicate elevation datum used for BFE in Item B9: ☐ NGVD 1929 ☐ NAVD 1988 ☐ Other (Describe) ____

B12. Is the building located in a Coastal Barrier Resources System (CBRS) area or Otherwise Protected Area (OPA)? ☐ Yes ☐ No
Designation Date____ ☐ CBRS ☐ OPA

SECTION C - BUILDING ELEVATION INFORMATION (SURVEY REQUIRED)

C1. Building elevations are based on: ☐ Construction Drawings* ☐ Building Under Construction* ☐ Finished Construction
*A new Elevation Certificate will be required when construction of the building is complete.

C2. Elevations – Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/AE, AR/A1-A30, AR/AH, AR/AO. Complete Items C2.a-h below according to the building diagram specified in Item A7. Use the same datum as the BFE.

Benchmark Utilized ____ Vertical Datum____

Conversion/Comments ____

Check the measurement used.

a) Top of bottom floor (including basement, crawlspace, or enclosure floor) ____.__ ☐ feet ☐ meters (Puerto Rico only)
b) Top of the next higher floor ____.__ ☐ feet ☐ meters (Puerto Rico only)
c) Bottom of the lowest horizontal structural member (V Zones only) ____.__ ☐ feet ☐ meters (Puerto Rico only)
d) Attached garage (top of slab) ____.__ ☐ feet ☐ meters (Puerto Rico only)
e) Lowest elevation of machinery or equipment servicing the building (Describe type of equipment and location in Comments) ____.__ ☐ feet ☐ meters (Puerto Rico only)
f) Lowest adjacent (finished) grade next to building (LAG) ____.__ ☐ feet ☐ meters (Puerto Rico only)
g) Highest adjacent (finished) grade next to building (HAG) ____.__ ☐ feet ☐ meters (Puerto Rico only)
h) Lowest adjacent grade at lowest elevation of deck or stairs, including structural support ____.__ ☐ feet ☐ meters (Puerto Rico only)

SECTION D - SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION

This certification is to be signed and sealed by a land surveyor, engineer, or architect authorized by law to certify elevation information. *I certify that the information on this Certificate represents my best efforts to interpret the data available. I understand that any false statement may be punishable by fine or imprisonment under 18 U.S. Code, Section 1001.*

☐ Check here if comments are provided on back of form.

Were latitude and longitude in Section A provided by a licensed land surveyor? ☐ Yes ☐ No

PLACE SEAL HERE

Certifier's Name License Number

Title Company Name

Address City State ZIP Code

Signature Date Telephone

IMPORTANT: In these spaces, copy the corresponding information from Section A.			For Insurance Company Use:
Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No.			Policy Number
City	State	ZIP Code	Company NAIC Number

SECTION D - SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION (CONTINUED)

Copy both sides of this Elevation Certificate for (1) community official, (2) insurance agent/company, and (3) building owner.

Comments

Signature Date

☐ Check here if attachments

SECTION E - BUILDING ELEVATION INFORMATION (SURVEY NOT REQUIRED) FOR ZONE AO AND ZONE A (WITHOUT BFE)

For Zones AO and A (without BFE), complete Items E1-E5. If the Certificate is intended to support a LOMA or LOMR-F request, complete Sections A, B, and C. For Items E1-E4, use natural grade, if available. Check the measurement used. In Puerto Rico only, enter meters.

E1. Provide elevation information for the following and check the appropriate boxes to show whether the elevation is above or below the highest adjacent grade (HAG) and the lowest adjacent grade (LAG).
a) Top of bottom floor (including basement, crawlspace, or enclosure) is ______. ____ ☐ feet ☐ meters ☐ above or ☐ below the HAG.
b) Top of bottom floor (including basement, crawlspace, or enclosure) is ______. ____ ☐ feet ☐ meters ☐ above or ☐ below the LAG.

E2. For Building Diagrams 6-9 with permanent flood openings provided in Section A Items 8 and/or 9 (see pages 8-9 of Instructions), the next higher floor (elevation C2.b in the diagrams) of the building is ________ . ____ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

E3. Attached garage (top of slab) is _______. _____ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

E4. Top of platform of machinery and/or equipment servicing the building is _______. ____ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

E5. Zone AO only: If no flood depth number is available, is the top of the bottom floor elevated in accordance with the community's floodplain management ordinance? ☐ Yes ☐ No ☐ Unknown. The local official must certify this information in Section G.

SECTION F - PROPERTY OWNER (OR OWNER'S REPRESENTATIVE) CERTIFICATION

The property owner or owner's authorized representative who completes Sections A, B, and E for Zone A (without a FEMA-issued or community-issued BFE) or Zone AO must sign here. *The statements in Sections A, B, and E are correct to the best of my knowledge.*

Property Owner's or Owner's Authorized Representative's Name

Address City State ZIP Code

Signature Date Telephone

Comments

☐ Check here if attachments

SECTION G - COMMUNITY INFORMATION (OPTIONAL)

The local official who is authorized by law or ordinance to administer the community's floodplain management ordinance can complete Sections A, B, C (or E), and G of this Elevation Certificate. Complete the applicable item(s) and sign below. Check the measurement used in Items G8 and G9.

G1. ☐ The information in Section C was taken from other documentation that has been signed and sealed by a licensed surveyor, engineer, or architect who is authorized by law to certify elevation information. (Indicate the source and date of the elevation data in the Comments area below.)

G2. ☐ A community official completed Section E for a building located in Zone A (without a FEMA-issued or community-issued BFE) or Zone AO.

G3. ☐ The following information (Items G4-G9) is provided for community floodplain management purposes.

G4. Permit Number	G5. Date Permit Issued	G6. Date Certificate Of Compliance/Occupancy Issued

G7. This permit has been issued for: ☐ New Construction ☐ Substantial Improvement

G8. Elevation of as-built lowest floor (including basement) of the building __________. _____ ☐ feet ☐ meters (PR) Datum__________

G9. BFE or (in Zone AO) depth of flooding at the building site __________. _____ ☐ feet ☐ meters (PR) Datum__________

G10. Community's design flood elevation __________. _____ ☐ feet ☐ meters (PR) Datum__________

Local Official's Name Title

Community Name Telephone

Signature Date

Comments

☐ Check here if attachments

Building Photographs

See Instructions for Item A6.

	For Insurance Company Use:
Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No.	Policy Number
City State ZIP Code	Company NAIC Number

If using the Elevation Certificate to obtain NFIP flood insurance, affix at least two building photographs below according to the instructions for Item A6. Identify all photographs with: date taken; “Front View” and “Rear View”; and, if required, “Right Side View” and “Left Side View.” If submitting more photographs than will fit on this page, use the Continuation Page on the reverse.

Building Photographs

Continuation Page

	For Insurance Company Use:
Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No.	Policy Number
City State ZIP Code	Company NAIC Number

If submitting more photographs than will fit on the preceding page, affix the additional photographs below. Identify all photographs with: date taken; “Front View” and “Rear View”; and, if required, “Right Side View” and “Left Side View.”

