New York State of Opportunity | Department of Environmental Conservation

STORMWATER MANAGEMENT DESIGN MANUAL

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Acknowledgments

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Preface

The New York State Stormwater Design Manual is prepared to provide standards for the design of the Stormwater Management Practices (SMPs) to protect the waters of the State of New York from the adverse impacts of urban stormwater runoff. This manual is intended to establish specifications and uniform criteria for the practices that are part of a Stormwater Pollution Prevention Plan (SWPPP).

This manual is intended primarily for engineers and other professionals who are engaged in the design of stormwater treatment facilities for new developments. Users are assumed to have a background in hydrology, hydraulics, and runoff and pollutant load computation. It is not intended to be a primer on any of these subjects. The manual may also be used by reviewing authorities to assess the adequacy of SWPPPs.

The Technical Standards, consisting of proven technology, are intended to serve as design criteria for the preparation of plans and specifications for Stormwater Management Practices, to suggest limiting values for items upon which an evaluation of such plans and specifications may be made by the reviewing authority, and to establish, as far as practicable, uniformity of practice. The technical standards constitute discharge technology requirements of the Clean Water Act. As statutory requirements and legal authority pertaining to stormwater management are not uniform across the State, and since conditions and administrative procedures and policies also differ, the use of these Standards must be adjusted to these variations.

The terms “shall” and “must” are used where the practice is sufficiently standardized to permit specific delineation of requirements or where safeguarding of the public health justifies such definite action. Other terms, such as “should,” “recommend,” and “preferred,” indicate desirable procedures or methods, with deviations subject to individual consideration.

Chapter 1: Introduction to the Manual

Section 1.1 Purpose of the Manual

The purpose of this manual is threefold:

1. To protect the waters of the State of New York from the adverse impacts of urban stormwater runoff
2. To provide design standards on the most effective stormwater management approaches including:
    - Incorporation of runoff reduction achieved by infiltration, groundwater recharge, reuse, recycle, evaporation/evapotranspiration through the use of runoff reduction techniques as a standard practice
    - Design and implementation of standard stormwater management practices (SMPs)
    - Implementation of a good operation, inspection, and maintenance program
3. To improve the quality of runoff reduction techniques and standard SMPs constructed in the State, specifically in regard to their performance, longevity, safety, ease of maintenance, community acceptance and environmental benefit

Section 1.2 How to Use the Manual

The New York State Stormwater Management Design Manual provides designers a general overview on how to select, locate, size, and design SMPs at a development site to comply with State stormwater performance standards. The manual also contains appendices with more detailed information on landscaping, SMP construction specifications, step-by-step SMP design examples and other assorted design tools. The manual is organized as follows:

Stormwater Design Chapters

Chapter 2. Impacts of New Development

This Chapter examines the physical, chemical, and biological effects of unmanaged stormwater runoff on the water quality of local streams and waterbodies. This brief overview provides the background for why the stormwater management manual is needed and how the new criteria will help local communities meet water quality standards.

Chapter 3. Stormwater Management Planning

This Chapter explains the required stormwater management planning process and steps for maintaining preconstruction natural hydrologic conditions of the site by application of environmentally-sound development principles, such as runoff reduction techniques, as well as steps involved in treatment and control of runoff discharges from the site in new development and redevelopment projects.

Chapter 4. Unified Stormwater Sizing Criteria

This Chapter explains sizing criteria for water quality, runoff reduction, channel protection, overbank flood control, and extreme flood management in the State of New York. The Chapter also outlines the basis for design calculations.

Chapter 5. Runoff Reduction Techniques

This Chapter provides planning and design criteria on runoff reduction approach and specifications for acceptable runoff reduction practices. This Chapter contains the following sections:

1. Planning for Runoff Reduction Techniques
    - Preservation of Natural Features and Conservation Design
    - Reduction of Impervious Cover
2. Runoff Reduction Techniques

Chapter 6. Standard Stormwater Management Practices

This Chapter presents specific performance criteria and design specifications for the design of the five groups of structural SMPs. Each group of SMPs have six performance criteria:

1. Feasibility
2. Conveyance
3. Pretreatment
4. Treatment
5. Landscaping
6. Maintenance

Chapter 7. Stormwater Management Design Examples

Design examples are provided to help designers and plan reviewers better understand the design criteria outlined in this manual. The step-by-step design examples demonstrate how the stormwater sizing criteria are applied, and some of the design procedures and performance criteria that should be considered when planning a new stormwater management practice. The following design examples are provided:

1. Conservation, Bioretention and Wet Pond
2. Filtration Bioretention & Infiltration Basin for Treatment of a Stormwater Hotspot
3. Dry Swale
4. Multiple Dry Wells in Series

Chapter 8. Urban Stormwater Management

This Chapter presents guidance for implementation of runoff reduction techniques and applicable SMPs, in both new development and redevelopment projects located in urban areas.

Chapter 9. Redevelopment Activity

This Chapter outlines alternative approaches and sizing criteria for addressing stormwater management at projects that include the disturbance and reconstruction of existing impervious surfaces (i.e. redevelopment activity). The approaches set forth in this Chapter comply with the Department's technical standards.

Chapter 10. Addressing Stormwater Pollutants of Concern

This Chapter presents common pollutants of concern found in stormwater runoff. Common pollutant sources and environmental fate and transport characteristics are provided and an overview of SMP pollutant removal capabilities as well as recommended SMP design modifications to further reduce specific pollutants of concern are discussed.

Chapter 11. Planting Guidance for Stormwater Management Practices

This Chapter provides guidance for selection of plants for stormwater management practices, in order to maximize the runoff reduction and water quality benefits.

Chapter 12. Maintenance Guidance

This Chapter provides maintenance guidance for 10 SMP groups that include each of the runoff reduction techniques and standard SMPs included in this Manual. A three-level inspection and maintenance hierarchy is established, with responsibilities and procedures being defined for each level. Recommendations for maintenance planning and budgeting are also included. The Chapter concludes by outlining the key components of Level 1, Level 2 and Level 3 Inspections including diagnostic and repair measures for specific issues.

Stormwater Design Appendices

The appendices contain the technical information needed to design, landscape and construct an SMP. There are a total of ten appendices:

Appendix A. Guidelines for Design of Dams

This appendix provides the general guidelines that New York State Department of Environmental Conservation offers the design engineers on the design of dams. These guidelines represent professional judgment and sound engineering practices for small dams.

Appendix B. Water Quality Peak Flow Rate

This appendix provides step-by-step instructions, including an example, for calculating the water quality peak flow rate for sizing flow-based practices.

Appendix C. Miscellaneous Details

The designs of various structures previously discussed in the manual are presented in Appendix C. These structures help enhance the performance of stormwater management practices, especially in cold climates. Schematics of structures such as weirs, trash racks, and observation wells are included.

Appendix D. Testing Requirements for SMPs

This appendix describes required soil testing for both the feasibility and design phases.

Appendices E. Plan Review Checklists

This appendix provides example checklists that can be used to assist in the stormwater management plan review.

Appendices F. Construction Inspection Checklists

This appendix provides example checklists that can be used to assist in construction inspection of an SMP.

Appendix G. Non-Erosive Velocities of Vegetated Channels

This appendix provides data on critical erosive velocities for vegetated channels.

Appendix H. Cold Climate Sizing Criteria

This appendix supplies guidance on sizing SMPs to account for cold climate conditions that might reduce performance. Sizing example that illustrate how to incorporate cold climate criteria into SMP design are also included.

Appendix I. Geomorphic Assessment

This appendix provides a description of the Distributed Runoff Control (DRC) methodology to size stormwater practices based on downstream geomorphic characteristics.

Section 1.3 Symbols and Acronyms

As an aid to the reader, **Table 1.1** outlines the symbols and acronyms that are used throughout the text. In addition, a glossary is provided at the end of this volume that defines the terminology used in the text.

Table 1.1 Key Symbols and Acronyms Cited in Manual

Symbol	Definition	Symbol	Definition
%ALT	Percent of redevelopment impervious area treated by alternative SMP	L_T	total length of underdrain piping
$\%IC_{RED}$	Percent reduction in existing disturbed impervious area	L_U	design length of underdrain pipe
%RR	Percent of redevelopment impervious area treated by runoff reduction technique	M	moisture in spring snowpack
%SMP	Percent of redevelopment impervious area treated by standard SMP	MS4	Municipal Separate Storm Sewer System
Φ	porosity	n	Manning's coefficient
A	Area	N	Number of specified object
A_b	bottom area	n_{DL}	maximum water retention of drainage layer
A_c	contributing drainage area	NOAA	National Oceanic and Atmospheric Administration
A_f	area of filter	NRCC	Northeast Regional Climate Center
A_{GR}	green roof surface area	NRCS	Natural Resources Conservation Service
Aic	total area of new impervious cover for project site	n_{SM}	maximum water retention of soil media
A_{imp}	impervious cover in contributing drainage area	NYSEFC	New York State Environmental Facilities Corporation
A_N	subcatchment area	%PT	Percent WQv pretreatment required
A_p	porous pavement surface area	P	90% rainfall depth
As	sedimentation basin surface area	P_1	1-yr 24-hr design storm rainfall depth
ASTM	American Society for Testing and Materials	P_2	2-yr 24-hr design storm rainfall depth
A_T	Surface area of the infiltration trench	P_{90}	calculated rainfall value
b	channel bottom width	P_w	wetted perimeter
B	maximum basin retention	Q	runoff
BMP	best management practice	Qf	extreme flood storage volume
BOD	biological oxygen demand	Qi	peak inflow discharge
C	number of check dams	Qo	peak outflow discharge
C_H	check dam height	Qp	overbank flood control storage volume
CN	curve number	R	ratio of contributing area, to porous pavement surface area
CN_N	curve number for subcatchment	RES	water reservoir for factor of safety
CN_W	weighted curve number	RRv	runoff reduction volume
COD	chemical oxygen demand	RRv_{min}	minimum runoff reduction volume
C_S	check dam spacing	R_s	snowmelt runoff
CWP	Center for Watershed Protection	R_V	volumetric runoff coefficient
d	WQv flow depth	S_n	annual snowfall

d_{10}	stone/soil particle diameter of which 10% of the sample is smaller than	S	HSG specific reduction factor
D_2	2-yr average flow depth	SI	stability index
d_b	depth of basin	S_L	slope
D_{DL}	depth of the drainage layer	S_P	spacing between underdrain pipes
d_f	depth of filter	t	thickness of dry well wall
DOT	Department of Transportation	T	travel time through filter strip
d_p	depth of stone	T_c	time of concentration
DP	minimum depth of permanent pool	t_f	design filter drain time
d_s	depth of sedimentation chamber	T_{max}	maximum temperature
D_{SM}	depth of soil media	TR-20	Technical Release No. 20 Project Formulation-Hydrology, computer program
d_t	depth of trench	TR-55	Technical Release No. 55 Urban Hydrology for Small Watersheds
du	dwelling units	t_s	thickness of stone reservoir
E	sediment basin efficiency	UIC	Underground Injection Control
ED	extended detention	USC	Unified Soil Classification
EPA	Environmental Protection Agency (United States)	USDA	United States Department of Agriculture
ET	summer evapotranspiration rate	V	velocity
f_c	soil infiltration rate	V_{10}	10-year peak discharge velocity
H	Inside height of dry well	V_C	channel volume provided
h:v	ratio of horizontal to vertical	V_i	inside volume of dry well
h_f	average height of ponding	Vol	Volume
HOA	homeowner’s association	Vr	volume of runoff
I	percent impervious cover	V_s	volume of storage
Ia	initial abstraction	V_{st}	volume of stone reservoir
IC	impervious cover	V_{sys}	volume of system
INF	monthly infiltration loss	Vt	total volume
k	permeability flow rate	Vv	volume of voids
K_{sat}	saturated hydraulic conductivity	V_w	volume provided per dry well
l:w	ratio of length to width	W	width
L	length	WQ_F	water quality peak flow rate
L_1	losses to hauling	WQ_v	water quality storage volume
L_2	losses to sublimation	WQ_v-ED	12-hr or 24-hr extended detention of the water quality volume
L_3	losses to winter melt	W_s	particle settling velocity
L_p	length provided	W_{Top}	channel top width
L_r	length required		

Chapter 2: Impacts of New Development

Urban development has a profound influence on the quality of New York's waters. To start, development dramatically alters the local hydrologic cycle (see **Figure 2.1**). The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the forest floor that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff.

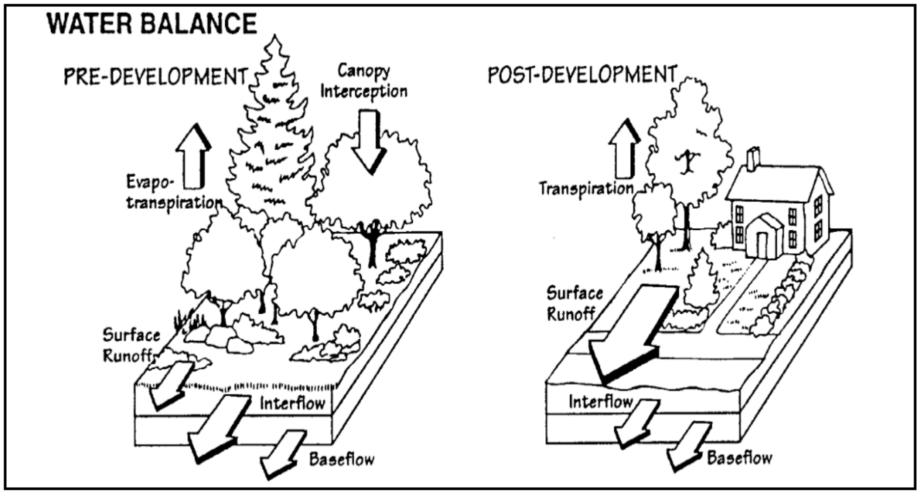


Figure 2.1 Water Balance at a Developed and Undeveloped Site (Schueler, 1987)

The situation worsens after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in **Figure 2.2**, which shows the increase in the volumetric runoff coefficient (R_v) as a function of site imperviousness. The runoff coefficient expresses the fraction of rainfall volume that is converted into stormwater runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre parking lot can produce 16 times more stormwater runoff than a one-acre meadow each year (Schueler, 1994).

The increase in stormwater runoff can be too much for the existing drainage system to handle. As a result, the drainage system is often "improved" to rapidly collect runoff and quickly convey it away (using curb and gutter, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, reservoirs, lakes or estuaries.

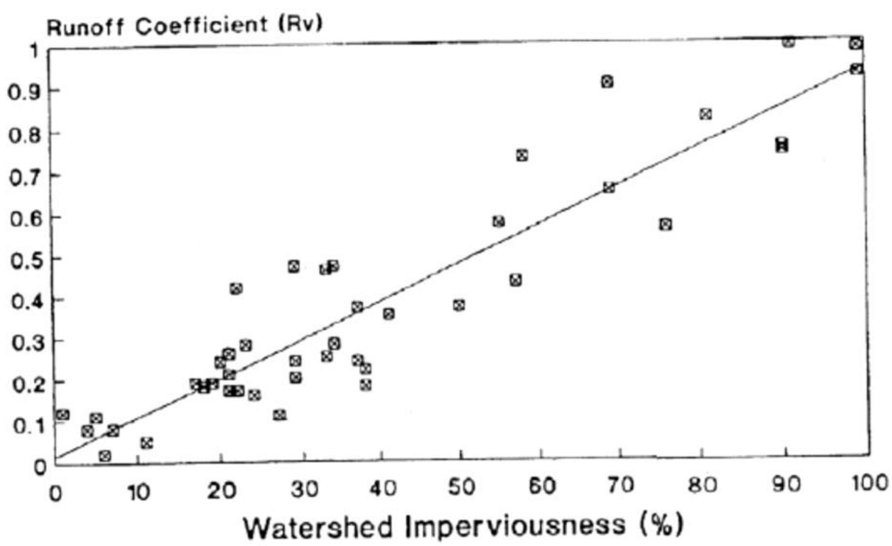


Figure 2.2 Relationship Between Impervious Cover and Runoff Coefficient (Schueler, 1987).

Section 2.1 Declining Water Quality

Impervious surfaces accumulate pollutants deposited from the atmosphere, leaked from vehicles, or windblown in from adjacent areas. During storm events, these pollutants quickly wash off, and are rapidly delivered to downstream waters. Some common pollutants found in urban stormwater runoff are profiled in **Table 2.1**.

Sediment (Suspended Solids)

Sources of sediment include washoff of particles that are deposited on impervious surfaces and erosion from streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997).

Table 2.1 National Median Concentrations for Chemical Constituents in Stormwater

Constituent	Units	Concentration
Total Suspended Solids[1]	mg/l	54.5
Total Phosphorus[1]	mg/l	0.26
Soluble Phosphorus[1]	mg/l	0.10
Total Nitrogen[1]	mg/l	2.00
Total Kjeldhal Nitrogen[1]	mg/l	1.47
Nitrite and Nitrate[1]	mg/l	0.53
Copper[1]	ug/l	11.1
Lead[1]	ug/l	50.7
Zinc[1]	ug/l	129
BOD[1]	mg/l	11.5
COD[1]	mg/l	44.7
Organic Carbon[2]	mg/l	11.9
PAH[3]	mg/l	3.5*
Oil and Grease[4]	mg/l	3.0*
Fecal Coliform[5]	col/100 ml	15,000*
Fecal Strep[5]	col/ 100 ml	35,400*
Chloride (snowmelt)[6]	mg/l	116

* Represents a Mean Value
Source:
1: Pooled NURP/USGS (Smullen and Cave, 1998)
2: Derived from the National Pollutant Removal Database (Winer, 2000)
3: Rabanal and Grizzard 1995
4: Crunkilton et al. (1996)
5: Schueler (1999)
6: Oberts 1994

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, lakes and estuaries. Turbidity resulting from sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. In addition, the reflected energy from light reflecting off of suspended sediment can increase water temperatures (Kundell and Rasmussen, 1995). Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems and smothering benthic organisms such as clams and mussels. Finally, sediment transports many other pollutants to the water resource.

Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, lakes, reservoirs and estuaries. This process is known as eutrophication. Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, animal waste, organic matter, and stream bank erosion. Another nitrogen source is fossil fuel combustion from automobiles, power plants and industry. Data from the upper Midwest suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer *et al*., 1997; Waschbusch *et al*., 2000; Bannerman *et al*., 1993).

Nutrients are of particular concern in lakes and estuaries and are a source of degradation in many of New York's waters. Nitrogen has contributed to hypoxia in the Long Island Sound and is a key pollutant of concern in the New York Harbor and the Peconic Estuary. Phosphorus in runoff has impacted the quality of a number of New York natural lakes, including the Finger Lakes and Lake Champlain, which are susceptible to eutrophication from phosphorus loading. Phosphorus has been identified as a key parameter in the New York City Reservoir system. The New York City DEP recently developed water quality guidance values for phosphorus for City drinking water reservoirs (NYC DEP, 1999); a source-water phosphorus guidance value of 15 µg/l has been proposed for seven reservoirs (Kensico, Rondout, Ashokan, West Branch, New Croton, Croton Falls, and Cross River) in order to protect them from use-impairment due to eutrophication, with other reservoirs using the State recommended guidance value of 20 µg/l.

Organic Carbon

Organic matter, washed from impervious surfaces during storms, can present a problem in slower moving downstream waters. Some sources include organic material blown onto the street surface, and attached to sediment from stream banks, or from bare soil. In addition, organic carbon is formed indirectly from algal growth within systems with high nutrient loads.

As organic matter decomposes, it can deplete dissolved oxygen in lakes and tidal waters. Declining levels of oxygen in the water can have an adverse impact on aquatic life. An additional concern is the formation of trihalomethane (THM), a carcinogenic disinfection by-product, due to the mixing of chlorine with water high in organic carbon. This is of particular importance in unfiltered water supplies, such as the New York City Reservoir System.

