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:

> Place stormwater in contact with the landscape and soil. 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.
>
> Select treatment areas that promote greater infiltration. 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

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