INSTRUCTIONS FOR COMPLETING THE ELEVATION CERTIFICATE

The Elevation Certificate is to be completed by a land surveyor, engineer, or architect who is authorized by law to certify elevation information when elevation information is required for Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/AE, AR/A1-A30, AR/AH, or AR/AO. Community officials who are authorized by law or ordinance to provide floodplain management information may also complete this form. For Zones AO and A (without BFE), a community official, a property owner, or an owner's representative may provide information on this certificate, unless the elevations are intended for use in supporting a request for a LOMA or LOMR-F. Certified elevations must be included if the purpose of completing the Elevation Certificate is to obtain a LOMA or LOMR-F.

The property owner, the owner's representative, or local official who is authorized by law to administer the community floodplain ordinance can complete Section A and Section B. The partially completed form can then be given to the land surveyor, engineer, or architect to complete Section C. The land surveyor, engineer, or architect should verify the information provided by the property owner or owner's representative to ensure that this certificate is complete.

In Puerto Rico only, elevations for building information and flood hazard information may be entered in meters.

SECTION A – PROPERTY INFORMATION

Items A1-A4. This section identifies the building, its location, and its owner. Enter the name(s) of the building owner(s), the building's complete street address, and the lot and block numbers. If the building's address is different from the owner's address, enter the address of the building being certified. If the address is a rural route or a Post Office box number, enter the lot and block numbers, the tax parcel number, the legal description, or an abbreviated location description based on distance and direction from a fixed point of reference. For the purposes of this certificate, "building" means both a building and a manufactured (mobile) home.

A map may be attached to this certificate to show the location of the building on the property. A tax map, FIRM, or detailed community map is appropriate. If no map is available, provide a sketch of the property location, and the location of the building on the property. Include appropriate landmarks such as nearby roads, intersections, and bodies of water. For building use, indicate whether the building is residential, non-residential, an addition to an existing residential or non-residential building, an accessory building (e.g., garage), or other type of structure. Use the Comments area of the appropriate section if needed, or attach additional comments.

Item A5. Provide latitude and longitude coordinates for the center of the front of the building. Use either decimal degrees (e.g., 39.5043°, -110.7585°) or degrees, minutes, seconds (e.g., 39° 30' 15.5", -110° 45' 30.7") format. If decimal degrees are used, provide coordinates to at least 4 decimal places or better. When using degrees, minutes, seconds, provide seconds to at least 1 decimal place or better. The latitude and longitude coordinates must be accurate within 66 feet. When the latitude and longitude are provided by a surveyor, check the "Yes" box in Section D and indicate the method used to determine the latitude and longitude in the Comments area of Section D. If the Elevation Certificate is being certified by other than a licensed surveyor, engineer, or architect, this information is not required. Provide the type of datum used to obtain the latitude and longitude. FEMA prefers the use of NAD 1983.

Item A6. If the Elevation Certificate is being used to obtain flood insurance through the NFIP, the certifier must provide at least two photographs showing the front and rear of the building taken within 90 days from the date of certification. The photographs must be taken with views confirming the building description and diagram number provided in Section A. To the extent possible, these photographs should show the entire building including foundation. If the building has split-level or multi-level areas, provide at least two additional photographs showing side views of the building. In addition, when applicable, provide a photograph of the foundation showing a representative example of the flood openings or vents. All photographs must be in color and measure at least 3"x3". Digital photographs are acceptable.

Item A7. Select the diagram on pages 7-9 that best represents the building. Then enter the diagram number and use the diagram to identify and determine the appropriate elevations requested in Items C2.a-h. If you are unsure of the correct diagram, select the diagram that most closely resembles the building being certified.

Item A8.a Provide the square footage of the crawlspace or enclosure(s) below the lowest elevated floor of an elevated building with or without permanent flood openings. Take the measurement from the outside of the crawlspace or enclosure(s). Examples of elevated buildings constructed with crawlspace and enclosure(s) are shown in Diagrams 6-9 on pages 8-9. Diagram 2, 4, or 9 should be used for a building constructed with a crawlspace floor that is below the exterior grade on all sides.

Items A8.b-d Enter in Item A8.b the number of permanent flood openings in the crawlspace or enclosure(s) that are no higher than 1.0 foot above the higher of the exterior or interior grade or floor immediately below the opening. (A permanent flood opening is a flood vent or other opening that allows the free passage of water automatically in both directions without human intervention.) If the interior grade elevation is used, note this in the Comments area of Section D. Estimate the total net area of all such permanent flood openings in square inches, excluding any bars, louvers, or other covers of the permanent flood openings, and enter the total in Item A8.c. If the net area cannot be reasonably estimated, provide the size of the flood openings without consideration of any covers and indicate in the Comments area the type of cover that exists in the flood openings. Indicate in Item A8.d whether the flood openings are engineered. If applicable, attach a copy of the Individual Engineered Flood Openings Certification or an Evaluation Report issued by the International Code Council Evaluation Service (ICC ES), if you have it. If the crawlspace or enclosure(s) have no permanent flood openings, or if the openings are not within 1.0 foot above adjacent grade, enter "0" (zero) in Items A8.b-c.

Item A9.a Provide the square footage of the attached garage with or without permanent flood openings. Take the measurement from the outside of the garage.

Items A9.b-d Enter in Item A9.b the number of permanent flood openings in the attached garage that are no higher than 1.0 foot above the higher of the exterior or interior grade or floor immediately below the opening. (A permanent flood opening is a flood vent or other opening that allows the free passage of water automatically in both directions without human intervention.) If the interior grade elevation is used, note this in the Comments area of Section D. This includes any openings that are in the garage door that are no higher than 1.0 foot above the adjacent grade. Estimate the total net area of all such permanent flood openings in square inches and enter the total in Item A9.c. If the net area cannot be reasonably estimated, provide the size of the flood openings without consideration of any covers and indicate in the Comments area the type of cover that exists in the flood openings. Indicate in Item A9.d whether the flood openings are engineered. If applicable, attach a copy of the Individual Engineered Flood Openings Certification or an Evaluation Report issued by the International Code Council Evaluation Service (ICC ES), if you have it. If the garage has no permanent flood openings, or if the openings are not within 1.0 foot above adjacent grade, enter "0" (zero) in Items A9.b-c.

SECTION B - FLOOD INSURANCE RATE MAP (FIRM) INFORMATION

Complete the Elevation Certificate on the basis of the FIRM in effect at the time of the certification.

The information for Section B is obtained by reviewing the FIRM panel that includes the building's location. Information about the current FIRM is available from the Federal Emergency Management Agency (FEMA) by calling 1-800-358-9616. If a Letter of Map Amendment (LOMA) or Letter of Map Revision (LOMR-F) has been issued by FEMA, please provide the letter date and case number in the Comments area of Section D or Section G, as appropriate.

For a building in an area that has been annexed by one community but is shown on another community's FIRM, enter the community name and 6-digit number of the annexing community in Item B1, the name of the county or new county, if necessary, in Item B2, and the FIRM index date for the annexing community in Item B6. Enter information from the actual FIRM panel that shows the building location, even if it is the FIRM for the previous jurisdiction, in Items B4, B5, B7, B8, and B9.