Bacteria

Bacteria levels in stormwater runoff routinely exceed public health standards for water contact recreation. Some stormwater sources include pet waste and urban wildlife. Other sources in developed land include sanitary and combined sewer overflows, wastewater, and illicit connections to the storm drain system. Bacteria is a leading contaminant in many of New York's waters, and has led to shellfish bed closures in the New York Bight Area, on Long Island, and in the Hudson-Raritan Estuary. In addition, Suffolk, Nassau, and Erie Counties issue periodic bathing-beach advisories each time a significant rainfall event occurs (NRDC, 2000).

Hydrocarbons

Vehicles leak oil and grease that contain a wide array of hydrocarbon compounds, some of which can be toxic to aquatic life at low concentrations. Sources are automotive, and some areas that produce runoff with high runoff concentrations include gas stations, commuter parking lots, convenience stores, residential parking areas, and streets (Schueler, 1994).

Trace Metals

Cadmium, copper, lead and zinc are routinely found in stormwater runoff. Many of the sources are automotive. For example, one study suggests that 50% of the copper in Santa Clara, CA comes from brake pads (Woodward-Clyde, 1992). Other sources of metals include paints, road salts, and galvanized pipes.

These metals can be toxic to aquatic life at certain concentrations and can also accumulate in the bottom sediments of lakes and estuaries. Specific concerns in aquatic systems include bioaccumulations in fish and macro-invertebrates, and the impact of toxic bottom sediments on bottom-dwelling species.

Pesticides

A modest number of currently used and recently banned insecticides and herbicides have been detected in urban and suburban streamflow at concentrations that approach or exceed toxicity thresholds for aquatic life. Key sources of pesticides include application to urban lawns and highway median and shoulder areas.

Chlorides

Salts that are applied to roads and parking lots in the winter months appear in stormwater runoff and meltwater at much higher concentrations than many freshwater organisms can tolerate. One study of four Adirondack streams found severe impacts to macroinvertebrate species attributed to chlorides (Demers and Sage, 1990). In addition to the direct toxic effects, chlorides can impact lake systems by altering their mixing cycle. In 1986, incomplete mixing in the Irondequoit Bay was attributed to high salt use in the region (MCEMC, 1987). A primary source of chlorides in New York State, particularly in the State's northern regions, is salt applied to road surfaces as a deicer.

Thermal Impacts

Runoff from impervious surfaces may increase temperature in receiving waters, adversely impacting aquatic organisms that require cold and cool water conditions (e.g., trout). Data suggest that increasing development can increase stream temperatures by between five- and twelve-degrees Fahrenheit, and that the increase is related to the level of impervious cover in the drainage area (Galli, 1991). Thermal impacts are a serious concern in trout waters, where cold temperatures are critical to species survival.

Trash and Debris

Considerable quantities of trash and debris are washed through the storm drain networks. The trash and debris accumulate in streams and lakes and detract from their natural beauty. Depending on the type of trash, this material may also lead to increased organic matter or toxic contaminants in water bodies.

Snowmelt Concentrations

The snow pack can store hydrocarbons, oil and grease, chlorides, sediment, and nutrients. In cold regions, the pollutant load during snowmelt can be significant, and chemical traits of snowmelt change over the course of the melt event. Oberts (1994) studied this phenomenon, and describes four types of snowmelt runoff (**Table 2.2**). Oberts and others have reported that 90% of the hydrocarbon load from snowmelt occurs during the last 10% of the event. From a practical standpoint, the high hydrocarbon loads experienced toward the end of the season suggest that stormwater management practices should be designed to capture as much of the snowmelt event as possible.

Table 2.2 Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)

Snowmelt Stage	Duration/ Frequency	Runoff Volume	Pollutant Characteristics
Pavement Melt	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants, chloride, nitrate, lead. Total load is minimal.
Roadside Melt	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants.
Pervious Area Melt	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants, moderate to high concentrations of particulate pollutants, depending on flow.
Rain-on-Snow Melt	Short	Extreme	High concentrations of particulate pollutants, moderate to high concentrations of soluble pollutants. High total load.

Section 2.2 Diminishing Groundwater Recharge and Quality

The slow infiltration of rainfall through the soil layer is essential for replenishing groundwater. Groundwater is a critical water resource across the State. Not only do many residents depend on groundwater for their drinking water, but the health of many aquatic systems is also dependent on its steady discharge. For example, during periods of dry weather, groundwater sustains flows in streams and helps to maintain the hydrology of non-tidal wetlands.

Because development creates impervious surfaces that prevent natural recharge, a net decrease in groundwater recharge rates can be expected in urban watersheds. Thus, during prolonged periods of dry weather, streamflow sharply diminishes. Another source of diminishing baseflow is well drawdowns as populations increase in the watershed. In smaller headwater streams, the decline in stream flow can cause a perennial stream to become seasonally dry. One study in Long Island suggests that the supply of baseflow decreased in some developing watersheds, particularly where the water supply was sewered (Spinello and Simmons, 1992; **Figure 2.3**).

Urban land uses and activities can also degrade *groundwater quality,* if stormwater runoff is infiltrated without adequate treatment. Certain land uses and activities are known to produce higher loads of metals and toxic chemicals and are designated as *stormwater hotspots*. Soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some polycyclic aromatic hydrocarbons (PAH's) can migrate into groundwater and potentially contaminate wells. Stormwater runoff from designated hotspots should never be infiltrated, unless the runoff receives full treatment with another practice.

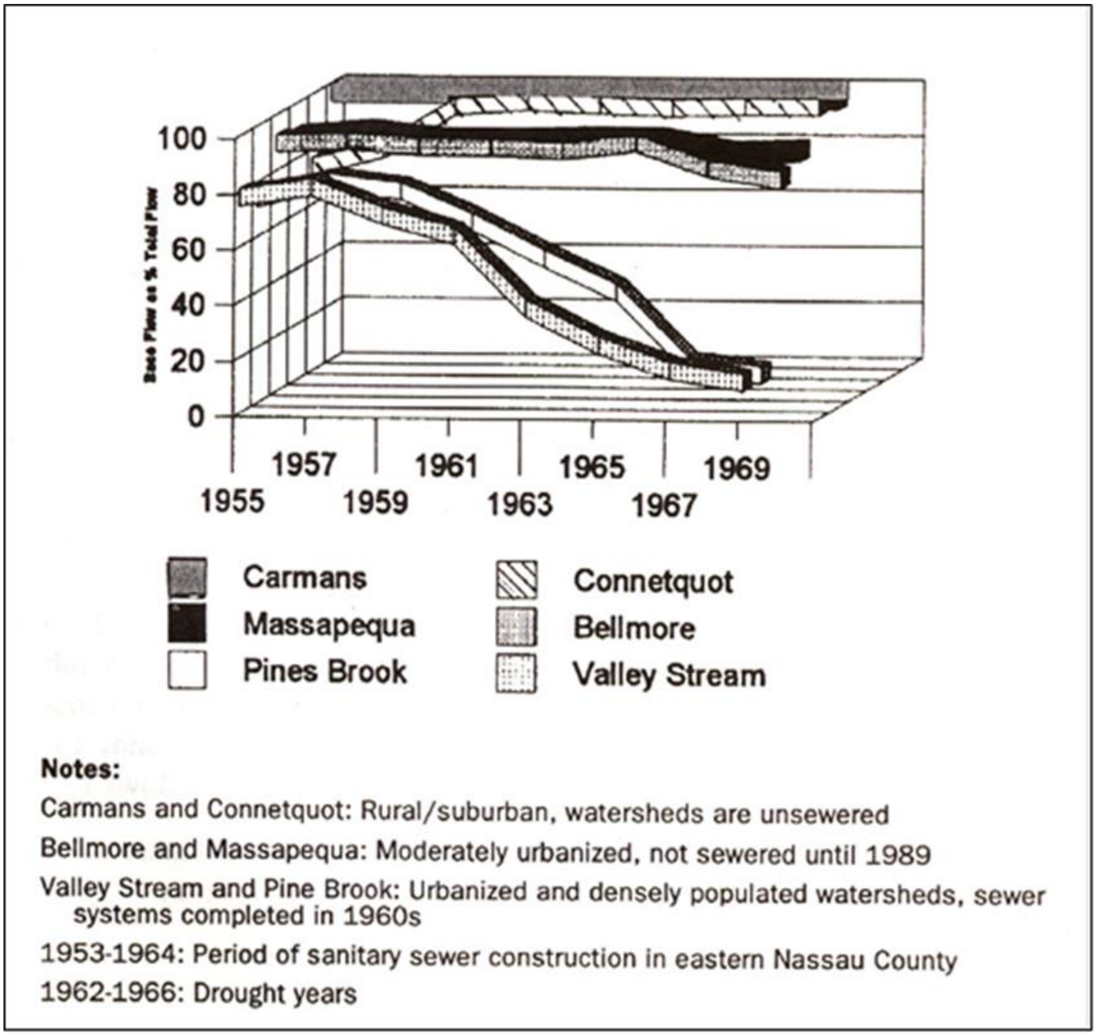


Figure 2.3 Declining Baseflow in Response to Development

Section 2.3 Impacts to the Stream Channel

As pervious meadows and forests are converted into less pervious urban soils, or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, the bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975). As **Figure 2.4** demonstrates, the total flow beyond the "critical erosive velocity" increases substantially after development occurs. The increased energy resulting from these more frequent bankfull flow events results in erosion and enlargement of the stream channel, and consequent habitat degradation.

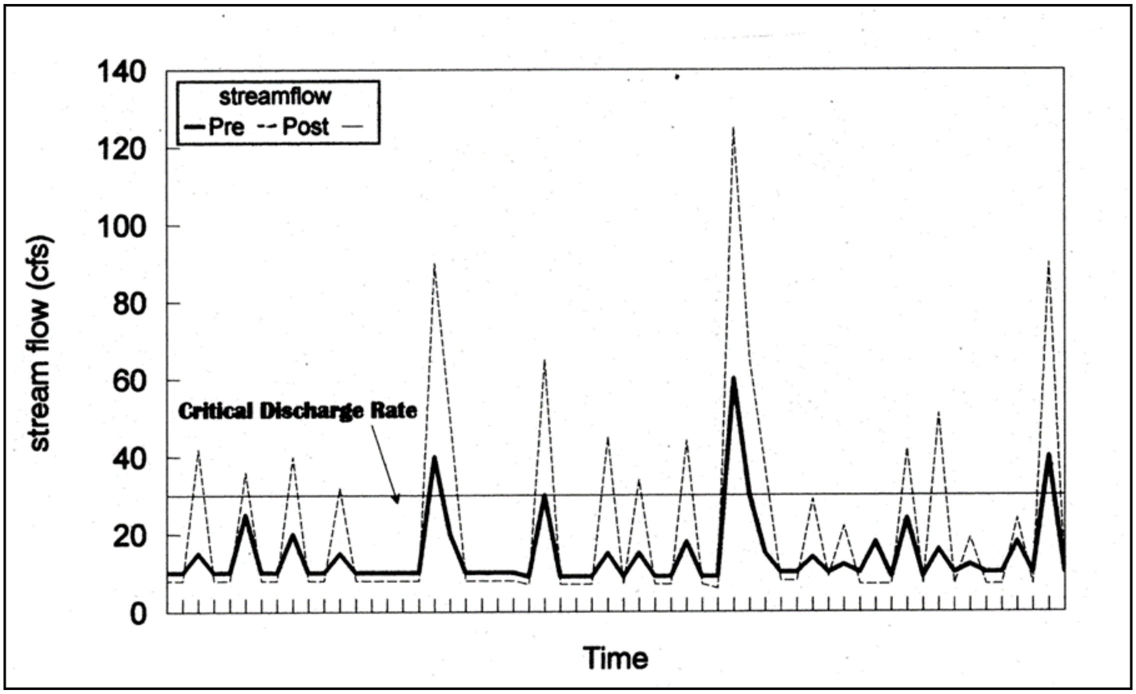


Figure 2.4 Increased Frequency of Erosive Flow After Development

Channel enlargement in response to watershed development has been observed for decades, with research indicating that the stream channel area expands to between two and five times its original size in response to upland development (Hammer, 1972; Morisawa and LaFlure, 1979; Allen and Narramore, 1985; Booth, 1990). One researcher developed a direct relationship between the level of impervious cover and the "ultimate" channel enlargement, the area a stream will eventually reach over time (MacRae, 1996; **Figure 2.5**).

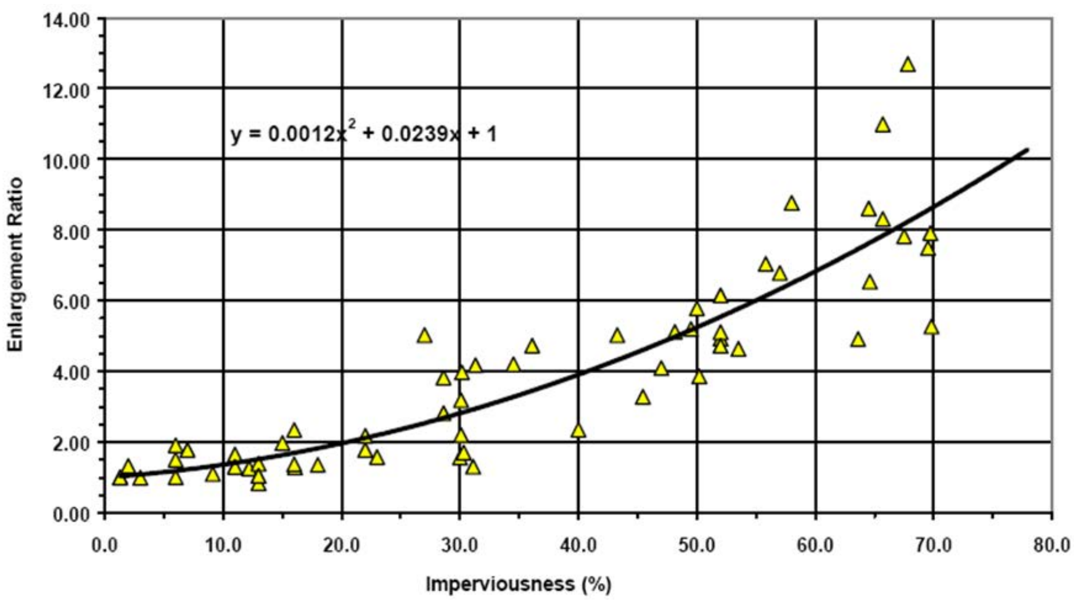


Figure 2.5 Relationship Between Impervious Cover and Channel Enlargement

Historically, New York has used two-year control (i.e., reduction of the peak flow from the two-year storm to pre-developed levels) to prevent channel erosion, as required in the 1993 SPDES General Permit (GP-93-06). Research suggests that this measure does not adequately protect stream channels (McCuen and Moglen, 1988, MacRae, 1996). Although the peak flow is lower, it is also extended over a longer period of time, thus increasing the duration of erosive flows. In addition, the bankfull flow event actually becomes more frequent after development occurs. Consequently, capturing the two-year event may not address the channel-forming event.

This stream channel erosion and expansion, combined with direct impacts to the stream system, act to decrease the habitat quality of the stream. The stream will thus experience the following impacts to habitat (**Table 2.3**):

- Decline in stream substrate quality (through sediment deposition and embedding of the substrate)
- Loss of pool/riffle structure in the stream channel
- Degradation of stream habitat structure
- Creation of fish barriers by culverts and other stream crossings
- Loss of "large woody debris," which is critical to fish habitat

Table 2.3 Impacts to Stream Habitat

Stream Channel Impact	Key Finding	Reference	Year
Habitat Characteristics			
Embeddedness	Interstitial spaces between substrate fill with increasing watershed imperviousness	Horner *et al*.	1996
Large Woody Debris (LWD)	Important for habitat diversity and anadramous fish.	Spence *et al.*	1996
	Decreased LWD with increases in imperviousness	Booth *et al.*	1996
Changes in Stream Features	Altered pool/riffle sequence with urbanization	Richey	1982
	Loss of habitat diversity	Scott *et al.*	1986
Direct Channel Impacts			
Reduction in 1st Order Streams	Replaced by storm drains and pipes increases erosion rate downstream	Dunne and Leopold	1972
Channelization and hardening of stream channels	Increase instream velocities often leading to increased erosion rates downstream	Sauer *et al.*	1983
Fish Blockages	Fish blockages caused by bridges and culverts	Metropolitan Washington Council of Governments	1989

Section 2.4 Increased Overbank Flooding

Flow events that exceed the capacity of the stream channel spill out into the adjacent floodplain. These are termed "overbank" floods and can damage property and downstream structures. While some overbank flooding is inevitable and sometimes desirable, the historical goal of drainage design in New York has been to maintain pre-development peak discharge rates for both the two- and ten-year frequency storm after development, thus keeping the level of overbank flooding the same over time. This management technique prevents costly damage or maintenance for culverts, drainage structures, and swales.

Overbank floods are ranked in terms of their statistical return frequency. For example, a flood that has a 50% chance of occurring in any given year is termed a "2-year" flood. The two-year event is also known as the "bankfull flood," as researchers have demonstrated that most natural stream channels in the State have just enough capacity to handle the two-year flood before spilling out into the floodplain. Although many factors, such as soil moisture, topography, and snowmelt, can influence the magnitude of a particular flood event, designers typically design for the "2-year" storm event. In New York State, the two-year design storm ranges between about 2.0 to 4.0 inches of rain in a 24-hr period. Similarly, a flood that has a 10% chance of occurring in any given year is termed a "10-year flood." A ten-year flood occurs when a storm event produces between 3.2 and 6.0 inches of rain in a 24-hr period. Under traditional engineering practice, most channels and storm drains in New York are designed with enough capacity to safely pass the peak discharge from the ten-year design storm.

Urban development increases the peak discharge rate associated with a given design storm, because impervious surfaces generate greater runoff volumes and drainage systems deliver it more rapidly to a stream. The change in post-development peak discharge rates that accompany development is profiled in **Figure 2.6**. Note that this change in hydrology increases not only the magnitude of the peak event, but the total volume of runoff produced.

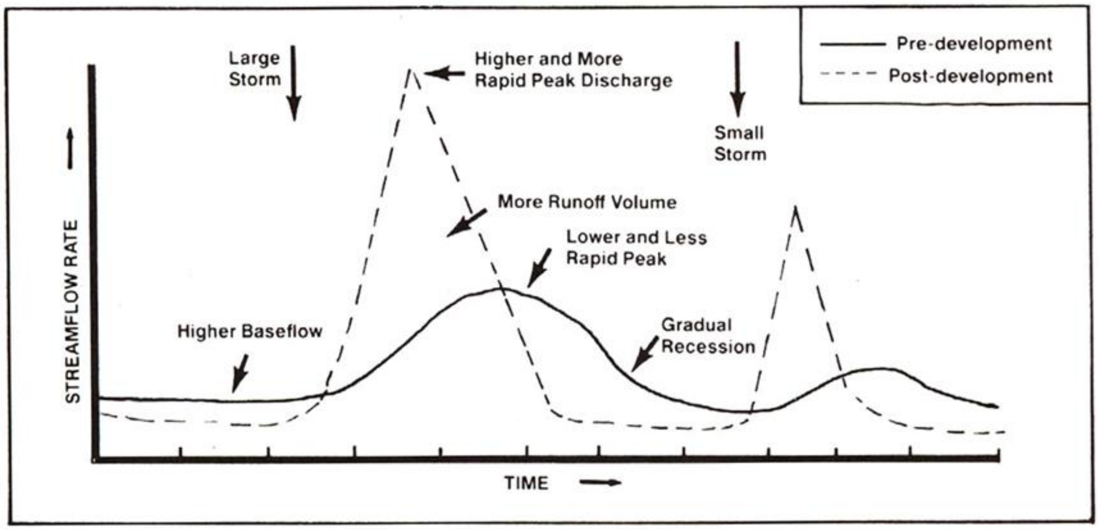


Figure 2.6 Hydrographs Before and After Development

Section 2.5 Floodplain Expansion

In general, floodplains are relatively low areas adjacent to rivers, lakes, and oceans that are periodically inundated. For the purposes of this document, the floodplain is defined as the land area that is subject to inundation from a flood that has a one percent chance of being equaled or exceeded in any given year. This is typically thought of as the 100-year flood. In New York, a 100-year flood typically occurs after between 5 and 8 inches of rainfall in a 24-hr period (i.e., the 100-year storm). However, snow melt combined with precipitation can also lead to a 100-year flood. These floods can be very destructive and can pose a threat to property and human life.