If the map in effect at the time of the building's construction was other than the current FIRM, and you have the past map information pertaining to the building, provide the information in the Comments area of Section D.

Item B1. NFIP Community Name & Community Number. Enter the complete name of the community in which the building is located and the associated 6-digit community number. For a newly incorporated community, use the name and 6-digit number of the new community. Under the NFIP, a "community" is any State or area or political subdivision thereof, or any Indian tribe or authorized native organization, that has authority to adopt and enforce floodplain management regulations for the areas within its jurisdiction. To determine the current community number, see the NFIP *Community Status Book*, available on FEMA's web site at http://www.fema.gov/fema/csb.shtm, or call 1-800-358-9616.

Item B2. County Name. Enter the name of the county or counties in which the community is located. For an unincorporated area of a county, enter "unincorporated area." For an independent city, enter "independent city."

Item B3. State. Enter the 2-letter state abbreviation (for example, VA, TX, CA).

Items B4-B5. Map/Panel Number and Suffix. Enter the 10-character "Map Number" or "Community Panel Number" shown on the FIRM where the building or manufactured (mobile) home is located. For maps in a county-wide format, the sixth character of the "Map Number" is the letter "C" followed by a four-digit map number. For maps not in a county-wide format, enter the "Community Panel Number" shown on the FIRM.

Item B6. FIRM Index Date. Enter the effective date or the map revised date shown on the FIRM Index.

Item B7. FIRM Panel Effective/Revised Date. Enter the map effective date or the map revised date shown on the FIRM panel. This will be the latest of all dates shown on the map. The current FIRM panel effective date can be determined by calling 1-800-358-9616.

Item B8. Flood Zone(s). Enter the flood zone, or flood zones, in which the building is located. All flood zones containing the letter "A" or "V" are considered Special Flood Hazard Areas. The flood zones are A, AE, A1-A30, V, VE, V1-V30, AH, AO, AR, AR/A, AR/AE, AR/A1-A30, AR/AH, and AR/AO. Each flood zone is defined in the legend of the FIRM panel on which it appears.

Item B9. Base Flood Elevation(s). Using the appropriate Flood Insurance Study (FIS) Profile, Floodway Data Table, or FIRM panel, locate the property and enter the BFE (or base flood depth) of the building site. If the building is located in more than one flood zone in Item B8, list all appropriate BFEs in Item B9. BFEs are shown on a FIRM or FIS Profile for Zones A1-A30, AE, AH, V1-V30, VE, AR, AR/A, AR/AE, AR/A1-A30, AR/AH, and AR/AO; flood depth numbers are shown for Zone AO. Use the AR BFE if the building is located in any of Zones AR/A, AR/AE, AR/A1-A30, AR/AH, or AR/AO. In A or V zones where BFEs are not provided on the FIRM, BFEs may be available from another source. For example, the community may have established BFEs or obtained BFE data from other sources for the building site. For subdivisions and other developments of more than 50 lots or 5 acres, establishment of BFEs is required by the community's floodplain management ordinance. If a BFE is obtained from another source, enter the BFE in Item B9. In an A Zone where BFEs are not available, complete Section E and enter N/A for Section B, Item B9. Enter the BFE to the nearest tenth of a foot (nearest tenth of a meter, in Puerto Rico).

Item B10. Indicate the source of the BFE that you entered in Item B9. If the BFE is from a source other than FIS Profile, FIRM, or community, describe the source of the BFE.

Item B11. Indicate the elevation datum to which the elevations on the applicable FIRM are referenced as shown on the map legend. The vertical datum is shown in the Map Legend and/or the Notes to Users on the FIRM.

Item B12. Indicate whether the building is located in a Coastal Barrier Resources System (CBRS) area or Otherwise Protected Area (OPA). (OPAs are portions of coastal barriers that are owned by Federal, State, or local governments or by certain non-profit organizations and used primarily for natural resources protection.) Federal flood insurance is prohibited in designated CBRS areas or OPAs for buildings or manufactured (mobile) homes built or substantially improved after the date of the CBRS or OPA designation. For the first CBRS designations, that date is October 1, 1983. Information about CBRS areas and OPAs may be obtained on the FEMA web site at http://www.fema.gov/business/nfip/cbrs/cbrs.shtm.

SECTION C - BUILDING ELEVATION INFORMATION (SURVEY REQUIRED)

Complete Section C if the building is located in any of Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/AE, AR/A1-A30, AR/AH, or AR/AO, or if this certificate is being used to support a request for a LOMA or LOMR-F. If the building is located in Zone AO or Zone A (without BFE), complete Section E instead. To ensure that all required elevations are obtained, it may be necessary to enter the building (for instance, if the building has a basement or sunken living room, split-level construction, or machinery and equipment).

Surveyors may not be able to gain access to some crawlspaces to shoot the elevation of the crawlspace floor. If access to the crawlspace is limited or cannot be gained, follow one of these procedures.

- Use a yardstick or tape measure to measure the height from the floor of the crawlspace to the "next higher floor," and then subtract the crawlspace height from the elevation of the "next higher floor." If there is no access to the crawlspace, use the exterior grade next to the structure to measure the height of the crawlspace to the "next higher floor."
- Contact the local floodplain administrator of the community in which the building is located. The community may have documentation of the elevation of the crawlspace floor as part of the permit issued for the building.
- If the property owner has documentation or knows the height of the crawlspace floor to the next higher floor, try to verify this by looking inside the crawlspace through any openings or vents.

In all three cases, provide the elevation in the Comments area of Section D on the back of the form and a brief description of how the elevation was obtained.

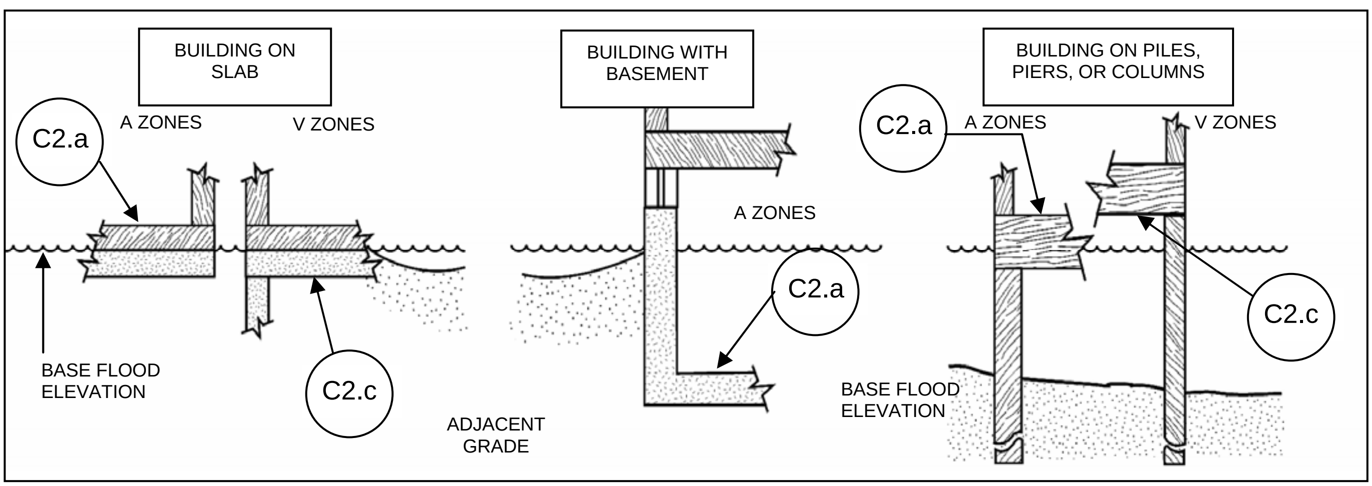
Item C1. Indicate whether the elevations to be entered in this section are based on construction drawings, a building under construction, or finished construction. For either of the first two choices, a post-construction Elevation Certificate will be required when construction is complete. If the building is under construction, include only those elevations that can be surveyed in Items C2.a-h. Use the Comments area of Section D to provide elevations obtained from the construction plans or drawings. Select "Finished Construction" only when all machinery and/or equipment such as furnaces, hot water heaters, heat pumps, air conditioners, and elevators and their associated equipment have been installed and the grading around the building is completed.

Item C2. A field survey is required for Items C2.a-h. Most control networks will assign a unique identifier for each benchmark. For example, the National Geodetic Survey uses the Permanent Identifier (PID). For the benchmark utilized, provide the PID or other unique identifier assigned by the maintainer of the benchmark. For GPS survey, indicate the benchmark used for the base station, the Continuously Operating Reference Stations (CORS) sites used for an On-line Positioning User Service (OPUS) solution (also attach the OPUS report), or the name of the Real Time Network used.

Also provide the vertical datum for the benchmark elevation. All elevations for the certificate, including the elevations for Items C2.a-h, must use the same datum on which the BFE is based. Show the conversion from the field survey datum used if it differs from the datum used for the BFE entered in Item B9 and indicate the conversion software used. Show the datum conversion, if applicable, in this section or in the Comments area of Section D.

For property experiencing ground subsidence, the most recent reference mark elevations must be used for determining building elevations. However, when subsidence is involved, the BFE should not be adjusted. Enter elevations in Items C2.a-h to the nearest tenth of a foot (nearest tenth of a meter, in Puerto Rico).

Items C2.a-d Enter the building elevations (excluding the attached garage) indicated by the selected building diagram (Item A7) in Items C2.a-c. If there is an attached garage, enter the elevation for top of attached garage slab in Item C2.d. (Because elevation for top of attached garage slab is self-explanatory, attached garages are not illustrated in the diagrams.) If the building is located in a V zone on the FIRM, complete Item C2.c. If the flood zone cannot be determined, enter elevations for all of Items C2.a-h. For buildings in A zones, elevations a, b, d, and e should be measured at the top of the floor. For buildings in V zones, elevation c must be measured at the bottom of the lowest horizontal structural member of the floor (see drawing below). For buildings elevated on a crawlspace, Diagrams 8 and 9, enter the elevation of the top of the crawlspace floor in Item C2.a, whether or not the crawlspace has permanent flood openings (flood vents). *If any item does not apply to the building, enter "N/A" for not applicable.*



Item C2.e Enter the lowest platform elevation of at least one of the following machinery and equipment items: elevators and their associated equipment, furnaces, hot water heaters, heat pumps, and air conditioners in an attached garage or enclosure or on an open utility platform that provides utility services for the building. Note that elevations for these specific machinery and equipment items are required in order to rate the building for flood insurance. Local floodplain management officials are required to ensure that all machinery and equipment servicing the building are protected from flooding. Thus, local officials may require that elevation information for all machinery and equipment, including ductwork, be documented on the Elevation Certificate. If the machinery and/or equipment is mounted to a wall, pile, etc., enter the platform elevation of the machinery and/or equipment. Indicate machinery/equipment type and its general location, e.g., on floor inside garage or on platform affixed to exterior wall, in the Comments area of Section D or Section G, as appropriate. *If this item does not apply to the building, enter "N/A" for not applicable.*

Items C2.f-g Enter the elevation of the ground, sidewalk, or patio slab immediately next to the building. For Zone AO, use the natural grade elevation, if available. This measurement must be to the nearest tenth of a foot (nearest tenth of a meter, in Puerto Rico) if this certificate is being used to support a request for a LOMA or LOMR-F.

Item C2.h Enter the lowest grade elevation at the deck support or stairs. For Zone AO, use the natural grade elevation, if available. This measurement must be to the nearest tenth of a foot (nearest tenth of a meter, in Puerto Rico) if this certificate is being used to support a request for a LOMA or LOMR-F.

SECTION D - SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION

Complete as indicated. This section of the Elevation Certificate may be signed by only a land surveyor, engineer, or architect who is authorized by law to certify elevation information. Place your license number, your seal (as allowed by the State licensing board), your signature, and the date in the box in Section D. You are certifying that the information on this certificate represents your best efforts to interpret the data available and that you understand that any false statement may be punishable by fine or imprisonment under 18 U.S. Code, Section 1001. Use the Comments area of Section D, on the back of the certificate, to provide datum, elevation, openings, or other relevant information not specified on the front.

SECTION E - BUILDING ELEVATION INFORMATION (SURVEY NOT REQUIRED) FOR ZONE AO & ZONE A (WITHOUT BFE)

Complete Section E if the building is located in Zone AO or Zone A (without BFE). Otherwise, complete Section C instead. Explain in the Section F Comments area if the measurement provided under Items E1- E4 is based on the “natural grade.”

Items E1.a and b Enter in Item E1.a the height to the nearest tenth of a foot (tenth of a meter in Puerto Rico) of the top of the bottom floor (as indicated in the applicable diagram) above or below the highest adjacent grade (HAG). Enter in Item E1.b the height to the nearest tenth of a foot (tenth of a meter in Puerto Rico) of the top of the bottom floor (as indicated in the applicable diagram) above or below the lowest adjacent grade (LAG). For buildings in Zone AO, the community’s floodplain management ordinance requires the lowest floor of the building be elevated above the highest adjacent grade at least as high as the depth number on the FIRM. Buildings in Zone A (without BFE) may qualify for a lower insurance rate if an engineered BFE is developed at the site.

Item E2. For Building Diagrams 6-9 with permanent flood openings (see pages 8-9), enter the height to the nearest tenth of a foot (tenth of a meter in Puerto Rico) of the next higher floor or elevated floor (as indicated in the applicable diagram) above or below the highest adjacent grade (HAG).