As with overbank floods, development sharply increases the peak discharge rate associated with the 100-year design storm. As a consequence, the elevation of a stream's 100-year floodplain becomes higher and the boundaries of its floodplain expand (see **Figure 2.7**). In some instances, property and structures that had not previously been subject to flooding are now at risk. Additionally, such a shift in a floodplain's hydrology can degrade wetland and forest habitats.

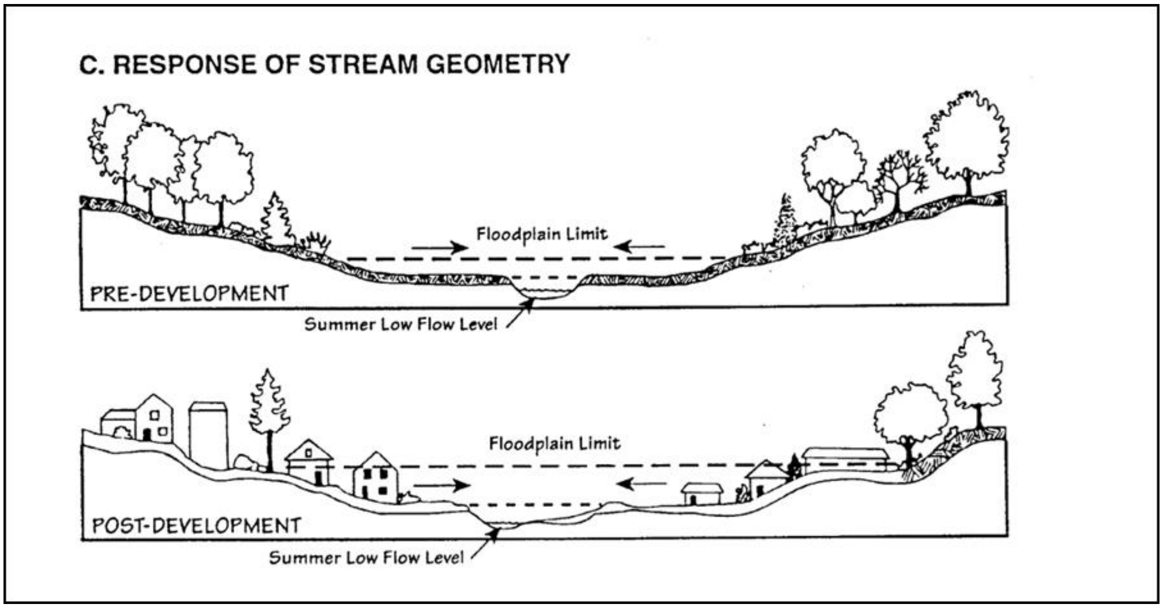


Figure 2.7 Floodplain Expansion with New Development

Section 2.6 Impacts to Aquatic Organisms

The decline in the physical habitat of the stream, coupled with lower base flows and higher stormwater pollutant loads, has a severe impact on the aquatic community. Research suggests that new development impacts aquatic insects, fish, and amphibians at fairly low levels of imperviousness, usually around 10% impervious cover (**Table 2.4**). New development appears to cause declining **richness** (the number of different species in an area or community), **diversity** (number and relative frequency of different species in an area or community), and **abundance** (number of individuals in a species).

Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms				
Watershed Indicator	**Key Finding**	**Reference**	**Year**	**Location**
Aquatic insects and fish	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had substantially lower EPT scores (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and IBI scores in the poor range.	Crawford & Lenat	1989	North Carolina
Insects, fish, habitat, water quality	Steepest decline of biological functioning after 6% imperviousness. There was a steady decline, with approx. 50% of initial biotic integrity at 45% I.	Horner *et al.*	1996	Puget Sound Washington
Fish, aquatic insects	A study of five urban streams found that as land use shifted from rural to urban, fish and macroinvertebrate diversity decreased.	Masterson & Bannerman	1994	Wisconsin
Insects, fish, habitat, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the percentage of total impervious area exceeded the 5-10% range.	May et al.	1997	Washington
Aquatic insects and fish	There was significant decline in the diversity of aquatic insects and fish at 10% impervious cover.	Metropolitan Washington Council of Governments	1992	Washington, DC
Aquatic insects and fish	Evaluation of the effects of runoff in urban and non-urban areas found that native fish and insect species dominated the non-urban portion of the watershed, but native fish accounted for only 7% of the number of species found in urban areas.	Pitt	1995	California
Wetland plants, amphibians	Mean annual water fluctuation inversely correlated to plant & amphibian density in urban wetlands. Declines noted beyond 10% impervious area.	Taylor	1993	Seattle
Aquatic insects & fish	Residential urban land use in Cuyahoga watersheds created a significant drop in IBI scores at around 8%, primarily due to certain stressors that functioned to lower the non-attainment threshold When watersheds smaller than 100mi^2 were analyzed separately, the level of urban land use for a significant drop in IBI scores occurred at around 15%.	Yoder et. al.	1999	Ohio
Aquatic insects & fish	All 40 urban sites sampled had fair to very poor index of biotic integrity (IBI) scores, compared to undeveloped reference sites.	Yoder	1991	Ohio

IBI: Index of Biotic Integrity - A measure of species diversity for fish and macroinvertebrates
EPT: A measure of the richness of three sensitive macro-invertebrates (may flies, caddis flies, and stone flies), used to indicate the ability of a waterbody to support sensitive organisms.

Section 2.7 Climate Change - Resiliency Planning Considerations

New York State is predicted to face challenges from a rapidly changing climate, to include:

- Increasing Temperature: Temperatures across NYS are expected to rise, which is further stressed by materials in the built environment that absorb the sun's heat throughout the day (Urban Heat Island effect), drive localized temperatures higher and increase the temperature of stormwater runoff entering heat-vulnerable environments.
- Increasing Precipitation: The intensity and frequency of precipitation events are projected to increase, resulting in the potential for stormwater management and conveyance systems to be overwhelmed, more frequent and severe flooding, and greater variability in rainfall events annually, including the chance of drought.
- Rising Sea Level: Flooding already impacts parts of the State and is projected to worsen as sea levels rise and inundate low-lying coastal areas during high tides.
- Shifting Ecology: Studies indicate that regional ecology, including significant and natural communities, will shift with the change in climate.

To strengthen New York's resiliency to these risks the Community Risk and Resiliency Act (CRRA) was adopted. The scale of impacts from climate change will vary across the state, and it is anticipated that climate change will result in chronic erosion, flooding, severe property damage and loss of ecological species.

Guidance related to climate resilient SMP design will be made available in a future version of the Design Manual. At this time, the following guidance documents have been issued by the NYSDEC and can be found on their website. They can be used as a reference for the design of climate change mitigation measures:

- Using Natural Measures to Reduce the Risk of Flooding and Erosion
- New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act
- New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act Estimating Guideline Elevations
- Tidal Wetlands Guidance: Living Shoreline Techniques in the Marine District of New York State

As noted above, specific climate resilient SMP design will be incorporated in a future version of the design manual, however, should a project owner/operator elect to incorporate climate change mitigation measures, the Design Professional should document these considerations in the Stormwater Pollution Prevention Plan (SWPPP).

Chapter 3: Stormwater Management Planning

This Chapter presents a required planning process that must be followed when addressing stormwater management in new development and redevelopment projects. This process is intended to guide the designer through steps that maintain pre-construction (Note: For new development, the pre-construction terminology indicates pre-development or natural conditions) hydrologic conditions of the site by application of environmentally-sound development principles, such as runoff reduction techniques, as well as treatment and control of runoff discharges from the site.

Section 3.1 Introduction

The increased emphasis on a holistic approach to resource protection, water quality treatment, flow volume control, maintenance cost reduction, and the dynamics of stormwater science has led to several changes in stormwater management. Carrying out stormwater management design standards for the past few years has provided the regulatory agencies, regulated entities, and design community with valuable experiences and a body of knowledge to enhance and improve urban runoff planning, methodologies, and techniques towards implementation of runoff reduction techniques.

In the context of stormwater management, the term runoff reduction technique includes a wide array of practices at multiple scales to manage and treat stormwater, maintain and restore natural hydrology and ecological function by infiltration, evapotranspiration, capture and reuse of stormwater, and establishment of natural vegetative features. On a regional scale, runoff reduction techniques are the preservation and restoration of natural landscape features, such as forests, floodplains and wetlands, coupled with policies such as infill and redevelopment that reduce overall imperviousness in a watershed or ecoregion. On the local scale runoff reduction techniques consists of site- and neighborhood-specific practices. Such practices essentially result in runoff reduction and or establishment of habitat areas with significant utilization of soils, vegetation, and engineered media rather than traditional hardscape collection, conveyance and storage structures. Some examples include green roofs, trees and tree boxes, pervious pavement, rain gardens, vegetated swales, planters, reforestation, and protection and enhancement of riparian buffers and floodplains.

Planners and designers must address this approach in a six step process that involves site planning and stormwater management practice (SMP) selection to meet the sizing criteria outlined in **Chapter 4**. The six steps include:

Step 1. Site Planning: provide an evaluation of the site's feasibility for implementation of each green infrastructure planning measure, in order to preserve natural resources and reduce impervious cover.

Step 2. Calculate Water Quality Volume (WQv) for the site.

Step 3. Apply Runoff Reduction (RR) techniques and standard SMPs with Runoff Reduction Volume (RRv) capacity to reduce total WQv. If 100% of the required WQv cannot be reduced, provide an evaluation of the site's feasibility for application of each RR technique and standard SMP with RRv capacity.

Step 4. If applicable, calculate the minimum RRv required.

Step 5. If applicable, apply standard SMPs to treat the remaining portion of WQv that was not addressed in Step 3 by RR techniques and standard SMPs with RRv capacity.

Step 6. Apply volume and peak rate control practices, where required, to meet quantity control criteria.

Refer to **Section 3.6** and the flow chart in **Figure 3.3**, for more detailed information on the six step process.

For detailed information on the State Pollutant Discharge Elimination System ("SPDES") General Permit for Stormwater Discharges from Construction Activity, as well as environmental permits under the Uniform Procedures Act (UPA) consult DEC website at http://www.dec.ny.gov/chemical/8468.html.

Section 3.2 Runoff Reduction Techniques for Stormwater Management

The runoff reduction approach for stormwater management reduces a site's impact on the aquatic ecosystem through the use of site planning measures, RR techniques, and certain standard SMPs with RRv capacity. The objective is to replicate pre-development hydrology and provide groundwater recharge by maintaining pre-construction infiltration, peak runoff flow, discharge volume, as well as minimizing concentrated flow by using runoff control techniques to provide treatment in a distributed manner before runoff reaches the collection system. This approach offers a distinct advantage over conventional "hard" stormwater infrastructure by reducing the production of runoff and the need for collection, storage, and treatment. When implemented throughout a development and watershed, runoff reduction techniques can (Coffman, 2002 and USEPA, 2007):

- Reduce runoff volume, peak flow, and flow duration
- Slow down the flow to increase time of concentration and promote infiltration and evapotranspiration
- Improve groundwater recharge
- Protect downstream water resources, including wetlands
- Reduce downstream flooding and property damage
- Reduce incidence of combined sewer overflow (CSOs)
- Provide water quality improvements/reduced treatment costs
- Reduce thermal pollution
- Improve wildlife habitat

For the greatest level of success at reducing the negative effects of stormwater, this approach must be incorporated into an iterative site planning and design process. During the iterative site planning and design process, the designer shall try implementing various combinations of RR techniques (described in this section) and certain standard SMPs with RRv capacity (described in **Section 3.3** and **Section 3.6**) to address stormwater runoff so that the RRv requirement is met. The design and layout of stormwater management features shall be conducted in unison with site planning and runoff reduction objectives. This approach has three primary components that mitigate the effects of stormwater runoff from development:

1. Avoiding the Impacts – *Avoid or minimize disturbance by preserving natural features and using conservation design techniques*
2. Reducing the Impacts – *Reducing the impacts of development by reducing impervious cover*
3. Managing the Impacts – *Manage the impacts by using natural features and runoff reduction practices to slow down the runoff, promote infiltration and evapo-transpiration, and consequently minimizing the need for the structural "end-of-pipe" practices*

RR techniques are highly effective when used to address stormwater runoff from smaller, more frequent storms. As precipitation size and intensity increase, pervious surfaces become less capable of infiltrating runoff and their peak flow reduction "benefits" diminish. Thus, runoff reduction is not generally sufficient to achieve volume and peak rate control for larger storms. Additional volume and peak rate control practices for meeting quantity control objectives must be documented in the Stormwater Pollution Prevention Plan (SWPPP).

Exceptions to Meeting the Runoff Reduction Volume (RRv) Criteria:

- Although encouraged, meeting the RRv criteria is not required for redevelopment activities that meet the criteria in **Chapter 9** of this manual.
- Meeting the RRv criteria is required for projects over karst geology. However, the use of large infiltration basins must be avoided. A geotechnical assessment is recommended for infiltration and recharge at small scales.
- For projects that meet the "hotspot" criteria in **Section 4.14** of this manual, designers shall use non-infiltration type practices, or two treatment practices in series (i.e. non-infiltration standard SMP/ runoff reduction technique, followed by an infiltration practice) to meet the RRv criteria.

A summary of the green infrastructure planning measures and RR techniques covered in this Manual can be found in **Table 3.1** and **Table 3.2**, respectively. The runoff reduction planning measures, presented in **Table 3.1**, are practices that indirectly result in runoff reduction. The RR techniques, presented in **Table 3.2**, are practices for which runoff reduction is quantified. Complete definition, design criteria, and sizing criteria for RR Techniques are presented in **Chapter 5** of this manual.

Table 3.1 Green Infrastructure Planning General Categories and Specific Practices

Group	Practice	Description
Preservation of Natural Resources	Preservation of Undisturbed Areas	Delineate and protect undisturbed forests, native vegetated areas, riparian corridors, water bodies, wetlands, and natural terrain.
	Preservation of Buffers	Delineate and protect naturally vegetated buffers along perennial streams, rivers, shorelines, and wetlands.
	Reduction of Clearing and Grading	Limit clearing and grading to the minimum amount needed for roads, driveways, foundations, utilities and stormwater management facilities.
	Locating Development in Less Sensitive Areas	Avoid sensitive resource areas such as floodplains, steep slopes, erodible soils, wetlands, mature forests and critical habitats by locating development to fit the terrain in areas that will create the least impact.
	Open Space Design	Use clustering, conservation design or open space design to reduce impervious cover, preserve more open space and protect water resources.
	Soil Restoration	Restore the original properties and porosity of the soil by deep till and amendment with compost to reduce the generation of runoff and enhance the runoff reduction performance of practices such as grass channels, filter strips, and tree clusters.
Reduction of Impervious Cover	Roadway Reduction	Minimize roadway widths and lengths, below local requirements, to reduce site impervious area
	Sidewalk Reduction	Minimize sidewalk lengths and widths, below local requirements, to reduce site impervious area
	Driveway Reduction	Minimize driveway lengths and widths, below local requirements, to reduce site impervious area
	Cul-de-sac Reduction	Minimize the number of cul-de-sacs and incorporate landscaped areas to reduce their impervious cover.
	Building Footprint Reduction	Reduce the impervious footprint of buildings by using alternate or taller buildings while maintaining the same floor to area ratio.
	Parking Reduction	Reduce imperviousness on parking lots by eliminating unneeded spaces, providing compact car spaces and efficient parking lanes, reducing stall dimensions below local requirements, using porous pavement surfaces in overflow parking areas, and using multi-storied parking decks where appropriate.

Table 3.2 Acceptable Runoff Reduction Techniques		
Group	**Practice**	**Description**
Runoff Reduction Techniques	Conservation of Natural Areas (RR-1)	Retain the pre-development hydrologic and water quality characteristics of undisturbed natural areas by permanently conserving these areas on a site. Undisturbed natural areas include: forest retention areas; reforestation areas; stream and river corridors; shorelines; wetlands, vernal pools, and associated vegetated buffers; and undisturbed open space.
	Sheet flow to Riparian Buffers/Filter Strips (RR-2)	Undisturbed natural areas such as forested conservation areas and stream buffers or vegetated filter strips and riparian buffers can be used to treat and control stormwater runoff from some areas of a development project.
	Tree Planting/Tree Pit/Tree Trench (RR-3)	Plant or conserve trees to reduce stormwater runoff, increase nutrient uptake, and provide bank stabilization. Trees can be used for applications such as landscaping, stormwater management practice areas, conservation areas and erosion and sediment control.
	Disconnection of Rooftop Runoff (RR-4)	Direct runoff from rooftop areas and upland overland runoff flow to designated pervious areas to reduce runoff volumes and rates.
	Vegetated Swale (RR-5)	The natural drainage paths, or properly designed vegetated channels, can be used instead of constructing underground storm sewers or concrete open channels to increase time of concentration, reduce the peak discharge, and provide infiltration.
	Rain Garden (RR-6)	Manage and treat small volumes of stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression.
	Stormwater Planter (RR-7)	Small, landscaped stormwater treatment devices that can be designed as infiltration or filtering practices. Stormwater planters use soil infiltration and biogeochemical processes to decrease stormwater quantity and improve water quality.
	Rainwater Harvesting System (RR-8)	Capture and store stormwater runoff to be used for irrigation systems or filtered and reused for non-contact activities.
	Porous Pavement (RR-9)	Pervious types of pavements that provide an alternative to conventional paved surfaces, designed to infiltrate rainfall through the surface, thereby reducing stormwater runoff from a site and providing some pollutant uptake in the underlying soils.
	Green Roof (RR-10)	Capture runoff by a layer of vegetation and soil installed on top of a conventional flat or sloped roof. The rooftop vegetation allows evaporation and evapotranspiration processes to reduce volume and discharge rate of runoff entering conveyance system.
	Stream Daylighting (RR-11)	Stream Daylight previously culverted/piped streams to restore natural habitats, better attenuate runoff by increasing the storage size, promoting infiltration, and help reduce pollutant loads.

Section 3.3 Standard Stormwater Management Practices for Treatment

This section presents a list of standard stormwater management practices (SMPs) that are acceptable for water quality treatment, data justifying the use of these practices, and the minimum criteria for addition of new practices to the list. The practices on the acceptable list have been selected based on the following criteria:

1. Can capture and treat the full water quality volume (WQ_v).
2. Are capable of 80% TSS removal and 40% TP removal.
3. Have acceptable longevity in the field.
4. Have a pretreatment device.

Standard SMPs are structural practices designed to capture and treat the water quality volume (the portion infeasible to retain on-site using RR techniques) through one or more pollutant removal pathways. Their performance is documented by removal efficiency of specific pollutants. Standard SMPs are often cited as "end-of-pipe" treatment systems, designed to function as storage or flow-through systems.

3.3.1 Practice List

Practices on the acceptable list will be presumed to meet water quality requirements set forth in this manual if designed in accordance with the sizing criteria presented in **Chapter 4**, constructed in accordance with the performance criteria in **Chapter 6**, and properly maintained in accordance with the prescribed maintenance criteria presented in **Chapter 12**. Acceptable practices are divided into five groups, including:

I. **Stormwater Ponds:** Practices that have either a permanent pool of water or a combination of permanent pool and extended detention capable of treating the WQ_v.

II. **Stormwater Wetlands:** Practices that include significant shallow marsh areas and may also incorporate small permanent pools and extended detention storage to achieve the full WQ_v.

III. **Infiltration Practices:** Practices that capture and temporarily store the WQ_v before allowing it to infiltrate into the soil.

IV. **Filtering Practices:** Practices that capture and temporarily store the WQ_v and pass it through a filter bed of sand, soil, or other acceptable treatment media.

V. **Open Channel Practices:** Practices explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means.

The following Table provides a summary of the standard SMPs acceptable for water quality treatment. Refer to the Standard SMP Feasibility Matrix and the one-page practice Fact Sheets in **Chapter 6,** for assistance in selection and suitability of each standard SMP.

Table 3.3 Standard Stormwater Management Practices Acceptable for Water Quality		
Group	**Practice**	**Description**
Pond	Micropool Extended Detention Pond (P-1)	Pond that treats the majority of the water quality volume through extended detention and incorporates a micropool at the outlet of the pond to prevent sediment resuspension.
	Wet Pond (P-2)	Pond that provides storage for the entire water quality volume in the permanent pool.
	Wet Extended Detention Pond (P-3)	Pond that treats a portion of the water quality volume by detaining storm flows above a permanent pool for a specified minimum detention time.
	Multiple Pond System (P-4)	A group of ponds that collectively treat the water quality volume.
Wetland	Shallow Wetland (W-1)	A wetland that provides water quality treatment entirely in a wet shallow marsh.
	Extended Detention Wetland (W-2)	A wetland system that provides some fraction of the water quality volume by detaining storm flows above the marsh surface.
	Pond/ Wetland System (W-3)	A wetland system that provides a portion of the water quality volume in the permanent pool of a wet pond that precedes the marsh for a specified minimum detention time.
	Pocket Wetland (W-4)	A shallow wetland design adapted for the treatment of runoff from small drainage areas that has variable water levels and relies on groundwater for its permanent pool.
	Gravel Wetland (W-5)	A wetland system filled with crushed stone that allows water quality volume to flow subsurface through the root zone.
Infiltration	Infiltration Trench (I-1)	An infiltration practice that stores the water quality volume in the void spaces of a gravel trench before it is infiltrated into the ground.
	Infiltration Basin (I-2)	An infiltration practice that stores the water quality volume in a shallow depression, before it is infiltrated it into the ground.
	Dry Well (I-3)	An infiltration practice that includes a shallow excavation filled with stone or an underground perforated structure surrounded by stone, that is designed to intercept and temporarily store runoff to promote infiltration into the surrounding native soils.
	Underground Infiltration (I-4)	An infiltration practice below grade that stores the water quality volume in pre-manufactured pipes, vaults or other modular structures, before it is infiltrated into the ground.
Filtering Practices	Surface Sand Filter (F-1)	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a sand matrix.
	Underground Sand Filter (F-2)	A filtering practice that treats stormwater as it flows through underground settling and filtering chambers.
	Perimeter Sand Filter (F-3)	A filter that incorporates a sediment chamber and filer bed as parallel vaults adjacent to a parking lot.
	Filtration Bioretention (F-4)	A shallow depression that treats stormwater as it flows through a soil matrix and is returned to the storm drain system.
	Infiltration Bioretention (F-5)	A shallow depression that treats stormwater as it flows through a soil matrix, before it is infiltrated into the ground.
	Bioslope (F-6)	Permeable engineered soil media that is installed along embankments or other slopes, designed to capture and treat stormwater runoff from adjacent impervious surfaces.
Open Channels	Dry Swale (O-1)	An open drainage channel or depression explicitly designed to detain and promote the filtration of stormwater runoff into the soil media.
	Wet Swale (O-2)	An open drainage channel or depression designed to retain water or intercept groundwater for water quality treatment.

3.3.2 Criteria for Practice Addition

The stormwater field is always evolving, and new technologies constantly emerge. The New York State Department of Environmental Conservation supports the development of innovative practices, provided the runoff reduction requirements are met, and allows the use of manufactured systems where specific site conditions demand. However, the Department currently does not have a stormwater management practice verification process in place. Instead, the Department relies on the verification and certification process, being implemented by other regulatory agencies with technical standards similar to those of New York State, to identify the alternative practices that are acceptable for installation in New York State**.**

The goals for performance of practices remain consistent with the performance criteria as stated in **Section 3.3** of this Manual. A list of acceptable sources of verification for new stormwater management practices is provided on the Department's website. All proposed alternative stormwater management practices in new construction are considered to be in deviation from State Standards. Such practices must provide a full description to justify the reason(s) for deviation as well as detailed justification on how the proposed practice is equivalent to the standards defined in this Design Manual. In order to be in compliance with the technical standards, projects must meet both required performance and sizing criteria. All proposed alternative practices must at minimum meet the sizing criteria as defined in **Chapter 4** of this Design Manual. The equivalency of the performance of the proposed new technologies to the performance criteria required by the State of New York must be verified and certified by one of the sources accepted by the Department and documented in the SWPPP. All design and plan review professionals must adhere to the design parameters that constitute the removal efficiency equivalent to the Department's performance criteria (80% TSS removal and 40% phosphorus removal).

Specific requirements for redevelopment applications are addressed in **Chapter 9** of this Design Manual.

Section 3.4 Quantity Controls

Quantity control practices are systems that are primarily designed for channel protection, safe conveyance of the flow, and flood control. Most quantity control facilities are structural systems that provide detention and control discharge rate. Some examples of quantity control practices include detention ponds, underground storage vaults (chambers, large diameter pipe), and blue roofs. Additional standard SMPs can be used to provide quantity control, based on the sizing criteria outlined in **Chapter 5** and **Chapter 6**.

Examples of practices that provide quantity control only are presented in **Table 3.4**.

Table 3.4 Stormwater Management Practices for Stormwater Quantity Control

Group	Practice	Description
Above ground systems	Dry Detention	Dry detention basins and dry extended detention basins are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts.
	Blue Roofs	Blue roofs (rooftop detention systems) are constructed by installing slotted flow restriction devices known as collars or restrictors around the roof drains of flat, structurally sound, waterproof roofs. By this mechanism, stormwater is detained on the roof and the peak rate of discharge is reduced.
Underground systems	Underground Storage Vaults (chambers, pipes)	An underground storage system is a subsurface stormwater system suitable for sites within high-density urban areas. Such systems are designed as an arched structure, a vault or large diameter pipe and function in both permeable and non-permeable soils for subsurface detention of stormwater runoff or infiltration. Chambers, vaults or pipes can decrease the peak flow when used with a controlled flow orifice at the outlet.

Section 3.5 Maintenance Requirements

The responsibility for implementation of long-term operation and maintenance of a post-construction stormwater management practice shall be vested with a responsible party by means of a legally binding and enforceable mechanism, such as a maintenance agreement, deed covenant or other legal measure. This mechanism shall protect the practice from neglect, adverse alteration and/or unauthorized removal. The mechanism and Operation and Maintenance (O&M) plan must be included in the SWPPP.

At a minimum, the O&M plan must address each of the following:

- An owner of a post-construction stormwater management practice (including RR techniques, standard SMPs, and alternative practices), shall erect or post a sign, in the immediate vicinity of each stormwater management practice. See **Figure 3.1** for an example. The sign(s) shall have minimum dimensions of 18 inches by 24 inches and shall have white letters on a green background and contain the following information:

    1. **Stormwater Management Practice**
       (Insert name of practice)
    2. (*Insert SPDES Construction Permit #*)
    3. Practice must be maintained in accordance with Operation & Maintenance plan.
    4. **THIS SIGN MAY NOT BE REMOVED OR ALTERED.**

Figure 3.1 Example Post-Construction Stormwater Management Practice Sign

  Alternatively, the owner may erect or post one comprehensive sign, in a highly visible area, that lists all stormwater management practices within the project site. The comprehensive sign shall include keyed numbers that correspond to each practice on site. With this approach, additional simplified signs shall be erected at each individual practice depicting their keyed number.

- For any practice or pretreatment device that has unrestricted access to ponded water of 3 ft or more, provide a 18"x12" warning sign per **Figure 3.2**. The sign shall have a white background, a black border and text, and red “Warning” text. Where a practice is enclosed with a fence, the practice shall be considered restricted and the sign not required.

Figure 3.2 Warning Sign

- Identification of the entity that will be responsible for long term operation and maintenance of the stormwater management practices.
- Identification of the mechanism(s) that will be used to ensure long term operation and maintenance of the stormwater management practices (Deed covenant, easements/rights-of-way, executed maintenance agreement, etc.). Include a copy of such mechanism.
- A copy of the site plan identifying all practices locations on site.
- A copy of the schematics of the practice, with the measurements of design specifications clearly defined.
- A list of maintenance requirements (already defined in this Design Manual and the additional site-specific requirements), proper frequency, and a maintenance log for tracking and observation.

Section 3.6 The Six Step Process for Stormwater Site Planning and Practice Selection

Stormwater management using runoff reduction techniques is summarized in the six step process described below, and as shown in the flow chart in **Figure 3.3**. Designers are required to adhere to the six step process when developing a SWPPP. This includes providing information in the SWPPP, which documents compliance with the required process. For projects with redevelopment activities, see **Chapter 9** for Step 3 redevelopment criteria. For urban development and redevelopment projects refer to **Chapter 8** for urban design considerations.

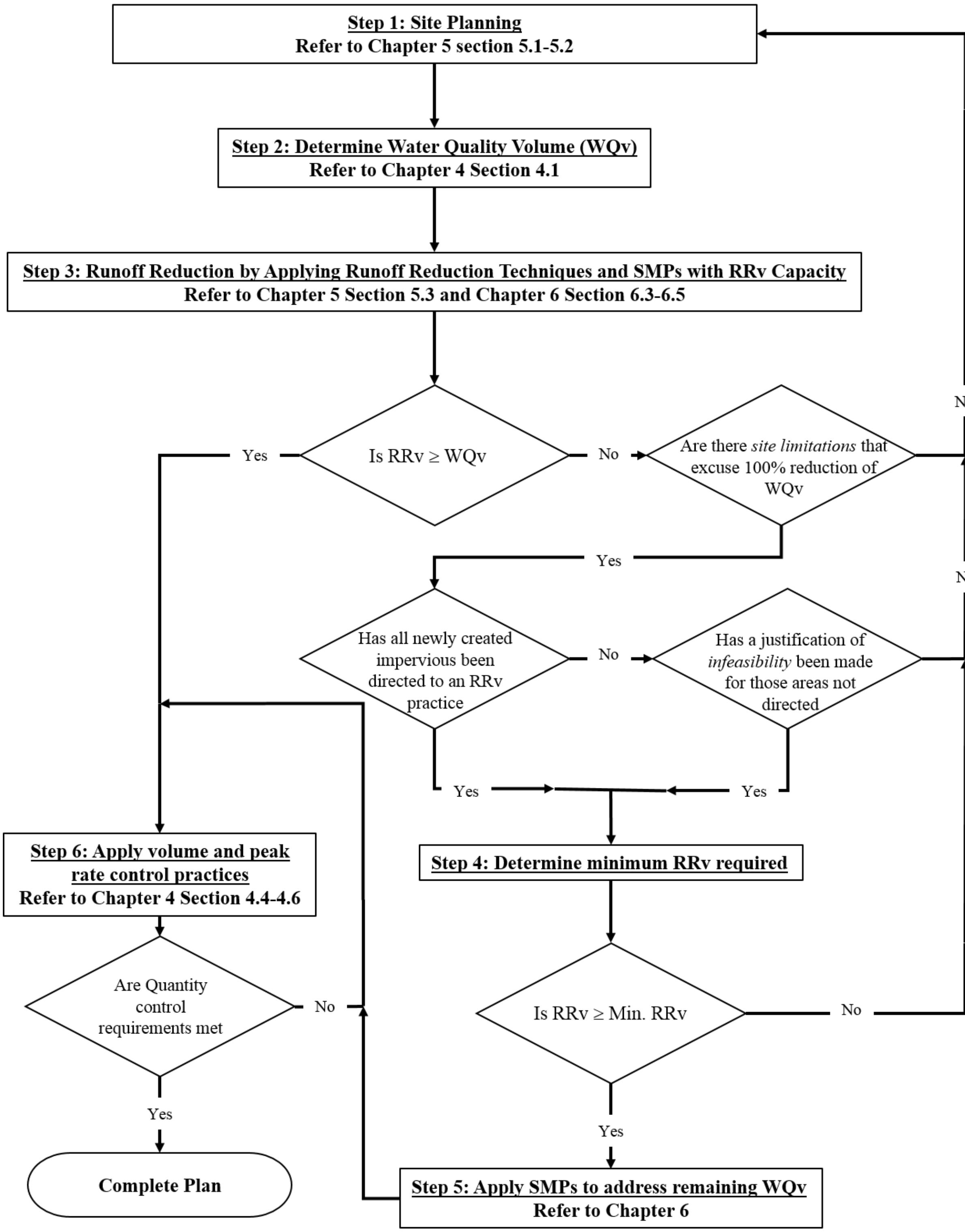


Figure 3.3 Stormwater Site Planning and Practice Selection Flow Chart

Step 1: Site Planning

In Step 1, the designer uses practices identified in **Table 3.1** to protect natural resources and utilize the hydrology of the site before laying out the proposed development. The Preservation of Natural Resources practices (see **Table 3.1**) include protecting natural areas, avoiding sensitive areas and minimizing grading and soil disturbance. The designer then considers practices to reduce impervious cover when laying out the initial site design. The Reduction of Impervious Cover practices (see **Table 3.1**) include conservation design and reducing impervious cover in roads, driveways and parking lots.

The SWPPP must include an evaluation of all the green infrastructure planning measures as they apply to the site. This evaluation process requires the following measures:

- Developing a map that identifies natural resource areas and drainage patterns; including but not limited to:
    - Wetlands (jurisdictional, wetland of special concern)
    - Waterways (major, perennial, intermittent, springs)
    - Buffers (stream, wetland, forest, etc.)
    - Floodplains
    - Forest, vegetative cover
    - Critical areas
    - Topography (contour lines, existing flow paths, steep slopes, etc.)
    - Soil (hydrologic soil groups, highly erodible soils, etc.)
    - Bedrock, significant geology features
- Devising the strategies for protection and enhancement of natural resources
    - Prior to site layout, preserve natural features (site fingerprinting)
    - Utilize natural features to preserve the natural hydrology
    - Maintain natural drainage design points
    - Maximize retention of forest cover and undisturbed soils
    - Avoid erodible soils on steep slopes and limit mass grading
- Reducing the impacts of development by reducing impervious surfaces
- Demonstrating that all reasonable opportunities for preserving natural conditions of the site are employed to minimize the runoff and maintain the pre-construction hydrology

During the planning step, the designer should check with the municipality to determine if there are local laws and ordinances that regulate wetlands, stream buffers, forest or habitat protection, erosion control or grading. If present, the local regulations will determine minimum areas of protection that the designer can then expand upon to maximize runoff reduction objectives. The designer should also consult the municipality for laws relating to conservation or cluster design, roads, driveways and parking lots to determine the level of flexibility in reducing impervious surfaces. This component of the plan must also be clearly addressed in the Erosion and Sediment Control (ESC) Plan (Development of ESC plan is provided in the New York Standards and Specifications for Erosion and Sediment Control). Description and minimum requirements for meeting site planning principles are presented in **Chapter 5** of this Manual.

The choices made by the designer should be influenced to some extent by the resource(s) being protected, and the region of New York State where the site is located. The following matrix (**Table 3.5**) presents some design considerations for six watershed or regional factors in New York:

- Sensitive Streams: The guidance presented here should apply to all trout waters and Class N waters, and any streams that support high biodiversity and water quality and have a low density of development.
- Aquifers: In sole source aquifers, special care should be taken to select practices and incorporate design considerations that protect the groundwater quality. The EPA "Map of Sole Source Aquifer Locations" (www.epa.gov) depicts sole source aquifers in the State of New York.
- Lakes: Lakes are of particular concern in New York, which has many natural lake systems and borders on two Great Lakes. The information in this matrix focuses on phosphorous removal, which is an important concern in most lake systems. It is important to note, however, that many lakes in New York State have other important issues to address. Some lakes, such as Onondaga Lake, have other specific concerns, such as toxics and metals. Each community should also take these goals into consideration when reviewing site plans.
- Reservoirs: For drinking water reservoirs, and in particular for unfiltered water supplies such as the New York City Reservoir system, turbidity, phosphorous removal, and bacteria are of particular concern. A particular reservoir may have other specific concerns, which should be identified as part of a Source Water Assessment.
- Estuary/Coastal: In New York State, coastal or estuary areas include the South Shore Estuary Reserve, Peconic Estuary, NY/NJ Harbor, and Hudson River Estuary. In these areas, nitrogen is typically a concern due to potential eutrophication. In addition, bacteria control is important to protect shellfish beds.

Table 3.5 Watershed/Regional Selection Matrix					
SMP Group	**Sensitive Stream**	**Aquifer**	**Lakes**	**Reservoir**	**Estuary/Coastal**
Ponds	Emphasize channel protection. Restrict in-stream practices. In trout waters, minimize permanent pool area, extended detention time and encourage shading.	May require liner if HSG A soils are present. Pretreat 100% of WQ_v from hotspots. Provide a 2' separation distance to water table.	Encourage the use of a large permanent pool to improve phosphorus removal.	Encourage the use of a large permanent pool to improve sediment and phosphorous removal. Promote long detention times to encourage bacteria removal.	Encourage long detention times to promote bacteria removal. Provides high nitrogen removal. In flat coastal areas, a pond drain may not be feasible.
Wetlands	Require channel protection. Restrict in-stream practices. Restrict use in trout waters.				
Infiltration	Strongly encourage use for groundwater recharge. Combine with a detention facility to provide channel protection.	Provide 100' horizontal separation distance from wells and 4' vertical distance from the water table.	OK. Provides high phosphorus removal.	Provide a 100' horizontal separation distance from public or private reservoirs Pretreat runoff prior to infiltration practices.	OK, but provide a separation distance to seasonal high water table. In the sandy soils typical of coastal areas, additional pretreatment may be required (See **Section 6.3.3**)
Filtering Systems	Combine with a detention facility to provide channel protection.	Excellent pretreatment for infiltration or open channel practices.	OK, but designs with a submerged filter may result in phosphorus release.	Excellent pretreatment for infiltration or open channel practices. Moderate to high coliform removal	Moderate to high coliform removal signs with a submerged filter bed appear to have very high nitrogen removal
Open Channels	Combine with a detention facility to provide channel protection.	OK, but hotspot runoff must be adequately pretreated	OK. Moderate phosphorous removal.	Poor coliform removal for wet swales.	Poor coliform removal for grass wet swales.

Step 2: Calculate Water Quality Treatment Volume (WQv)

In Step 2, the designer calculates the required WQ_v for the site using the criteria in **Chapter 4**. Once the preliminary site layout is prepared, impervious areas are defined, and sub-catchments are delineated, the designer should calculate the water quality volume. This initial calculation of WQ_v may have to be revised after RR techniques are applied.

Step 3: Apply RR Techniques and Standard SMPs with RRv Capacity to Reduce Total WQv

In Step 3, the designer experiments with combinations of RR techniques and standard SMPs with RR_v capacity on the site. In each case, the designer estimates the spatial area to be treated by each RR technique, potentially reducing the required WQ_v by incorporating RR techniques or standard SMPs with RR_v capacity within each drainage area on the site.

The RR techniques are listed in **Table 3.6**, and are divided into two categories for Area Reduction and Volume Reduction. For each RR technique, a designer can apply the following percentages of WQ_v towards meeting the RR_v sizing criteria, provided the design of the practice complies with the design and sizing criteria in **Chapter 5**:

Table 3.6 Runoff Reduction Capacity for Runoff Reduction Techniques

RR Technique with RRv Capacity	RRv Capacity (% of WQ_v reduced by practice)
RR Techniques (Area Reduction)	
Conservation of Natural Areas	100%
Sheet flow to Riparian Buffers/Filter Strips	100%
Tree Planting	100%
Disconnection of Rooftop Runoff	100%
RR Techniques (Volume Reduction)	
Tree Pit[1]/Tree Trench[1]	100% for tree pits without underdrains and tree trenches
	40% for tree pits with underdrains
Vegetated Swale	20% in HSG A or B
	10% in HSG C or D
	15% in Modified HSG C
	12% in Modified HSG D
Rain Garden[1]	100% without underdrains
	40% with underdrains
Stormwater Planter[1]	100% without underdrain
	40% with underdrains
Rainwater Harvesting System	100%
Porous Pavement	100% without underdrains
	40% with underdrains
Green Roof	100%

[1]For practices with underdrains that require sizing the surface area of the filter bed using Darcy's Law, the designer can elect to oversize the surface area of the filter bed to provide additional storage volume and receive additional RRv credit up to 100% of the WQv required. The total RRv credit shall be the percentage, noted above, applied to the storage volume provided. The storage volume provided shall be considered the volume within the filter media and the volume of ponding occurring during the WQv event.