Item E3. Enter the height to the nearest tenth of a foot (tenth of a meter in Puerto Rico), in relation to the highest adjacent grade next to the building, for the top of attached garage slab. (Because elevation for top of attached garage slab is self-explanatory, attached garages are not illustrated in the diagrams.) *If this item does not apply to the building, enter “N/A” for not applicable.*

Item E4. Enter the height to the nearest tenth of a foot (tenth of a meter in Puerto Rico), in relation to the highest adjacent grade next to the building, of the platform elevation that supports the machinery and/or equipment servicing the building. Indicate machinery/equipment type in the Comments area of Section F. *If this item does not apply to the building, enter “N/A” for not applicable.*

Item E5. For those communities where this base flood depth is not available, the community will need to determine whether the top of the bottom floor is elevated in accordance with the community’s floodplain management ordinance.

SECTION F - PROPERTY OWNER (OR OWNER’S REPRESENTATIVE) CERTIFICATION

Complete as indicated. This section is provided for certification of measurements taken by a property owner or property owner’s representative when responding to Sections A, B, and E. The address entered in this section must be the actual mailing address of the property owner or property owner’s representative who provided the information on the certificate.

SECTION G - COMMUNITY INFORMATION (OPTIONAL)

Complete as indicated. The community official who is authorized by law or ordinance to administer the community’s floodplain management ordinance can complete Sections A, B, C (or E), and G of this Elevation Certificate. Section C may be filled in by the local official as provided in the instructions below for Item G1. If the authorized community official completes Sections C, E, or G, complete the appropriate item(s) and sign this section.

Check **Item G1** if Section C is completed with elevation data from other documentation, including elevations obtained from the Community Rating System Elevation Software, that has been signed and sealed by a licensed surveyor, engineer, or architect who is authorized by law to certify elevation information. Indicate the source of the elevation data and the date obtained in the Comments area of Section G. If you are both a community official and a licensed land surveyor, engineer, or architect authorized by law to certify elevation information, and you performed the actual survey for a building in Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/A1-A30, AR/AE, AR/AH, or AR/AO, you must also complete Section D.

Check **Item G2** if information is entered in Section E by the community for a building in Zone A (without a FEMA-issued or community-issued BFE) or Zone AO.

Check **Item G3** if the information in Items G4-G10 has been completed for community floodplain management purposes to document the as-built lowest floor elevation of the building. Section C of the Elevation Certificate records the elevation of various building components but does not determine the lowest floor of the building or whether the building, as constructed, complies with the community's floodplain management ordinance. This must be done by the community. Items G4-G10 provide a way to document these determinations.

Item G4. Permit Number. Enter the permit number or other identifier to key the Elevation Certificate to the permit issued for the building.

Item G5. Date Permit Issued. Enter the date the permit was issued for the building.

Item G6. Date Certificate of Compliance/Occupancy Issued. Enter the date that the Certificate of Compliance or Occupancy or similar written official documentation of as-built lowest floor elevation was issued by the community as evidence that all work authorized by the floodplain development permit has been completed in accordance with the community's floodplain management laws or ordinances.

Item G7. New Construction or Substantial Improvement. Check the applicable box. "Substantial Improvement" means any reconstruction, rehabilitation, addition, or other improvement of a building, the cost of which equals or exceeds 50 percent of the market value of the building before the start of construction of the improvement. The term includes buildings that have incurred substantial damage, regardless of the actual repair work performed.

Item G8. As-built lowest floor elevation. Enter the elevation of the lowest floor (including basement) when the construction of the building is completed and a final inspection has been made to confirm that the building is built in accordance with the permit, the approved plans, and the community's floodplain management laws or ordinances. Indicate the elevation datum used.

Item G9. BFE. Using the appropriate FIRM panel, FIS Profile, or other data source, locate the property and enter the BFE (or base flood depth) of the building site. Indicate the elevation datum used.

Item G10. Community's design flood elevation. Enter the elevation (including freeboard above the BFE) to which the community requires the lowest floor to be elevated. Indicate the elevation datum used.

Enter your name, title, and telephone number, and the name of the community. Sign and enter the date in the appropriate blanks.

BUILDING DIAGRAMS

The following diagrams illustrate various types of buildings. Compare the features of the building being certified with the features shown in the diagrams and select the diagram most applicable. Enter the diagram number in Item A7, the square footage of crawlspace or enclosure(s) and the area of flood openings in square inches in Items A8.a-c, the square footage of attached garage and the area of flood openings in square inches in Items A9.a-c, and the elevations in Items C2.a-h.

In A zones, the floor elevation is taken at the top finished surface of the floor indicated; in V zones, the floor elevation is taken at the bottom of the lowest horizontal structural member (see drawing in instructions for Section C).

DIAGRAM 1A

All slab-on-grade single- and multiple-floor buildings (other than split-level) and high-rise buildings, either detached or row type (e.g., townhouses); with or without attached garage.

Distinguishing Feature – The bottom floor is at or above ground level (grade) on at least one side.*

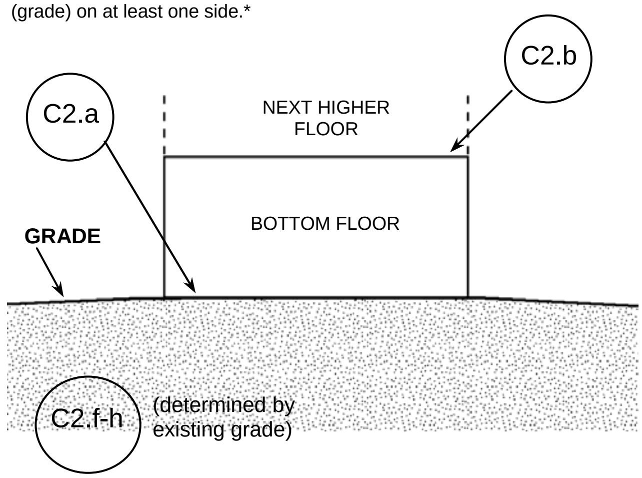


DIAGRAM 1B

All raised-slab-on-grade or slab-on-stem-wall-with-fill single- and multiple-floor buildings (other than split-level), either detached or row type (e.g., townhouses); with or without attached garage.

Distinguishing Feature – The bottom floor is at or above ground level (grade) on at least one side.*