The standard SMPs with RRv capacity are listed in **Table 3.7**. For each standard SMP with RRv capacity, a designer can apply the following percentages of WQ_v towards meeting the RRv sizing criteria, provided the design of the practice complies with the design and sizing criteria in **Chapter 6**:

Table 3.7 Runoff Reduction Capacity for Standard SMPs

SMP	RRv Capacity (% of WQ_v reduced by practice)
Infiltration Practices	100%
Infiltration Bioretention	100%
Filtration Bioretention[1]	40%
Bioslope	40% in HSG A or B
	20% in HSG C or D
Dry Swale	40% in HSG A or B
	20% in HSG C or D

[1]For practices with underdrains that require sizing the surface area of the filter bed using Darcy's Law, the designer can elect to oversize the surface area of the filter bed to provide additional storage volume and receive additional RRv credit up to 100% of the WQv required. The total RRv credit shall be the percentage, noted above, applied to the storage volume provided. The storage volume provided shall be considered the volume within the filter media and the volume of ponding occurring during the WQv event.

If the standard SMPs with RRv capacity listed above are being implemented to address the RRv criteria, the practices must be designed to capture runoff near the source. The practices must be localized systems that are installed throughout the site at each runoff source, thereby minimizing the use of traditional "end-of- pipe" treatment systems.

By applying a combination of RR techniques and standard SMPs with RRv capacity, the designer must reduce 100% of the WQ_v calculated in Step 2. If the RRv calculated in this step is greater than or equal to the WQ_v calculated in Step 2, the designer has met the RRv requirement and may proceed to Step 6. Unless it can be demonstrated that site limitations exist to provide relief from reducing 100% of the WQ_v, designers must return to Step 1 to see if an alternative site plan or combination of RR techniques and standard SMPs with RRv capacity can be applied to achieve compliance with the RRv sizing criteria. Acceptable site limitations include conditions that prevent the use of an infiltration technique and or infiltration of the total WQ_v, such as seasonal high water table, shallow depth to bedrock, and soils with an infiltration rate less than 0.5 in/hr. For construction activities that cannot reduce the total WQ_v, the designer shall identify the specific site limitations in the SWPPP. For each area where runoff from newly constructed impervious area is not directed towards a RR technique or standard SMP with RRv capacity, the designer must provide justification in the SWPPP as to why each of the aforementioned practices are infeasible. If a demonstration of infeasibility cannot be made, then the designer must return to Step 1 to see if an alternative site plan or combination of the RR techniques and standard SMPs with RRv capacity can be applied to achieve compliance with the RRv sizing criteria.

Step 4: Calculate the minimum RRv required

In Step 4, the designer calculates the minimum RRv required for the construction activity using the criteria in **Section 4.3** of this Design Manual and compares this to the runoff reduction achieved in Step 3. In no case shall the runoff reduction achieved from the newly constructed impervious areas be less than the Minimum RRv.

Step 5: Apply Standard SMPs to Address Remaining WQv

In Step 5, the designer uses standard SMPs (see **Table 3.7**) such as ponds, stormwater wetlands, or filtering practices, to treat the remaining water quality volume that cannot be reduced by applying RR techniques and standard SMPs with RRv capacity. The designer must verify that the RRv requirement has been met; otherwise the plan does not comply with the required sizing criteria in **Chapter 4**.

Step 6: Apply Volume and Peak Rate Control Practices if Still Needed to Meet Requirements

The channel protection volume, overbank flood control, and extreme flood control must be met for the plan to be completed. In Step 6, the designer may use practices such as infiltration basins, dry detention basins, and blue roofs to meet water quantity requirements, if not already achieved under the previous steps.

Chapter 4: Unified Stormwater Sizing Criteria

Section 4.1 Introduction

This Chapter presents a unified approach for sizing runoff reduction techniques and standard SMPs to meet pollutant removal goals, reduce channel erosion, prevent overbank flooding, and help control extreme floods. For a summary, please consult **Table 4.1** below. The remaining sections describe the sizing criteria in detail and present guidance on how to properly compute and apply the required reduction and storage volumes.

Table 4.1 New York Stormwater Sizing Criteria

Water Quality Volume (WQ_v)	90% Rule: WQ_v(acre-feet) = [(P)(Rv)(A)] /12 Rv = 0.05+0.009(I) I = Impervious Cover (Percent) P(inches) = 90% Rainfall Event Number (See **Figure 4.1**) [2] A = Contributing Area (acres)
Runoff Reduction Volume (RRv)	RRv (acre-feet) = Reduction of the total WQ_v by application of runoff reduction techniques and standard SMPs with RRv capacity to replicate pre-development hydrology. The minimum required RRv is defined by the Specific Reduction Factor (S), provided objective technical justification is documented.
Channel Protection Volume (CPv)[1]	Default Criterion: CPv (acre-feet) = 24-hr extended detention of post-developed 1-year, 24-hr design storm; remaining after runoff reduction. Where site conditions allow, Runoff reduction of total CPv, is encouraged for Sites Larger than 50 Acres: Distributed Runoff Control - geomorphic assessment to determine the bank full channel characteristics and thresholds for channel stability and bedload movement.
Overbank Flood (Qp)[1]	Qp(cfs)=Control the peak discharge from the 10-year storm to 10-year pre-development rates.
Extreme Flood (Qf)[1]	Qf(cfs)=Control the peak discharge from the 100-year storm to 100-year pre-development rates. Safely pass the 100-year design storm.
Alternative method	Design, construct, and maintain systems sized to capture, reduce, reuse, treat, and manage rainfall on-site, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event, computed by an acceptable continuous simulation model.

[1]Channel protection, overbank flood, and extreme flood requirements may be waived in some instances if the conditions specified in this Chapter are met. For SMPs involving dams, follow **Appendix A**, Guidelines for Design of Dams for safe passage of the design flood.

[2]For required sizing criteria in redevelopment projects and phosphorus limited watersheds refer to **Chapter 9** and **Section 4.3**, respectively.

Section 4.2 Water Quality Volume (WQ_v)

The Water Quality Volume (WQ_v) is intended to improve water quality by capturing and treating runoff from small, frequent design storms that tend to contain higher pollutant levels. New York has defined the WQ_v as the volume of stormwater runoff, generated from the 90th percentile rain event (90% of all 24-hr design storms, in a given year), that shall be captured and treated by stormwater management practice(s). The WQ_v is directly related to the amount of impervious cover constructed at a site. Contour lines of the 90% rainfall event are presented in **Figure 4.1**. The minimum 90% rainfall value shall be 1.0 inch.

The following equation shall be used to determine the water quality storage volume WQ_v (in acre-feet of storage):

$$WQv = \frac{P * R_v * A}{12}$$

Where:

WQ_v = water quality volume (in acre-feet)

P = 90% Rainfall Event Number (see **Figure 4.1**)

R_v = 0.05 + 0.009(I), where I is percent impervious cover

A = contributing area (acres)

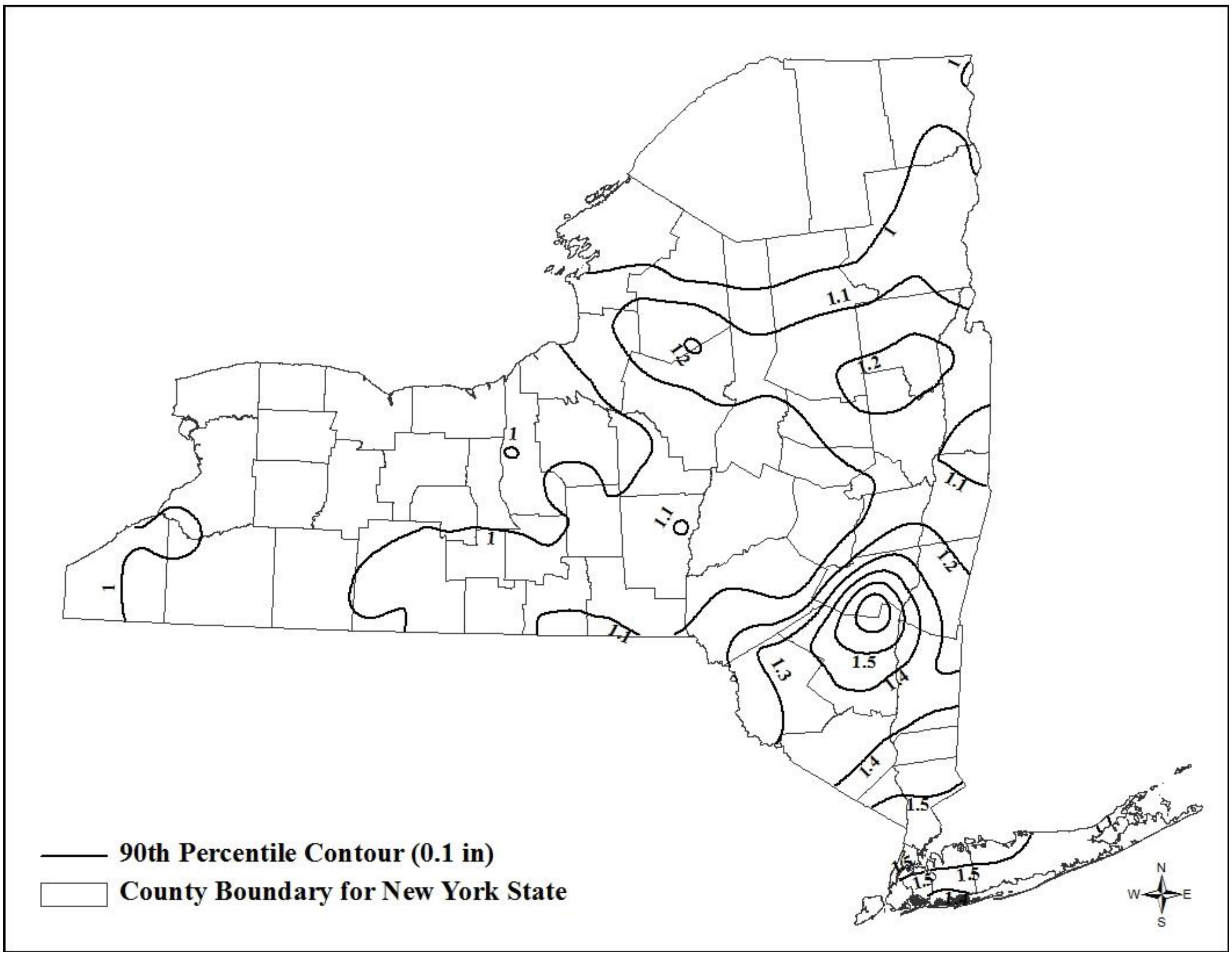


Figure 4.1 90th Percentile Rainfall in New York State (NYSDEC, 2013)

Basis of Design for Water Quality

As a basis for design, the following assumptions may be made:

Measuring Impervious Cover: the measured area of a site plan that does not have permanent vegetative or permeable cover shall be considered total impervious cover. Where site size makes direct measurement of impervious cover impractical, the land use/impervious cover relationships presented in **Table 4.2** can be used to initially estimate impervious cover. In site specific planning impervious cover must be calculated based the specific proposed impervious cover.

Table 4.2 Land Use and Impervious Cover
(Source: Cappiella and Brown, 2001)

Land Use Category	Mean Impervious Cover (%)
Agriculture	2
Open Urban Land*	9
2 Acre Lot Residential	11
1 Acre Lot Residential	14
1/2 Acre Lot Residential	21
1/4Acre Lot Residential	28
1/8 Acre Lot Residential	33
Townhome Residential	41
Multifamily Residential	44
Institutional**	28-41
Light Industrial	48-59
Commercial	68-76

* Open urban land includes developed park land, recreation areas, golf courses, & cemeteries.

** Institutional is defined as places of worship, schools, hospitals, government offices, & police and fire stations.

- *Aquatic Resources:* More stringent local regulations may be in place or may be required to protect drinking water reservoirs, lakes, or other sensitive aquatic resources. Consult the local authority to determine the full requirements for these resources.
- *SMP Treatment:* The final WQ_v, remaining after application of runoff reduction sizing criterion, shall be treated by an acceptable practice from the list presented in this manual. Please consult **Chapter 3** for a list of acceptable practices.
- *Determining Peak Discharge for WQ_v Storm:* When designing flow splitters for off-line practices, consult the small storm hydrology method provided in **Chapter 9**.
- *Extended Detention for Water Quality Volume:* The water quality requirement for storage systems can be met by providing 24-hrs of the WQ_v (provided a micropool is specified) extended detention. A local jurisdiction may reduce this requirement to as little as 12-hrs in trout waters to prevent stream warming.
- *Off-site Areas:* Where off-site areas will drain to the SMP, calculate imperviousness of the off-site contributing drainage area based on its current condition. If water quality treatment is provided off-line, the practice must only treat on-site runoff.

Section 4.3 Water Quality Volume (WQ_v) for Enhanced Phosphorus Removal Watersheds

For watersheds requiring enhanced phosphorus removal, the WQ_v shall be sized to capture and treat the 1-yr 24-hr design storm. Refer to **Chapter 10** for additional information regarding pollutants of concern. The following equation shall be used to determine the water quality storage volume WQ_v (in acre-feet of storage):

$$WQv = \frac{P_1 * R_v * A}{12}$$

Where:

WQ_v = water quality volume (in acre-feet)

P_1 = 1-yr 24-hr design storm (inches)

R_v = 0.05 + 0.009(**I**), where **I** is percent impervious cover

A = site area in acres (Contributing area)

Section 4.4 Runoff Reduction Volume (RRv)

Runoff reduction shall be achieved by infiltration, groundwater recharge, reuse, recycle, evaporation/evapotranspiration of 100 percent of the post-development water quality volume. The goal of runoff reduction is to replicate pre-development hydrology by maintaining pre-construction infiltration, peak runoff flow, and discharge volume, as well as minimizing concentrated flow, by application of practices that provide source control treatment in a distributed manner before runoff reaches the collection system. This requirement shall be accomplished by application of on-site runoff reduction techniques and/or standard SMPs with runoff reduction capacity.

Runoff reduction volume (RRv) shall be calculated using one of the following methods:

- Area reduction (contributing area or contributing impervious area) in WQ_v computation (as defined in **Chapter 5**)
- Volume reduction using runoff reduction techniques (as defined in **Chapter 3, Table 3.6**)
- Volume reduction using standard SMPs with runoff reduction capacity (as defined in **Chapter 3, Table 3.7**)

For practices with underdrains that require sizing the surface area of the filter bed using Darcy's Law, the designer can elect to oversize the surface area of the filter bed to provide additional storage volume and receive additional RRv credit up to 100% of the WQv required. The total RRv credit shall be the percentage, as noted in **Tables 3.6 and 3.7**, applied to the storage volume provided. The storage volume provided shall be considered the volume within the filter media and the volume of ponding occurring during the WQv event.

Projects that cannot meet 100% of the runoff reduction requirement, due to site limitations that prevent the use of an infiltration practice and/or infiltration of the total WQ_v, shall identify the specific site limitations in the SWPPP. Typical site limitations include: seasonal high water table, shallow depth to bedrock, and soils with an infiltration rate less than 0.5 in/hr.

In no case shall the runoff reduction achieved from the newly constructed impervious areas be less than the minimum runoff reduction volume (RRv_{min}) determined by the following equation:

$$RRv_{min} = \frac{P * R_v * Aic * S}{12}$$

Where:

P = 90% Rainfall Event Number (see **Figure 4.1**)

RRv_{min} = Minimum runoff reduction volume required from impervious area (acre-ft)

R_v = 0.05+0.009(**I**) where **I** is 100% impervious

Aic = Total area of new impervious cover

S = Hydrologic Soil Group (HSG) Specific Reduction Factor (*S*)

The specific reduction factor (S) is based on the HSGs present at a site. The following lists the specific reduction factors for the HSGs:

- HSG A = 0.55
- HSG B = 0.40
- HSG C = 0.30
- HSG D = 0.20

Runoff reduction techniques are intended to be applied for source control treatment. As such, multiple runoff reduction techniques may be utilized on a site to maximize storage volume and achieve greater reduction. However, reduction cannot be claimed twice for an identical area of the site (e.g., claiming the stream buffers and disconnecting rooftops over the same site area).

Section 4.5 Runoff Reduction Volume (RRv) for Enhanced Phosphorus Removal Watersheds

For watersheds requiring enhanced phosphorus removal, runoff reduction shall apply the WQv resulting from the 1-yr 24-hr design storm, as calculated in **Section 4.3**. Similarly, the minimum RRv is calculated using the 1-yr 24-hr design storm and Specified Reduction Factors outlined in **Section 4.4**.

Section 4.6 Stream Channel Protection Volume Requirements (CPv)

Stream Channel Protection Volume Requirements (CPv) are designed to protect stream channels from erosion. This goal is accomplished by providing 24-hr extended detention of the 1-year, 24-hr design storm, that remains after runoff reduction.

Meeting stream channel protection objectives through runoff reduction is encouraged and the volume reduction achieved through RR techniques and/or standard SMPs with RRv capacity can be deducted from CPv. Trout waters may be exempt from the 24-hr extended detention requirement, requiring only 12 hrs of extended detention, when there is a direct discharge to the trout water. Detention time shall be calculated using either the center of mass method or plug flow calculation method.

For developments greater than 50 acres, with impervious cover greater than 25%, it is recommended that a detailed geomorphic assessment be performed to determine the appropriate level of control. **Appendix I** provides guidance on how to conduct this assessment.

Detention ponds or underground detention systems and vaults are methods to meet the CPv requirement (and subsequent Qp and Qf criteria). Note that, although these practices meet water quantity goals, they are unacceptable for water quality because of poor pollutant removal and need to be coupled with a practice listed in **Table 3.2** and **Table 3.3**. The CPv requirement may also be provided above the water quality (WQ_v) storage in a wet pond or stormwater wetland.

Basis for Determining Channel Protection Storage Volume

The following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) shall be used to determine peak discharge rates.
- Rainfall data and distribution curves shall be established for the 1-year 24-hr design storm, using the process outlined in **Section 4.9.**
- Off-site areas shall be modeled as "present condition".
- The length of sheet flow used in T_c calculations is limited to no more than 150 ft for pre-development conditions and no more than 100 ft for post-development conditions. On areas of extremely flat terrain (<1% average slope), this maximum distance is extended to 250 ft for pre-development conditions and 150 ft for post-development conditions. If the start of a T_c flow path is unchanged (undisturbed) from pre- to post-development conditions, then the sheet flow length shall be identical.
- The CPv storage volume shall be computed using one of the following methods:
  - Center-of-mass detention time: time difference between the center of mass of the inflow hydrograph (entering the SMP) and the center of mass of the outflow hydrograph (leaving the SMP).
  - Plug flow detention time: theoretical average detention time.

- Where a CPv control orifice is provided, the minimum orifice size shall be 3 inches, with acceptable external trash rack or orifice protection (See **Appendix C** for details of a low flow orifice and trash rack options).
- CPv shall be addressed for the entire site. If a site consists of multiple design points, CPv shall be determined and provided for each design point.
- Extended detention storage provided for the CPv does not meet the WQv requirement (that is CPv and WQv shall be treated separately). However, both water quality and channel protection storage may be provided in the same SMP.

The Channel Protection Volume requirements may be waived if:

- Reduction of the entire CPv volume is achieved at a site through runoff reduction or infiltration systems.
- CPv is not required at sites where the 1-year post-development peak discharge is less than or equal to 2.0 cfs.
- Where a CPv control orifice is provided, the minimum orifice size shall be 3 inches, with acceptable external rack or internal orifice protection (See **Appendix C** for details of a low flow orifice and trash rack options).
- The site directly discharges into a fifth order or larger water body (streams, rivers, or lakes) or tidal waters, where the increase in smaller flows will not impact the stream bank or channel integrity. However, the point of discharge must be adequately protected against scour and erosion by the increased peak discharge.

Streams are classified using the New York State Codes Rules and Regulations (NYCRR), Volumes B-F, Parts 800-941. However, this classification system does not provide a numeric stream order. The methodology identified in this Manual is consistence with Strahler-Horton methodology. For an example of stream order identification see **Section 4.12**.

Section 4.7 Overbank Flood Control Criteria (Qp)

The primary purpose of the overbank flood control sizing criterion is to prevent an increase in the frequency and magnitude of out-of-bank flooding generated by urban development (i.e., flow events that exceed the bank full capacity of the channel, and therefore must spill over into the floodplain).

Basis for Design of Overbank Flood Control

When addressing the overbank flooding design criteria, the following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) will be used to determine peak discharge rates.
- Rainfall data and distribution curves shall be established for the 10-year 24-hr design storm, using the process outlined in **Section 4.9.**
- When the pre-development land use is agriculture, the curve number for the pre-developed condition shall be taken as “meadow”.
- Off-site areas shall be modeled as "present condition" for the 10-year design storm.
- The length of sheet flow used in T_c calculations is limited to no more than 150 ft for pre-development conditions and no more than 100 ft for post-development conditions. On areas of extremely flat terrain (<1% average slope), this maximum distance is extended to 250 ft for pre-development conditions and 150 ft for post-development conditions. If the start of T_c flow path is unchanged (undisturbed) from pre- to post-development conditions, then the sheet flow length shall be identical.
- Overbank Flood Control shall be addressed for the entire site. If a site consists of multiple design points, Overbank Flood Control shall be determined and provided for each design point.

Overbank Flood Control requires storage to attenuate the post-development 10-year, 24-hr peak discharge rate (Qp) to pre-development rates.

The Overbank Flood Control requirement may be waived if:

- The site directly discharges into a fifth order or larger water body (streams, rivers, or lakes) or tidal waters, where the increase in smaller flows will not impact the stream bank or channel integrity. However, the point of discharge must be adequately protected against scour and erosion by the increased peak discharge. Refer to **Section 4.12** for instructions.

- A downstream analysis reveals that overbank control is not needed (see **Section 4.13**).

Section 4.8 Extreme Flood Control Criteria (Qf)

The intent of the extreme flood criteria is to (a) prevent the increased risk of flood damage from large design storms, (b) maintain the boundaries of the pre-development 100-year floodplain, and (c) protect the physical integrity of stormwater management practices.

Basis of Design for Extreme Flood Control Criteria

When addressing the extreme flood design criteria, the following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) will be used to determine peak discharge rates.
- Rainfall data and distribution curves shall be established for the 100-year 24-hr design storm, using the process outlined in **Section 4.9.**
- Off-site areas shall be modeled as "present condition" for the 100-year design storm.
- The length of sheet flow used in T_c calculations is limited to no more than 150 ft for pre-development conditions and no more than 100 ft for post-development conditions. On areas of extremely flat terrain (<1% average slope), this maximum distance is extended to 250 ft for pre-development conditions and 150 ft for post-development conditions. If the start of T_c flow path is unchanged (undisturbed) from pre- to post-development conditions, then the sheet flow length shall be identical.
- Extreme Flood Control shall be addressed for the entire site. If a site consists of multiple design points, Extreme Flood Control shall be determined and provided for each design point.

Extreme Flood Control requires storage to attenuate the post-development 100-year, 24-hr peak discharge rate (Qf) to pre-development rates.

The Extreme Flood Control requirement may be waived if:

- The site directly discharges into a fifth order or larger water body (streams, rivers, or lakes) or tidal waters, where the increase in smaller flows will not impact the stream bank or channel integrity. However, the point of discharge must be adequately protected against scour and erosion by the increased peak discharge. Refer to **Section 4.12** for instructions.
- A downstream analysis reveals that 100-year control is not needed (see **Section 4.13**)

Section 4.9 Rainfall Data, Distribution Curves and Hydrologic Modeling

Rainfall distribution curves are developed from rainfall data and describe how a storm's total rainfall amount will be distributed over a specific length of time, such as 24 hours. It is based on historic rainfall values, over a wide range of time intervals, for various frequency storms. Properly calculated rainfall distribution curves are critical when evaluating the hydrologic character of a drainage area and when sizing hydraulic structures.

Rainfall data for the Stream Channel Protection Volume, Overbank Flood Control and Extreme Flood Control design storms shall be taken from:

- NRCC and NRCS joint collaborative website (http://precip.eas.cornell.edu); or
- National Oceanic and Atmospheric Administration (NOAA) - Atlas 14 (https://hdsc.nws.noaa.gov/hdsc/pfds/).

Hydraulic and hydrologic modeling software, such as USDA NRCS TR20, HydroCAD, Pond Pack, StormCAD, Hydraflow, and Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) and others, shall be used to extract rainfall frequency and duration data, for the project location, to create intensity-duration-frequency (IDF) curves, and then convert into rainfall distribution curves.

The following provides the step-by-step process to generate rainfall distribution curves using the NRCC and NRCS website and HydroCAD. This process is similar for both rainfall data sources listed above.

1. Go to the NRCC and NRCS website and select the tab "Data and Products.
2. Use the location map to zoom into the project site. If the marker is not located on the project site, double click on the map to relocate the marker.

3. From the Products list, select “Extreme Precipitation Tables – Text/CSV”. At the bottom of the page, set smoothing to “No”, then click “Submit”.
4. Select “Save As”, navigate to the project folder. Rename the file starting with NY- (example: NY-Cicero.txt) and save the file into you project folder. The NY- in the project name is required in order for HydroCAD to place the IDF file in the correct location.
5. Once the file is in the project folder, rename the file to change the “.txt” extension to a “.hci” extension (example: NY-Cicero.hci). This “.hci” extension is required in order for HydroCAD to recognize this as an IDF file.
6. Open or create a model using HydroCAD in the project folder where the IDF file, created above, is located.
7. From the “Settings” drop down select “Calculations”, pick the “Rainfall” tab. Click on the “Import Events From…” and select “IDF file”. The “.hci” file, saved previously, should be listed in the “Rainfall IDF File:” drop down under the “NY-“ tab.
8. Click “View IDF”.
9. Click “More IDF data”.
10. Select “Convert” tab and under “Rainfall IDF File” select the correct IDF file.
11. Click “Create Mass Curves”. Click “OK” to close out of all menus. If prompted click “yes” to overwrite all storm events.
12. From the “Settings” drop down select “Calculations”, pick the “Rainfall” tab. In the “Storm Type” drop down navigate to the “NY-” tab and select the newly created mass curve file.
13. If prompted click “yes” to overwrite all storm events. Rainfall data, using the newly created mass curve file, should auto populate into the rainfall data settings.

Section 4.10 Alternative Method

New development causes changes to runoff volume, flow rates, timing of runoff and, most importantly, habitat destruction and degradation of the physical and chemical quality of the receiving waterbody. Traditionally, TR-55 and TR-20 (or approved equivalent) are used for evaluation of hydrology and sizing of stormwater management practices. With an increasing need for assessment of the long-term effects of development and maintenance of pre-development hydrology, continuous simulation modeling is an effective alternative method for analysis and evaluation of flow-duration, downstream quality, quantity, biological, and hydro-habitat sustainability.

Continuous simulation models utilize historical precipitation records for estimating runoff volumes, duration, and pollutant loading. This method allows for examination of a watershed parameters’ response to long term effects of design storms, instead of the response to a site level single theoretical design storm provided by single event-based models. Calculation of WQ_v using continuous simulation modeling accounts for infiltration, evapotranspiration, depression storage, and system storage, which allows a detailed and objective comparison of alternative treatments to determine if watershed characteristics are maintained by those treatments. Consequently, continuous simulation modeling allows for simulation of runoff reduction techniques and performance of flow duration analyses. An objective application of a continuous simulation model involves a calibrated model for a watershed on interest and incorporation of regional goals.

The following lists the guidelines for the design of stormwater management systems using a continuous simulation model:

- Design, construct, and maintain systems sized to capture, reduce, reuse, treat, and manage rainfall on-site, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event.
- The 95th percentile rainfall event is the event whose precipitation total is greater than or equal to 95 percent of all design storms over a given period of record.
- A minimum period of 20 years precipitation records is required to determine the 95^{th} percentile storm and derive the corresponding design storm.
- Select a practice(s) that provides infiltration, evapotranspiration, reuse, or recycle of this volume.
- 100% of the volume of water from storms less than or equal to the 95th percentile event shall not be discharged to surface water.

- Perform an analysis that shows post-construction flow-duration, shape of the hydrograph, and downstream quality and quantity does not exceed pre-construction hydrology.
- Site evaluation and soils analysis must conform to the standards provided in this Manual.
- The stormwater management practices employed must conform to the standards provided in this Manual.

Some examples of continuous simulation modeling tools include:

Stormwater Management Model (SWMM)

is an EPA supported urban runoff hydrology, hydraulics, and runoff quality model with detailed design tools capable of flow routing and storage for surface, sub-surface, stormwater and combined sewer overflow conveyance and groundwater systems, as well as determining the treatment capacity of stormwater management practices. Various applications of SWMM have utilized the detailed features of this model for simulating runoff reduction design features.

Source Loading and Management Model for Windows (WinSLAMM)

is a mid-range empirical model for evaluation of stormwater runoff loading in urban watersheds. This modeling tool uses small storm hydrology methods and calculates the runoff from historical precipitation data for a given period of time, pollutant loading from various land uses, and allows the user to simulate the stormwater load reduction effected by incorporating control devices. The stormwater management practices provided in WinSLAMM include several SMPs, runoff reduction design details and maintenance BMPs.

Hydrologic Simulation Program Fortran (HSPF)

is an EPA supported program for simulation of watershed hydrology and water quality. The HSPF model uses information such as the time history of rainfall, temperature, soil, land surface such as land cover and land-use patterns; and land management practices to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed. The model also predicts flow rate, sediment load, and nutrient concentrations.

A successful example of the use of HSPF for stormwater applications is the Western Washington Hydrologic Model (WWHM). Similar adaptation of the models for applications in New York State will require several verifications such as validation of input variables, accurate precipitation data, and calibration of the model.

Section 4.11 Conveyance Criteria

In addition to the stormwater treatment volumes described above, this manual also provides guidance on safe and non-erosive conveyance to, from, and through SMPs. Typically, the targeted storm frequencies for safe conveyance to SMPs are the 2-year and 10-year design storms. The 2-year design storm is used to ensure non-erosive flows through roadside swales, overflow channels, over berms within practices. Rainfall depths for the 2-year, 24-hr design storm throughout New York State shall be taken from the NRCC and NRCS joint collaborative website or NOAA - Atlas 14, as outlined in **Section 4.9**.

The 10-year design storm is typically used as a target sizing for outfalls, and as a safe conveyance criterion for open channel practices and overflow channels. The 10-year design storm is recommended as a minimum sizing criterion for closed conveyance systems. Note that some agencies or municipalities may use a different design storm for this purpose.

Section 4.12 Stream Order Identification

This section provides an example to help identify stream order based on Strahler-Horton Method. A network of streams drain each watershed. Streams can be classified according to their order in that network. A stream that has no tributaries or branches is defined as a first-order stream. When two first-order streams combine, a second-order stream is created, and so on. **Figure 4.2** illustrates the stream order concept (Schueler, T. 1995).

Evaluation of stream order must be performed using the Watershed Assessment, Tracking and Environmental Results System (WATERS) GeoViewer to determine if quantity controls do not apply. WATERS was developed by the USEPA and utilizes data from the National Hydrography Dataset Plus (NHDPlus). NHDPlus is an integrated suite of geospatial datasets that incorporate features of the National Hydrography Dataset (NHD) and the National Elevation Dataset (NED) at 1:100K scale. This application-ready data set is an outcome of a multi-agency effort aimed at developing many useful variables for water quality and quantity evaluation including stream order. Use the link below to access the WATERS GeoViewer.

Link: https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=ada349b90c26496ea52aab66a092593b

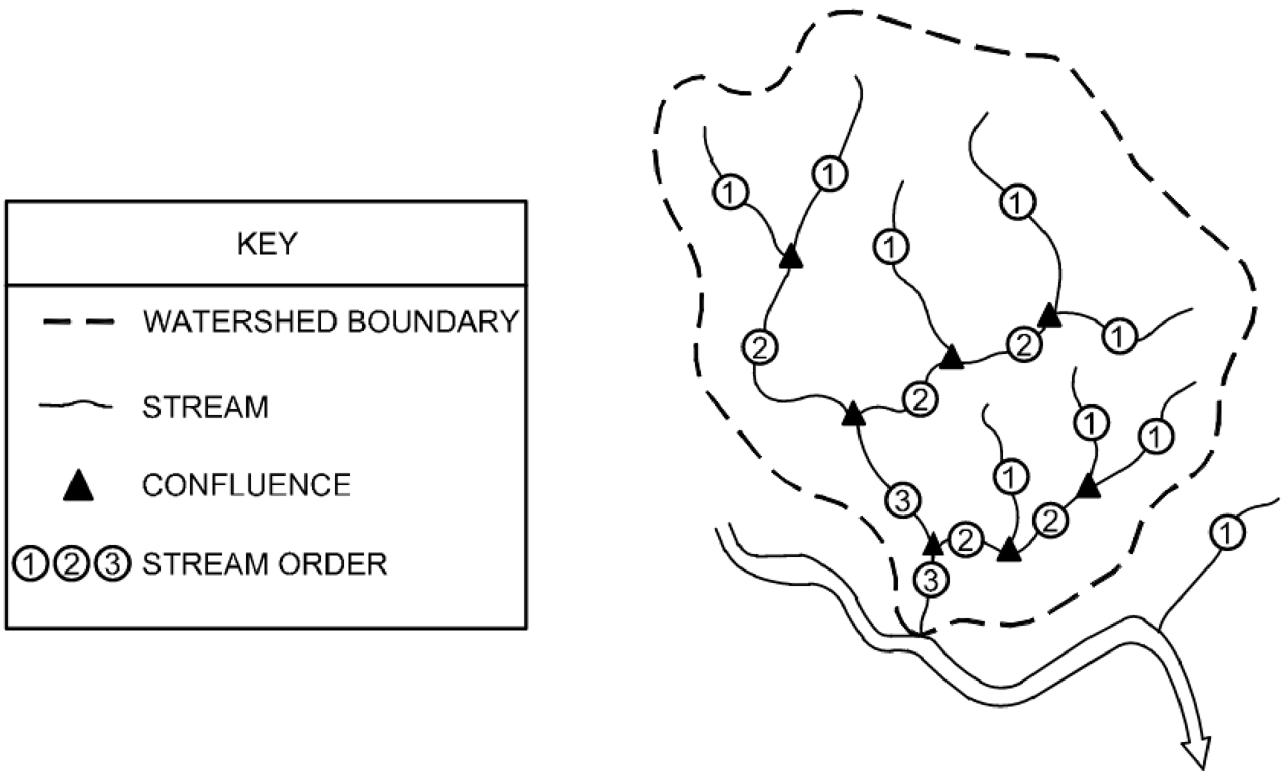


Figure 4.2 A Network of Headwater and Third-order Streams (Source: Schueler, 1995)

Section 4.13 Downstream Analysis

Overbank, and extreme flood requirements may be waived based on the results of a downstream analysis. In addition, such an analysis for overbank and extreme flood control is recommended for larger sites (i.e., greater than 50 acres) to size facilities in the context of a larger watershed. The analysis will help ensure that storage provided at a site is appropriate when combined with upstream and downstream flows. For example, detention at a site may in some instances exacerbate flooding problems within a watershed. This section provides brief guidance for conducting this analysis, including the specific points along the downstream channel to be evaluated and minimum elements to be included in the analysis.

Downstream analysis can be conducted using the 10% rule, meaning the analysis should extend from the point of discharge downstream to the point on the stream where the site represents 10% of the total drainage area. For example, the analysis points for a 10-acre area would include points on the stream from the points of discharge to the nearest downstream point with a drainage area of 100 acres. The required elements of the downstream analysis are as follows:

- Compute pre-development and post-development peak flows and velocities for design storms (e.g., 10-year and 100-year), at all downstream confluences with first order or higher streams up to and including the point where the 10% rule is met. These analyses shall include scenarios both with and without stormwater treatment practices in place, where applicable.
- Evaluate hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel.
- Assess water surface elevations to determine if an increase in water surface elevations will impact existing buildings and other structures.

The design, or exemption, at a site level can be approved if both of the following criteria are met:

- Peak flow rates increase by less than 5% of the pre-developed condition for the design storm (e.g., 10-year or 100-year)
- No downstream structures or buildings are impacted.

Section 4.14 Stormwater Hotspots

Stormwater Hotspots are defined as areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. These areas can include commercial, industrial, institutional, municipal, or transportation activities that, in addition to generating higher concentrations of pollutants, can present a higher risk for spills, leaks or illicit discharges. If a site is designated as a hotspot, a range of stormwater treatment and pollution prevention measures shall be applied to protect surface waters and groundwater.

When a development or redevelopment project includes an activity that is designated as a stormwater hotspot, consideration shall be taken to isolate the hotspot from the remaining watershed. To achieve isolation of a stormwater hotspot, the following criteria shall be met:

- Upgradient flow shall be diverted around the hotspot area and shall be conveyed to a separate stormwater practice (if treatment is required).
- The hotspot area shall be captured at the source and conveyed to a suitable stormwater practice.
- All tributary area that is conveyed to the stormwater practice treating the hotspot area, shall be subject to the same treatment requirements as the hotspot.

Table 4.3 provides a list of designated stormwater hotspots for the State of New York. The table looks at the illicit discharge potential of each of the activities listed. The potential for an activity to produce an illicit discharge is rated as either high, medium or low. This rating is based on the likelihood that is has a direct connection to a storm drain system (closed system) or that it can produce a transitory discharge (overland flow). These activities are further categorized as:

- Level 1: Hotspots with anticipated moderate pollutant concentration. Application of infiltration practices shall be restricted to provide two treatment practices in series (i.e. non-infiltration standard SMP, followed by an infiltration practice), both of which are sized to treat the entire WQv. Credit for RRv and WQv treated cannot be taken for the first practice in series.
- Level 2: Hotspots with anticipated severe pollutant concentrations. Application of infiltration practices is prohibited, and non-infiltration practices shall be applied to meet the RRv criteria.

It shall be noted that large highways (average daily traffic (ADT) volume greater than 25,000) are not designated as stormwater hotspots. However, based on the potential for contaminants within stormwater runoff as ADT increases, it is important to ensure that highway stormwater management plans adequately protect groundwater.

Not all practices are suitable for treatment of stormwater hotspots. In addition, the design of some practices may need modification to accommodate higher concentrations of pollutants. Refer to **Chapters 5** and **6** for practice suitability and design modifications to treat stormwater hotspots.

Table 4.3 Designated Stormwater Hotspots

Activities		Illicit Discharge Potential		Level 1 (Infiltration Restricted)	Level 2 (Infiltration Prohibited)
		Closed System	Overland Flow		
Industrial activities that are eligible for coverage under the Multi-Sector General Permit for Stormwater Discharges Associated with Industrial Activities (MSGP) [1]	Industrial activities subject to effluent limitation guidelines	Medium	High		✓
	Industrial activities within Sectors C, J, L or U that are located within watersheds requiring enhanced phosphorus removal	Medium	High		✓
	All other industrial activities	Medium	Medium	✓	
Fueling stations		Medium	High		✓
Petroleum storage facilities		High	High		✓
Uncovered vehicle, aircraft, boat, and heavy equipment maintenance facilities		Low	Medium	✓	
Uncovered vehicle, aircraft, boat, and heavy equipment cleaning facilities		Low	Low	✓	
Uncovered vehicle, aircraft, boat, and heavy equipment storage areas		Low	Medium	✓	
Uncovered loading/unloading facilities and recessed loading areas		Low	Medium	✓	
Public works yard with salt storage		Medium	High		✓
Public works yard without salt storage		Medium	Medium	✓	
Facilities that generate or store hazardous materials		Low	High		✓
Wastewater, solid waste, and composting facilities		Low	High		✓
Nurseries/garden centers		Low	Medium	✓	

[1]At a minimum, infiltration shall be restricted for all industrial activities within the MSGP. However, certain activities with greater pollutant thresholds may prohibit the use of infiltration

Chapter 5: Runoff Reduction Techniques

This Chapter presents planning and design of runoff reduction techniques. Runoff reduction planning includes measures for preservation of natural features of the site and reduction of proposed impervious cover. The runoff reduction techniques include practices that enable reductions in the calculated runoff from contributing areas and the required water quality volume.