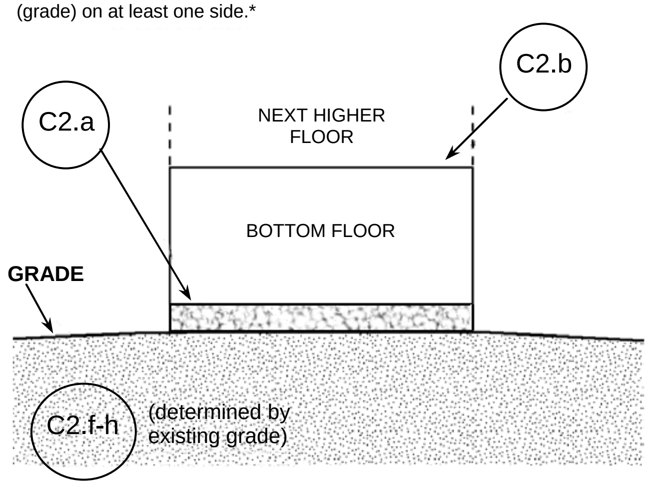
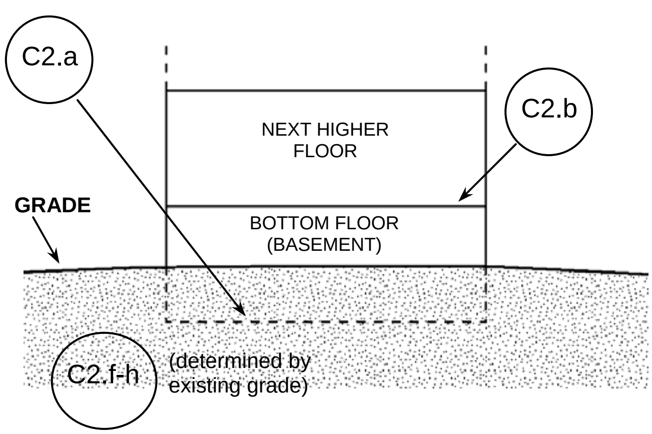


DIAGRAM 2

All single- and multiple-floor buildings with basement (other than split-level) and high-rise buildings with basement, either detached or row type (e.g., townhouses); with or without attached garage.

Distinguishing Feature – The bottom floor (basement or underground garage) is below ground level (grade) on all sides.*



* A floor that is below ground level (grade) on all sides is considered a basement even if the floor is used for living purposes, or as an office, garage, workshop, etc

DIAGRAM 3

All split-level buildings that are slab-on-grade, either detached or row type (e.g., townhouses); with or without attached garage.

Distinguishing Feature – The bottom floor (excluding garage) is at or above ground level (grade) on at least one side.*

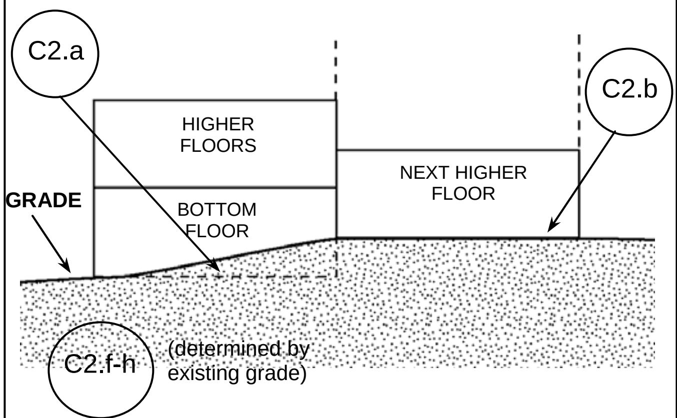


DIAGRAM 4

All split-level buildings (other than slab-on-grade), either detached or row type (e.g., townhouses); with or without attached garage.

Distinguishing Feature – The bottom floor (basement or underground garage) is below ground level (grade) on all sides.*

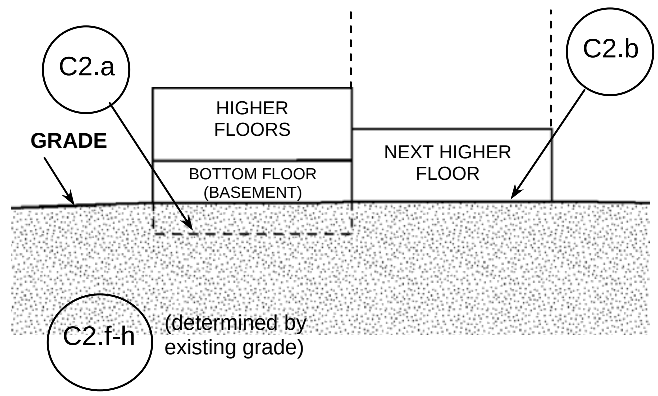


DIAGRAM 5

All buildings elevated on piers, posts, piles, columns, or parallel shear walls. No obstructions below the elevated floor.

Distinguishing Feature – For all zones, the area below the elevated floor is open, with no obstruction to flow of flood waters (open lattice work and/or insect screening is permissible).

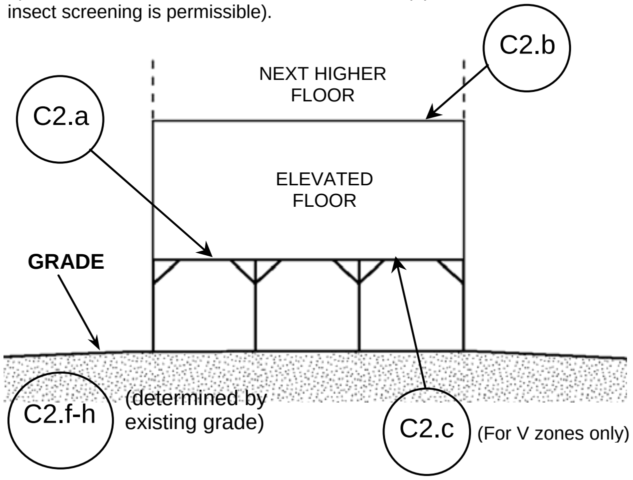
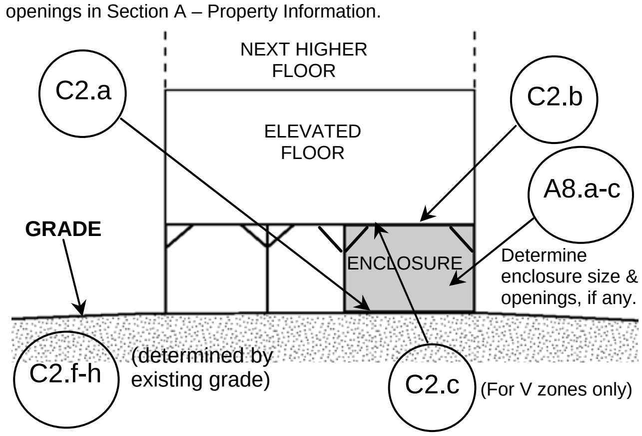


DIAGRAM 6

All buildings elevated on piers, posts, piles, columns, or parallel shear walls with full or partial enclosure below the elevated floor.

Distinguishing Feature – For all zones, the area below the elevated floor is enclosed, either partially or fully. In A Zones, the partially or fully enclosed area below the elevated floor is with or without openings** present in the walls of the enclosure. Indicate information about enclosure size and openings in Section A – Property Information.



* A floor that is below ground level (grade) on all sides is considered a basement even if the floor is used for living purposes, or as an office, garage, workshop, etc.

** An "opening" is a permanent opening that allows for the free passage of water automatically in both directions without human intervention. Under the NFIP, a minimum of two openings is required for enclosures or crawlspaces. The openings shall provide a total net area of not less than one square inch for every square foot of area enclosed, excluding any bars, louvers, or other covers of the opening. Alternatively, an Individual Engineered Flood Openings Certification or an Evaluation Report issued by the International Code Council Evaluation Service (ICC ES) must be submitted to document that the design of the openings will allow for the automatic equalization of hydrostatic flood forces on exterior walls. A window, a door, or a garage door is not considered an opening; openings may be installed in doors. Openings shall be on at least two sides of the enclosed area. If a building has more than one enclosed area, each area must have openings to allow floodwater to directly enter. The bottom of the openings must be no higher than one foot above the higher of the exterior or interior grade or floor immediately below the opening. For more guidance on openings, see NFIP Technical Bulletin 1.