All runoff reduction techniques require proper maintenance. Without proper maintenance, practices will not function as originally designed and may cease to function altogether. The design of all runoff reduction techniques includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see **Chapter 12**.

Section 5.1 Planning for Runoff Reduction: Preservation of Natural Features and Conservation Design

The first step in planning for stormwater management using runoff reduction is to avoid or minimize land disturbance by preserving natural areas. Development should be strategically located based on the location of resource areas and physical conditions at a site. Also, in finalizing construction, soils must be restored to the original properties and according to the intended function of the proposed practices. Preservation of natural features includes techniques to foster the identification and preservation of natural areas that can be used in the protection of water, habitat and vegetative resources. Conservation design includes laying out the elements of a development project in such a way that the site design takes advantage of a site's natural features, preserves the more sensitive areas and identifies any site constraints and opportunities to prevent or reduce negative effects of development. The green infrastructure planning measures for preservation of natural features and conservation design are outlined in the following sections, and include:

- **Section 5.1.1**: Preservation of Undisturbed Areas
- **Section 5.1.2**: Preservation of Buffers
- **Section 5.1.3**: Reduction of Clearing and Grading
- **Section 5.1.4**: Locating Development in Less Sensitive Areas
- **Section 5.1.5**: Open Space Design
- **Section 5.1.6**: Soil Restoration

5.1.1 Preservation of Undisturbed Areas

Description

Important natural features and areas such as undisturbed forested and native vegetated areas, natural terrain, riparian corridors, wetlands and other important site features should be delineated and placed into permanent conservation areas.

Key Benefits

- Helps to preserve a site's natural hydrology and water balance
- Can act as a non-structural stormwater feature to promote additional filtration and infiltration
- Can help to preserve a site's natural character, habitat and aesthetic appeal
- Has been shown to increase property values for adjacent parcels
- Can reduce structural stormwater management storage requirement and may be used in runoff reduction calculations (see **Section 5.3**)

Typical Perceived Obstacles and Realities

- Preserved conservation areas may limit the development potential of a site – With clustering and other development incentives, development yield can be maintained
- Preserved conservation areas may harbor nuisance wildlife, vegetation, and insects and may present safety hazards - Once established, natural conservation areas must be protected during construction and managed after occupancy by a responsible party able to maintain the areas in a natural state in perpetuity; proper management and maintenance will address nuisance and safety issues

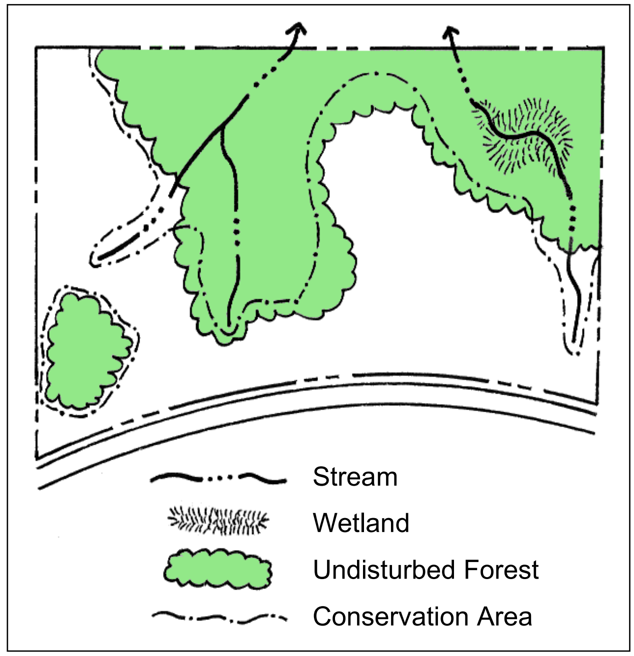


Figure 5.1 Example of natural resource inventory plan (Source: Georgia Stormwater Manual, 2001)

Figure 5.2 Aerial photograph of development project illustrating preservation of undisturbed natural areas (Source: Arendt, 1996)

Using this Practice

- Delineate and define natural conservation areas before performing site layout and design.
- Ensure that conservation areas and native vegetation are protected in an undisturbed state through the design, construction and occupancy stages.
- Check with the municipality to determine if there are local laws and ordinances that regulate wetlands, stream buffers, forests or habitat protection.

Discussion

Conservation of natural areas such as undisturbed forested and native-vegetated areas, natural terrain, riparian corridors and wetlands on a development project can help to preserve pre-development hydrology of the site and aid in reducing stormwater runoff and pollutant load. Previously disturbed and/or managed forest areas may be considered for permanent conservation if they are judged to provide the benefits outlined in this section. Undisturbed vegetated areas also promote soil stabilization and provide for filtering and infiltration of runoff.

Natural conservation areas are typically identified through a site-analysis stage using mapping and field-reconnaissance assessments. Areas proposed for protection should be delineated early in the planning stage, long before any site design, clearing or construction begins. When done before the concept-plan phase, the planned conservation areas can be used to guide the layout of a project. **Figure 5.1** shows components of a natural resources inventory map with proposed conservation areas delineated.

Preservation areas should then be incorporated into site-development plans and clearly marked on all construction and grading plans to ensure that construction activities are kept out of these areas and that native vegetation is undisturbed. The boundaries of each conservation area should be mapped by carefully determining the limit which should not be crossed by construction activity.

Once established, natural conservation areas must be protected during construction and managed after occupancy by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, conservation areas are protected by legally enforceable deed restrictions, conservation easements or a maintenance agreement. When one or more of these measures is applied, a permanently protected natural area can be used to reduce the area required for treatment by structural stormwater management measures (see **Figure 5.2** for a representative project illustrating natural resource area protection).

5.1.2 Preservation of Buffers

Description

Naturally vegetated buffers should be defined, delineated and preserved along perennial streams, rivers, shorelines and wetlands.

Key Benefits

- Riparian buffers treat stormwater and improve water quality
- Can be used as nonstructural stormwater infiltration zones
- Can keep structures out of the floodplain and provide a right-of-way for large flood events
- Help to preserve riparian ecosystems and habitats
- Can serve as recreational areas
- May be used in runoff reduction calculations if the criteria in this section are met

Typical Perceived Obstacles and Realities

- Buffers may result in a potential loss of developable land – Regulatory tools or other incentives may be available to protect the interests of property owners
- Private landowners may be required to provide public access to privately held stream buffers – Effective buffers can be maintained in private ownership through deed restrictions and conservation easements
- Nuisance wildlife, vegetation, and insects will be present due to the natural buffer area – Once established, vegetated buffers must be protected during construction and managed after occupancy by a responsible party able to maintain the areas in a natural state in perpetuity; proper management and maintenance will address nuisance issues

Using this Practice

- Delineate and preserve naturally vegetated riparian buffers (as well as vegetated buffers along streams listed as intermittent by the Department)
- Define the width, identify the target vegetation, and designate methods to preserve the buffer indefinitely
- Ensure that buffers and native vegetation are protected throughout planning, design, construction and occupancy
- Consult local planning authority for local wetland and/or stream regulations or guidelines for more stringent minimum buffer width

Figure 5.3 Buffer around Rondout Creek, Accord, NY

Discussion

A riparian buffer is a special type of natural conservation area along a stream, wetland or shoreline where development is restricted or prohibited. The primary function of buffers is to protect and physically separate a stream, lake, coastal shoreline or wetland from polluted stormwater discharges from future disturbance or encroachment. If properly designed, a buffer can provide stormwater management functions, can act as a right-of-way during floods, and can sustain the integrity of water-resource ecosystems and habitats. An example of a riparian stream buffer is shown in **Figure 5.3**.

Forested riparian buffers should be maintained and managed and reforestation should be encouraged where no wooded buffer exists. Proper restoration should include all layers of the forest plant community, including understory, shrubs and groundcover, not just trees. A riparian buffer can be of fixed or variable width but should be continuous and not interrupted by impervious areas that would allow stormwater to concentrate and flow into the stream without first flowing through the buffer.

Ideally, riparian buffers should be sized to include the 100-year floodplain as well as steep banks and freshwater wetlands. The buffer depth needed to perform properly will depend on the size of the stream and the surrounding conditions, but a minimum 25-ft undisturbed vegetative buffer is needed for even the smallest perennial streams, and a 50-ft or larger undisturbed buffer is ideal. Even with a 25-ft undisturbed buffer, additional zones can be added to extend the total buffer to at least 75 ft from the edge of the stream. The three distinct zones within the 75-ft depth are shown in **Figure 5.4**. The function, vegetative target and allowable uses vary by zone as described in **Table 5.1**.

These recommendations are minimum standards for most streams. Some streams and watersheds may benefit from additional measures to ensure adequate protection. In some areas, specific state laws or local ordinances already require stricter buffers than are described here. The buffer widths discussed are not intended to modify or supersede wider or more restrictive buffer requirements that are already in place.

As stated above, the streamside or inner zone should consist of a minimum of 25 ft of undisturbed mature forest. In addition to runoff protection, this zone provides bank stabilization as well as shading and protection for the stream. This zone should also include wetlands and any critical habitats, and its width should be adjusted accordingly. The middle zone provides a transition between upland development and the inner zone and should consist of managed woodland that allows for infiltration and filtration of runoff. An outer zone allows more clearing and acts as a further setback for impervious surfaces. It also functions to prevent encroachment and filter runoff. It is here that flow into the buffer should be transformed from concentrated flow into sheet flow to maximize ground contact with the runoff.

Development within the riparian buffer should be limited only to those structures and facilities that are absolutely necessary. Such limited development should be specifically identified in any codes or ordinances enabling the buffers. When construction activities do occur within the riparian corridor, specific mitigation measures should be required, such as deeper buffers or riparian buffer improvements.

Generally, the riparian buffer should remain in its natural state. However, some maintenance and management are periodically necessary, such as planting to minimize concentrated flow, removal of exotic plant species when these species are detrimental to the vegetated buffer and removal of diseased or damaged trees.

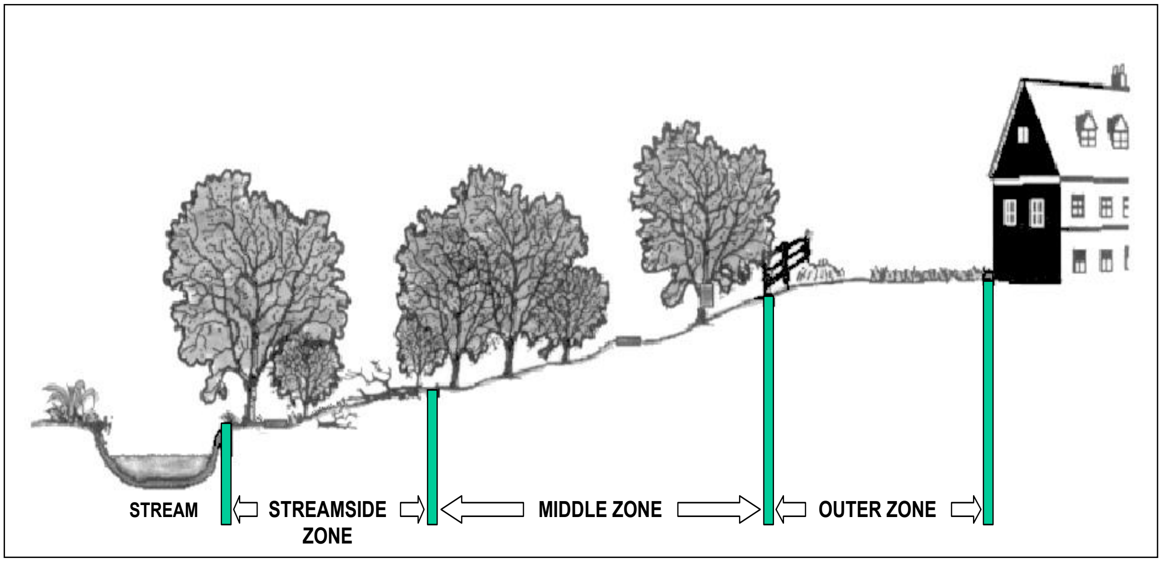


Figure 5.4: Three-zone stream buffer system (Source: Adapted from Schueler, 1995)

Table 5.1 Riparian Buffer Management Zones (Source: Adapted from Schueler, 1995)			
	Streamside Zone	**Middle Zone**	**Outer Zone**
Width	Minimum 25 ft plus wetlands and critical habitat	Variable, depending on stream order, slope, and 100-year floodplain (min. 25 ft.)	25-ft minimum setback from structures
Vegetative Target	Perennial grasses on steep slopes, undisturbed mature forest. Reforest if necessary.	Managed forest, some clearing allowed	Forest encouraged, but usually turfgrass
Allowable Uses	Very restricted (e.g., flood control, utility easements, footpaths)	Restricted (e.g., some recreational uses, some stormwater controls, bike paths)	Unrestricted (e.g., non-structural residential uses, including lawn, garden, most stormwater controls)

5.1.3 Reduction of Clearing and Grading

Description

Clearing and grading of the site should be limited to the minimum amount needed for the development function, road access and infrastructure (e.g., utilities, wastewater disposal, stormwater management). Site layout should be designed to disturb the smallest possible land area on a site.

Key Benefits

- Preserves more undisturbed natural areas on a development site
- Areas of a site that are conserved in their natural state retain their natural hydrology and do not contribute to construction erosion
- Native trees, shrubs and grasses provide natural landscaping, reducing costs and contributing to the overall quality and viability of the environment.

Typical Perceived Obstacles and Realities

- Preserving trees during construction is expensive – *Minimizing clearing during construction can reduce earth movement and reduce erosion and sediment control costs*
- People prefer large lawns – *Lots with trees may have a higher value than those without*
- Preserved conservation areas may harbor nuisance wildlife, vegetation, and insects and may present safety hazards – *Once established, natural conservation areas must be protected during construction and managed after occupancy by a responsible party to maintain the areas in a natural state in perpetuity; proper management and maintenance will address nuisance and safety issues*

Using this Practice

- Restrict clearing to minimum reqd. for building footprints, construction access, and safety setbacks
- Establish limits of disturbance for all development activities
- Site layout should be designed to minimize clearing and grading
- Avoid mass grading of a site – divide into smaller areas for phased grading
- Use conservation design, open-space or “cluster” developments
- Consult local planning authority for local clearing and grading regulations

Discussion

Minimal disturbance methods should be used to limit the amount of clearing and grading that takes place on a development site, preserving more of the undisturbed vegetation and natural hydrology of a site. A limit of disturbance (LOD) should be established based on the maximum disturbance zone. These maximum distances should reflect reasonable construction techniques and equipment needs, together with the physical situation of the development site, such as slopes or soils. LOD distances may vary by type of development, size of lot or site and by the specific development feature involved.

Site "foot-printing" should be used that maps all of the limits of disturbance to identify the smallest possible land area on a site which requires clearing or land disturbance. An example of site foot-printing is illustrated in **Figure 5.6**. Sites should be designed so that they fit the terrain (see **Figure 5.6**). During construction, special procedures and equipment that reduce land disturbance should be used. Alternative site designs should be considered to minimize limits of clearing, such as “cluster” developments (see **Section 5.1.5**).

Figure 5.6 Example of site foot-printing (Source: Georgia Stormwater Manual, 2001)

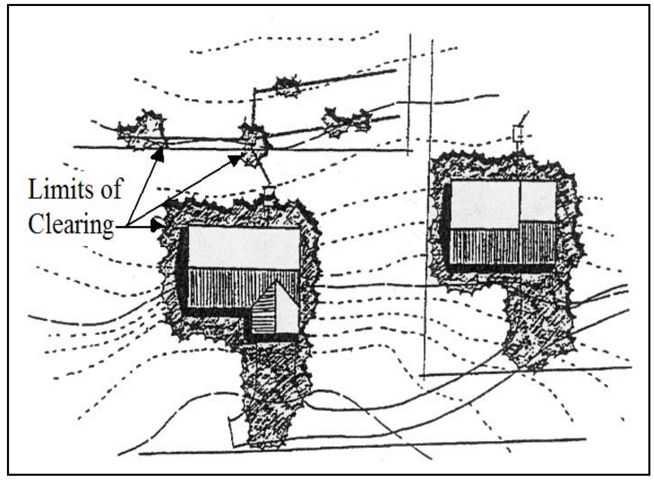


Figure 5.6 Design plan showing limits of clearing (in dark shading) (Source: DDNREC, 1997)

5.1.4 Locating Development in Less Sensitive Areas

Description

Development sites should be located to avoid sensitive resource areas such as floodplains, steep slopes, erodible soils, wetlands, mature forests and critical habitat areas. Buildings, roadways and parking areas should be located to fit the terrain and in areas that will create the least impact.

Key Benefits

- Preserving floodplains provides a natural right-of-way and temporary storage for large flood events; keeps people and structures out of harm's way and helps to preserve riparian ecosystems and habitats
- Preserving steep slopes and building on flatter areas helps to prevent soil erosion and minimizes stormwater runoff; helps to stabilize hillsides and soils and reduces the need for cut-and-fill and grading
- Avoiding development on erodible soils can prevent sedimentation problems and water-quality degradation. Areas with highly permeable soils can be used as nonstructural stormwater infiltration zones
- Fitting the design to the terrain and in less sensitive areas helps to preserve the natural hydrology and drainageways of a site; reduces the need for grading and land disturbance, and provides a framework for site design and layout

Typical Perceived Obstacles and Realities

- Costs will be higher for developments due to increased planning and design, localized construction and less developable land – *Developments that protect sensitive areas may have higher market value, less liability for potential natural disasters, such as flooding or slope failures and lower construction costs for areas that require less earthwork or difficult terrain, such as steep slopes or wetland areas to work around*

Using this Practice

- Ensure all development activities do not encroach on, fill or alter designated floodplain and/or wetland areas
- When the reconstruction of a stormwater facility falls within the 100-year floodplain, facility structures shall be protected from physical damage by the 100-year flood. Treatment facilities shall remain fully operational and accessible during the 25-year flood. Outfall pipes in the floodplain may need flap gates to keep floodwaters from backing up into the stormwater facility.
- Avoid development on steep slope areas and minimize grading and flattening of hills and ridges
- Leave wetlands, floodplains, and areas of porous or highly erodible soils as undisturbed conservation areas
- Develop roadway patterns to fit the site terrain, and locate buildings and impervious surfaces away from steep slopes, drainage ways and floodplains
- Locate sites in areas less sensitive to disturbance or have a lower value in terms of hydrologic function

Discussion

Development in floodplain areas can reduce the ability of the floodplain to convey stormwater, potentially causing safety problems or significant damage to the site in question, as well as to both upstream and downstream properties. The entire 100-year full-buildout floodplain should be avoided for clearing or building activities and should be preserved in a natural, undisturbed state. Where possible, the 500-year floodplain should also be preserved in a natural state and/or designated for parks, recreation or agriculture. Development on slopes with a grade of 15% or greater should be avoided, if possible, to limit soil loss, erosion, excessive stormwater runoff and the degradation of surface water. Excessive grading should be avoided on all slopes (**Figure 5.7**), as should the flattening of hills and ridges. Steep slopes should be kept in an undisturbed natural condition to help stabilize hillsides and soils. On steep slopes, new development, re-grading, or stripping of vegetation must be minimized.