DIAGRAM 7

All buildings elevated on full-story foundation walls with a partially or fully enclosed area below the elevated floor. This includes walkout levels, where at least one side is at or above grade. The principal use of this building is located in the elevated floors of the building.

Distinguishing Feature – For all zones, the area below the elevated floor is enclosed, either partially or fully. In A Zones, the partially or fully enclosed area below the elevated floor is with or without openings* present in the walls of the enclosure. Indicate information about enclosure size and openings in Section A – Property Information.

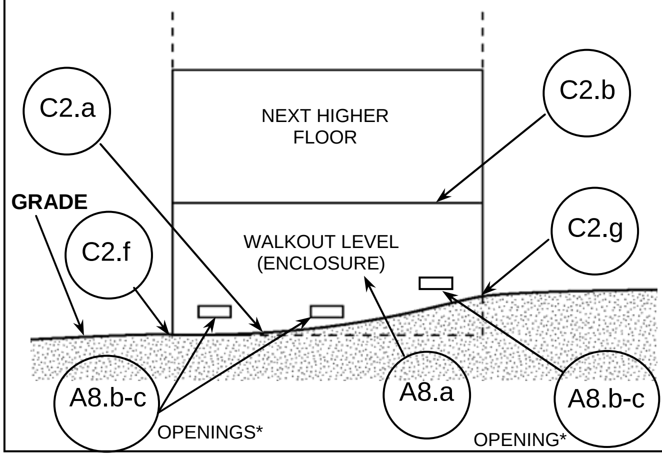


DIAGRAM 8

All buildings elevated on a crawlspace with the floor of the crawlspace at or above grade on at least one side, with or without an attached garage.

Distinguishing Feature – For all zones, the area below the first floor is enclosed by solid or partial perimeter walls. In all A zones, the crawlspace is with or without openings* present in the walls of the crawlspace. Indicate information about crawlspace size and openings in Section A – Property Information.

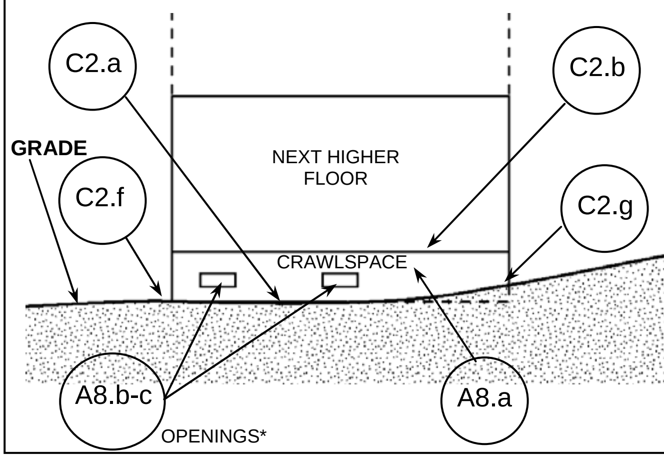
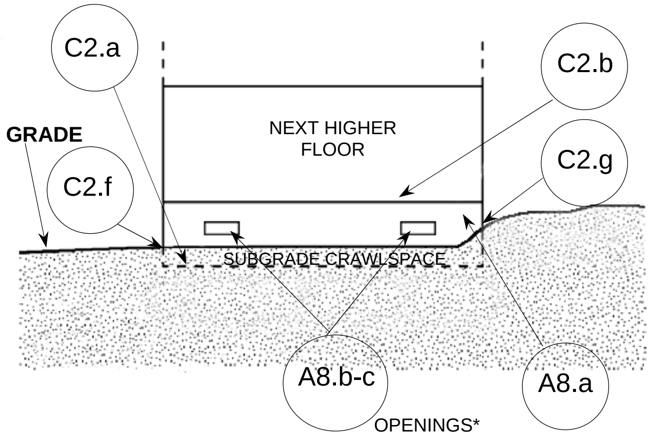


DIAGRAM 9

All buildings (other than split-level) elevated on a sub-grade crawlspace, with or without attached garage.

Distinguishing Feature – The bottom (crawlspace) floor is at or below ground level (grade) on all sides.** (If the distance from the crawlspace floor to the top of the next higher floor is more than 5 feet, or the crawlspace floor is more than 2 feet below the grade (LAG) on all sides, use Diagram 2.)



* An "opening" is a permanent opening that allows for the free passage of water automatically in both directions without human intervention. Under the NFIP, a minimum of two openings is required for enclosures or crawlspaces. The openings shall provide a total net area of not less than one square inch for every square foot of area enclosed, excluding any bars, louvers, or other covers of the opening. Alternatively, an Individual Engineered Flood Openings Certification or an Evaluation Report issued by the International Code Council Evaluation Service (ICC ES) must be submitted to document that the design of the openings will allow for the automatic equalization of hydrostatic flood forces on exterior walls. A window, a door, or a garage door is not considered an opening; openings may be installed in doors. Openings shall be on at least two sides of the enclosed area. If a building has more than one enclosed area, each area must have openings to allow floodwater to directly enter. The bottom of the openings must be no higher than one foot above the higher of the exterior or interior grade or floor immediately below the opening. For more guidance on openings, see NFIP Technical Bulletin 1.

** A floor that is below ground level (grade) on all sides is considered a basement even if the floor is used for living purposes, or as an office, garage, workshop, etc.

GUIDANCE FOR "NO-RISE / NO-IMPACT" CERTIFICATION FOR PROPOSED DEVELOPMENTS IN REGULATORY FLOODWAYS

The National Flood Insurance Program (NFIP) floodplain management criterion that is adopted by all participating communities in their local ordinances, as described in Title 44 of the Code of Federal Regulations, Section 60.3(d)(3), states:

> "A community shall prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in any increase in flood levels within the community during the occurrence of the base flood discharge."

Prior to issuing any development permits involving activities in a regulatory floodway, the community must obtain a certification stating the proposed development will not impact the pre-project base flood elevations, regulatory floodway elevations, or regulatory floodway widths. The certification should be obtained from the permittee and be signed and sealed by a professional engineer in accordance with State Licensing Board specifications.

The engineering or "No-Rise / No-Impact" certification must be supported by technical data. The supporting technical data should be based upon the standard step-backwater hydraulic model utilized to develop the regulatory floodway shown on the community's effective Flood Insurance Rate Map (FIRM) or Flood Boundary and Floodway Map (FBFM) and the results tabulated in the community's Flood Insurance Study (FIS).

Communities are required to review and approve or disapprove the "No-Rise/No-Impact" submittals; however, they may request technical assistance and review from the FEMA regional office. If this alternative is chosen, the submittal will be treated as a Conditional Letter of Map Revision (CLOMR) by the National Service Provider, and will be subject to the same fees as such.

To support a "No-Rise / No-Impact" certification for proposed developments encroaching onto the regulatory floodway, a community will require that the following procedures be followed:

1. Currently Effective Model

Furnish a written request for the step-backwater hydraulic model for the specified stream and community, identifying the limits of the requested data. A fee will be assessed for providing the data. Send data requests to:

FEMA Project Library
3601 Eisenhower Avenue
Alexandria, VA 22304-6425
Fax: (703) 751-7391

2. Duplicate Effective Model

Upon receipt of the step-backwater hydraulic model, the engineer should run the effective hydraulic model to duplicate the data in the effective FIS.

3. Existing Conditions Model

Revise the duplicate effective model to reflect site-specific existing conditions by adding new cross-sections (two or more) in the area of the proposed development, without the proposed development in place. Regulatory floodway limits should be manually set at the new cross-section locations by measuring from the effective FIRM or FBFM. The cumulative reach lengths of the waterway should remain unchanged. The results of these analyses will indicate the base flood elevations and the regulatory floodway elevations for the effective hydraulic model revised to incorporate existing conditions at the proposed project site.

4. Proposed Conditions Model

Modify the existing conditions models to reflect the proposed development using the new cross-sections, while retaining the currently adopted regulatory floodway widths. The overbank roughness parameters should remain the same unless a valid explanation of how the proposed development will impact the roughness parameters is included with the supporting data. The results of this floodway hydraulic model will indicate the regulatory floodway elevations for proposed conditions at the project site. These results must indicate NO impact on the base flood elevations, regulatory floodway elevations, or regulatory floodway widths shown in the duplicate Effective Model or in the Existing Conditions Model (items 2 and 3 above, respectively).

The "no-impact" analysis along with supporting data and the original engineering certification must be reviewed by the appropriate community official prior to issuing a development permit. The original effective FIS model, the duplicate effective FIS model, the Existing Conditions Model, and the Proposed Conditions Model should be reviewed for any changes in the base flood elevations, regulatory floodway elevations and floodway widths.

The “No-Rise / No-Impact” supporting data should include, but may not be limited to:

(1) Copy of the currently effective FIS hydraulic models (legible hard copy and a disc (if available))

(2) Duplicate effective FIS hydraulic models (hard copy and a disc).

(3) Existing conditions hydraulic models (hard copy and a disc).

(4) Proposed conditions hydraulics models (hard copy and a disc)

(5) Annotated effective FIRM or FBFM and topographic map, showing regulatory floodplain and floodway boundaries, the additional cross-sections, and the site location along with the proposed topographic modifications.

(6) Documentation clearly stating analysis procedures. All modifications made to the duplicate effective hydraulic models to correctly represent existing conditions, as well as those made to the existing conditions models to represent proposed conditions should be well documented and submitted with all supporting data.

(7) Annotated effective Floodway Data Table (from the FIS report).

(8) Statement defining source of additional cross-sections, topographic data, and other supporting information.

(9) Cross-section plots of the additional cross sections for existing and proposed conditions hydraulic models.

(10) Certified planimetric (boundary survey) information indicating the location of structures on the property.

(11) Hard copy of all output files.

(12) Clear explanation of how roughness parameters were obtained (if different from those used in the effective hydraulic models).

(13) Engineering certification (sample attached).

The engineering “No-Rise / No-Impact” certification and supporting technical data must stipulate NO impact or NO changes to the base flood elevations, regulatory floodway elevations, or regulatory floodway widths at the new cross-sections and at all existing cross-sections anywhere in the model. Therefore, the revised computer model should be run for a sufficient distance upstream and downstream of the development site to insure proper “No-Rise / No-Impact” certifications.

Attached is a SAMPLE “No-Rise / No-Impact” certification form that can be completed by a registered professional engineer and supplied to the community along with the supporting technical data when applying for a development permit. This form does not have to be utilized to submit for a “No-Rise / No-Impact” certification. It is provided as a guide, if needed.

Note: Definitions of terms base flood, development, and regulatory floodway are same as those included in Title 44 of the Code of Federal Regulations, Section 59.1. Additional regulations pertaining to this certification are described in Title 44 of the Code of Federal Regulations, Section 65.3.

SAMPLE FORM

FLOODWAY "NO-RISE / NO-IMPACT" CERTIFICATION

This document is to certify that I am duly qualified engineer licensed to practice in the State of

______________________ . It is to further certify that the attached technical data supports
(State)

the fact that proposed ______________________ will not impact the base flood
(Name of Development)

elevations, floodway elevations, and floodway widths on ______________________ at published
(Name of Stream)

cross sections in the Flood Insurance Study for, ______________ , dated ______________
(Name of community) *(Date)*

and will not impact the base flood elevations, floodway elevations, and floodway widths at the unpublished cross-sections in the area of the proposed development.

SEAL, SIGNATURE AND DATE

____
Name

____
Title

____

____
Address

FOR COMMUNITY USE ONLY:		
Community Approval		
☐ Approved	☐ Disapproved	
Community Official's Name	Community Official's Signature	Title

FEMA, MT
DTD.09/2004

Appendix E - Plant Selection Guidance

Below is a list of plant species suitable for moist to wet soil in the City of Aspen. For more information, please consult a local landscaper or landscape architect or contact the City of Aspen Parks Department at 970-920-5120.

Scientific Name	Common Name
Alnus incana ssp. tenuifolia	**thinleaf alder**
Betula nana	**bog birch**
Betula occidentalis	**river birch**
Calamagrostis canadensis	**bluejoint reedgrass**
Carex aquatilis	**water sedge**
Carex bebbii	**Bebb's sedge**
Carex geyerii*	**Geyer's sedge**
Carex lanuginosa	**woolly sedge**
Carex microptera	**smallwing sedge**
Carex nebrascensis	**Nebraska sedge**
Carex utriculata	**beaked sedge**
Chrysothamnus viscidiflorus	**yellow rabbitbrush**
Cornus sericea	**redosier dogwood**
Deschampsia caespitosa	**tufted hairgrass**
Eleocharis palustris	**creeping spikerush**
Glyceria striata	**fowl mannagrass**
Iris missouriensis	**Rocky Mountain iris**
Juncus arcticus (J. balticus)	**arctic rush**
Juncus mertensianus	**Merten's rush**
Juncus saximontanus	**swordleaf rush**
Juncus torreyi	**Torrey's rush**
Salix bebbiana	**Bebb's willow**
Salix drummondiana	**Drummond's willow**
Salix eriocephala var. ligulifolia	**strapleaf willow**
Salix exigua	**coyote willow**
Salix geyeriana	**Geyer's willow**
Salix lasiandra	**whiplash willow**
Salix monticola	**Rocky Mountain willow**
Schoenoplectus acutus	**hardstem bulrush**
Schoenoplectus pungens	**common threesquare**
Sparganium eurycarpum	**broadfruit burreed**