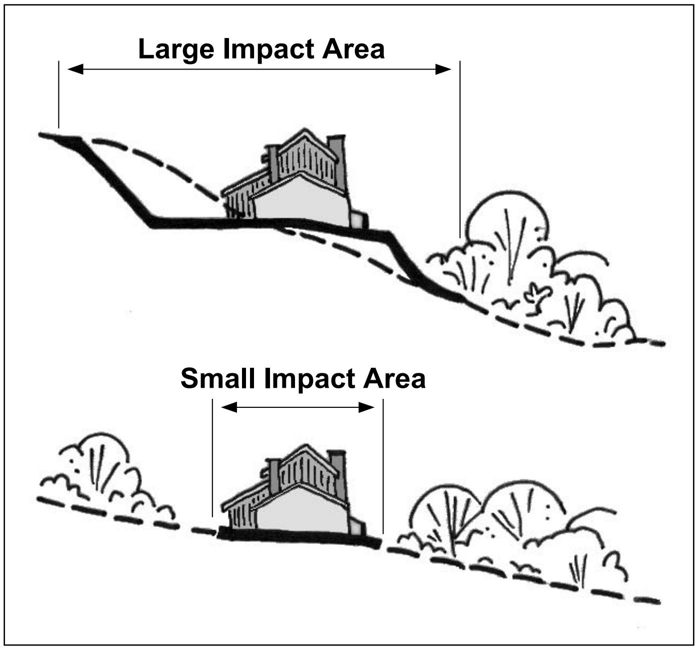


Figure 5.7 Cut and fill grading on steep slopes impacts larger areas than flatter slopes (Source: MPCA, 1989)

Areas of a site with hydrologic soil group A and B soils, (consult Natural Resources Conservation Service website for hydrological soil groups) such as sands and sandy loam soils, should be conserved as much as possible, and these areas should ideally be incorporated into undisturbed natural or open-space areas (**Figure 5.8**). Conversely, buildings and other impervious surfaces should be located on those portions of the site with the *least* permeable soils. Similarly, areas on a site with highly erodible or unstable soils should be avoided for land-disturbing activities and buildings to prevent erosion and sedimentation problems as well as potential structural problems. These areas should be left in an undisturbed and vegetated condition.

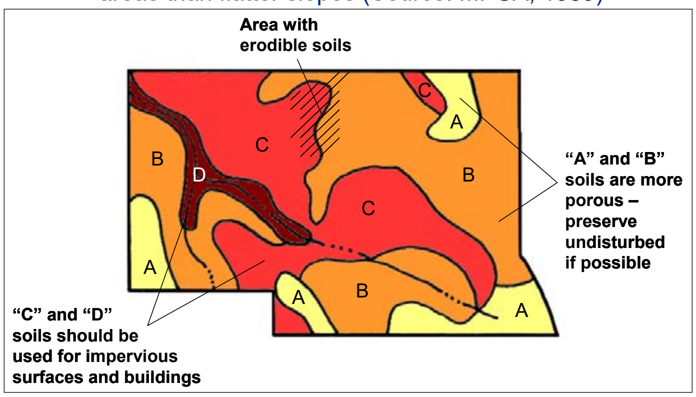


Figure 5.8 Using soil mapping to guide development (Source: Georgia Stormwater Manual, 2001)

The layout of roadways and buildings on a site should generally conform to the landforms on a site (**Figure 5.9**). Natural drainage ways and stream buffer areas should be preserved by designing road layouts around them. Buildings should be sited to use the natural grading and drainage system and avoid the unnecessary disturbance of vegetation and soils.

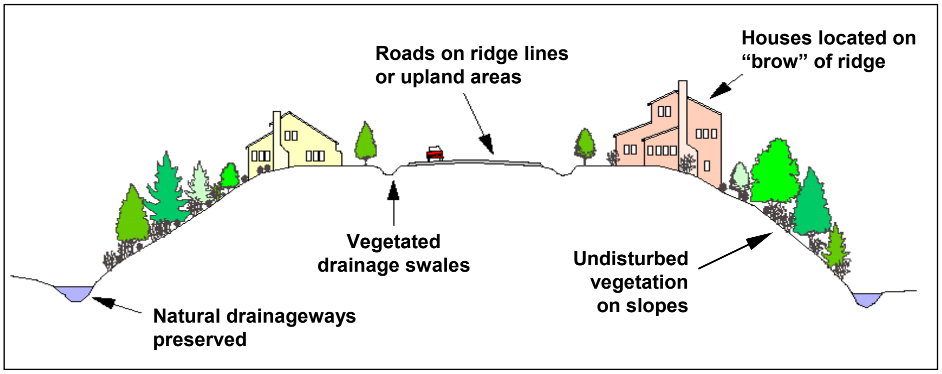


Figure 5.9 Preserving the Natural topography of a Site
(Source: Adapted from Prince George's County, 1999)

Roadway patterns on a site should be chosen to provide access schemes which match the terrain. In rolling or hilly terrain, streets should be designed to follow natural contours to reduce clearing and grading. In flatter areas, a traditional grid pattern of streets or "fluid" grids which bend and may be interrupted by natural drainage ways may be more appropriate. In much the same way that a development should be designed to conform to the terrain of the site, layout should also be designed so that the areas of development are placed in the locations of the site that minimize the hydrologic impact of the project. This is accomplished by steering development to areas of the site that are less sensitive to land disturbance or have a lower value in terms of hydrologic function. **Figure 5.10** shows a development site where the natural features have been mapped in order to delineate the hydrologically sensitive areas. Through careful site planning, sensitive areas can be set aside as natural open space areas. In many cases, such areas can be used as buffer spaces between land uses on or between adjacent sites.

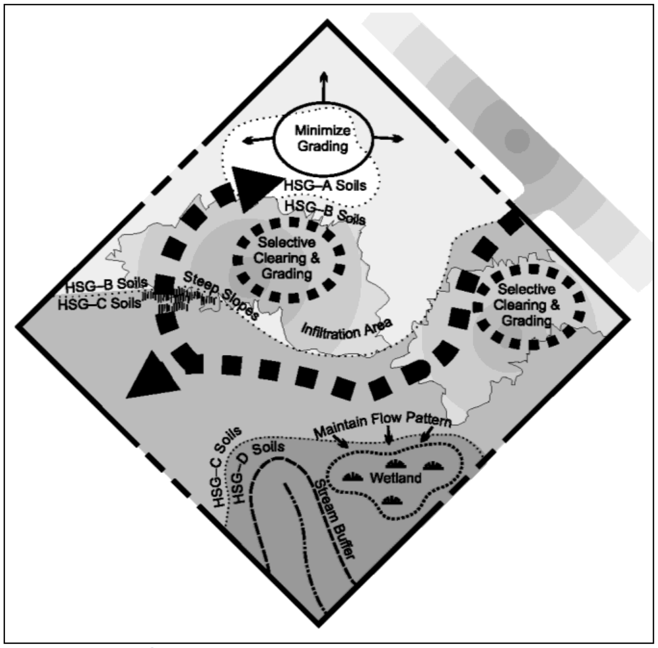


Figure 5.10 Guiding development to less sensitive site areas
(Source: Georgia Stormwater Manual, 2001)

5.1.5 Open Space Design

Description

Conservation development, clustering or open space design incorporates smaller lot sizes to reduce overall impervious cover while providing more undisturbed open space and protection of water resources.

Key Benefits

- Can be used to preserve natural hydrology and drainageways
- Can be used to preserve and protect natural conservation areas and other site resources
- Reduces the need for grading and land disturbance
- Reduces infrastructure needs and overall development costs
- Allows flexibility to developers to implement creative site designs including better stormwater management practices

Typical Perceived Obstacles and Realities

- Smaller lot sizes and compact development may be perceived by developers as less marketable – *Open space designs can be highly desirable and have economic advantages such as cost savings and higher market appreciation*
- Lack of speed and certainty in the review process may be of concern – *Consult with the local review authority to review requirements*; prospective homebuyers may be reluctant to purchase homes due to concerns *regarding management of the community open space – Proper methods and implementation of maintenance agreements are available; natural open space reduces maintenance costs and can help keep association fees down*
- Cluster developments appear incompatible with adjacent land uses and are equated with increased noise and traffic – *Open space design allows preservation of natural areas, using less space for streets, sidewalks, parking lots, and driveways; incorporating buffers into the design can help alleviate incompatibility with other competing land uses*

Using this Practice

- Use a site design which concentrates development and preserves open space and natural areas of the site
- Locate the developed portion of the cluster areas in the least sensitive areas of the site
- Consult with the municipality to find out whether there is a local law or ordinance for cluster development, open space design, conservation design or flexible subdivisions
- Where allowed by the municipality, utilize reduced setbacks and frontages, and narrower right-of-way widths to design non-traditional lot layouts within the cluster

Figure 5.11 Aerial view of an open space or "cluster" subdivision (Source: Georgia Stormwater Manual, 2001)

Discussion

Conservation development, also known as "open space residential design" (OSRD), or clustering, is a green infrastructure planning technique that concentrates structures and impervious surfaces in a compact area in one portion of the development site in exchange for providing open space, natural areas or agricultural lands elsewhere on the site. Typically, smaller lots and/or nontraditional lot designs are used to cluster development and create more conservation areas on the site.

Conservation development has many benefits compared with conventional development or residential subdivisions: this technique can reduce impervious cover, stormwater pollution, construction costs, and the need for grading and landscaping, while providing for the conservation of natural areas. **Figure 5.11** and **Figure 5.12** show examples of open space developments.

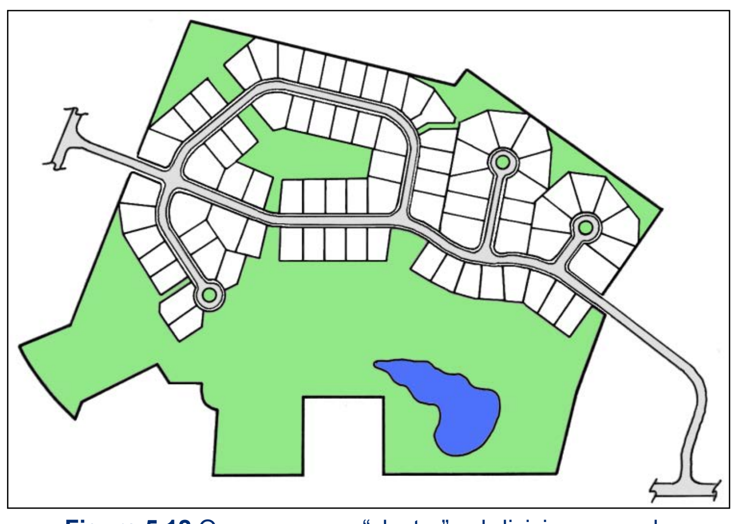


Figure 5.12 Open space or "cluster" subdivision example (Source: Georgia Stormwater Manual, 2001)

Along with reduced imperviousness, conservation design provides a host of other environmental benefits lacking in most conventional designs. These developments reduce potential pressure to encroach on conservation and buffer areas because enough open space is usually reserved to accommodate these protection areas. As less land is cleared during the construction process, alteration of the natural hydrology and the potential for soil erosion are also greatly diminished. Perhaps most importantly, open space design reserves 25 to 50 percent of the development site in conservation areas that would not otherwise be protected.

Conservation development can also be significantly less expensive to build than conventional projects. Most of the cost savings are due to reduced infrastructure cost for roads and stormwater management controls and conveyances. While conservation developments are frequently less expensive to build, developers find that these properties often command higher prices than those in more conventional developments. Several studies estimate that residential properties in developments with open space garner premiums that are higher than conventional subdivisions and moreover, sell or lease at increased rates. Once established, common open space and natural conservation areas must be managed by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, the conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements. Flexible lot shapes and setback and frontage distances allow site designers to create attractive and unique lots that provide homeowners with enough space while allowing for the preservation of natural areas in a residential subdivision. A narrower Right-of-Way will consume less land that may be better used for housing lots and allow for a more compact site design. **Figure 5.14** and **Figure 5.13** illustrate various nontraditional lot designs.

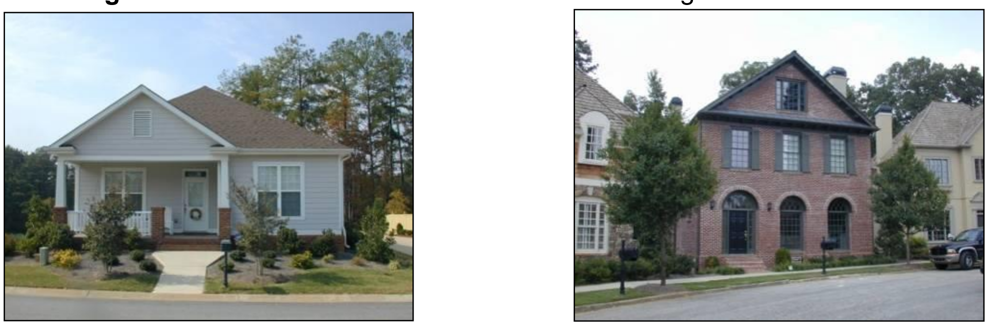


Figure 5.14 Lots with reduced front and side setbacks

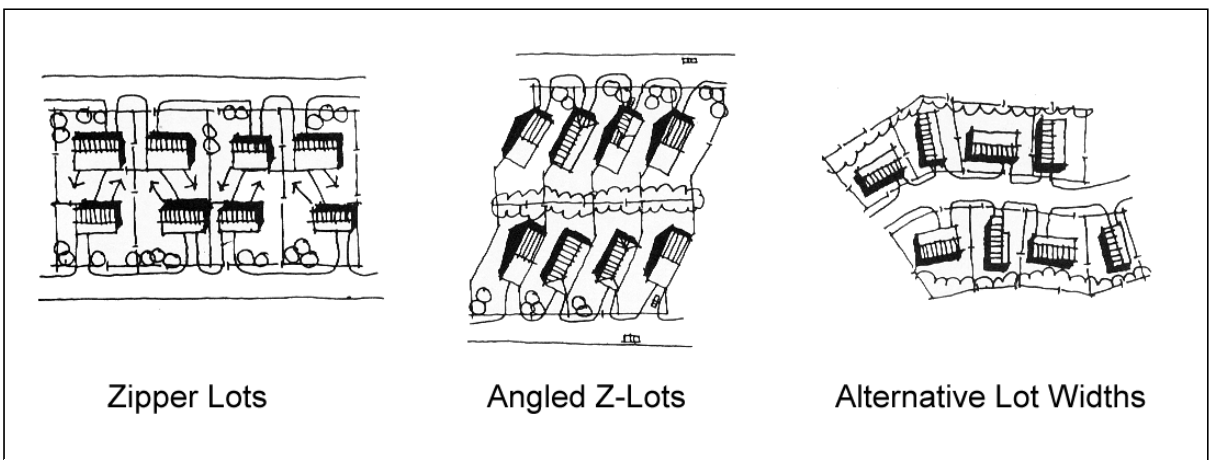


Figure 5.13 Nontraditional lot design (Source: ULI, 1992)

5.1.6 Soil Restoration

Description

Soil Restoration, in accordance with the latest version of the NYSDEC Deep-Ripping and Decompaction, is a required practice applied across areas of a development site where soils have been disturbed and will be vegetated in order to recover the original properties and porosity of the soil. Healthy soil is vital to a sustainable environment and landscape. A deep, well-drained soil, rich in organic matter, absorbs rainwater, helps prevent flooding and soil erosion, filters out water pollutants, and promotes vigorous plant growth that requires less irrigation, pesticides, and fertilizer.

Soil Restoration is applied in the cleanup, restoration, and landscaping phase of construction followed by the permanent establishment of an appropriate, deep-rooted groundcover to help maintain the restored soil structure. Soil restoration includes mechanical decompaction, compost amendment, or both.

Many runoff reduction practices need Soil Restoration measures applied over and adjacent to the practice to achieve runoff reduction performance. (See typical compacted soil in **Figure 5.15**). Consult individual profile sheets for specific design criteria.

Figure 5.15 Shows typical compacted soils that nearly reach the bulk density of concrete (Schueler et al 2000)

Key Benefits

- More marketable buildings and landscapes
- Less stormwater runoff, better water quality
- Healthier, aesthetically pleasing landscapes
- Increased porosity on redevelopment sites where impervious cover is converted to pervious
- Achieves performance standards on runoff reduction practices
- Decreases runoff volume generated and lowers the demand on runoff control structures
- Enhances direct groundwater recharge
- Promotes successful long-term revegetation by restoring soil organic matter, permeability, drainage and water holding capacity for healthy root system development of trees, shrubs and deep-rooted ground covers, minimizing lawn chemical requirements, plant drowning during wet periods, and burnout during dry periods

Typical Perceived Obstacles and Realities

- Higher cost due to soil restoration- *application of soil de-compaction and enhancement may have additional initial cost; however, they provide benefit in reducing the need for conveyance structures.*
- Space constraints and obstruction for use of equipment - *post construction space may limit the ability of some of the de-compaction equipment, however, alternative equipment and sensible planning help overcome this obstacle.*

Discussion

Tilling exposes compacted soil devoid of oxygen to air and recreates temporary air space. In addition, research has shown that the incorporation of organic compost, can greatly improve temporary water storage in the soil and subsequent runoff reduction through infiltration and evapotranspiration.

Soils that have a permanent high water table close to the surface (0-12 inches), either influenced by a clay or other highly impervious layer of material, may have bulk densities so naturally high that compaction has little added impact on infiltration (Lacey 2008). However, these soils will still benefit from the addition of compost. The water holding capacity, penetration, structural stability, and fertility of clay soils were improved with compost mixing (Avnimelech and Cohen 1988).

Table 5.2 describes various soil disturbance activities related to land development, soil types and the requirements for soil restoration for each activity. Soil Restoration or modification of curve numbers is a <u>required</u> practice. Restoration is applied across areas of a development site where soils have been compacted and will be vegetated according to the criteria defined in **Table 5.2**. If Soil Restoration is not applied according to these criteria, designers are required to:

a) Increase the calculated WQ_v by factoring in the compacted areas that have not been kept as impervious cover (including areas of cut or fill, heavy traffic areas on site, or Impervious Cover reduction in redevelopment projects unless aeration or full soil restoration is applied, per **Table 5.2**).

b) Change by one level the post-construction hydrologic soil group (HSG) to a less permeable group than the original condition. This is applied to all volumetric and discharge rate control computations.

Table 5.2 Soil Restoration Requirements			
Type of Soil Disturbance	**Soil Restoration Requirement**		**Comments/Examples**
No soil disturbance	Restoration not permitted		Preservation of Natural Features
Minimal soil disturbance	Restoration not required		Clearing and grubbing
Areas where topsoil is stripped only - no change in grade	HSG A &B	HSG C&D	Protect area from any ongoing construction activities.
	apply 6 inches of topsoil	Aerate* and apply 6 inches of topsoil	
Areas of cut or fill	HSG A &B	HSG C & D	
	Aerate and apply 6 inches of topsoil	Apply full Soil Restoration **	
Heavy traffic areas on site (especially in a zone 5-25 ft around buildings but not within a 5 ft perimeter around foundation walls)	Apply full Soil Restoration** de-compaction and compost enhancement)		
Areas where Runoff Reduction and/or Infiltration practices are applied	Restoration not required but may be applied to enhance the reduction specified for appropriate practices.		Keep construction equipment from crossing these areas. To protect newly installed practice from any ongoing construction activities construct a single-phase operation fence area
Redevelopment projects	Soil Restoration is required on redevelopment projects in areas where existing impervious area will be converted to pervious area as well as existing pervious areas.		

*Aeration includes the use of machines such as tractor-drawn implements with coulters making a narrow slit in the soil, a roller with many spikes making indentations in the soil, or prongs which function like a mini-subsoiler.

** Refer to latest version of NYSDEC Deep-Ripping and Decompaction.

Using this Practice

During periods of relatively low to moderate subsoil moisture, the disturbed subsoils are returned to rough grade and the following Soil Restoration steps applied:

1. Apply 3 inches of compost over subsoil
2. Till compost into subsoil to a depth of at least 12 inches using a cat-mounted ripper, tractor-mounted disc, or tiller, mixing, and circulating air and compost into subsoils
3. Rock-pick until uplifted stone/rock materials of 4 inch and larger size are cleaned off the site
4. Apply topsoil to a depth of 6 inches.
5. Vegetate as required by approved plan.

Figure 5.16 Soil aerator implement

At the end of the project an inspector should be able to push a 3/8 inch metal bar 12 inches into the soil just with body weight. **Figure 5.16** and **Figure 5.17** show two attachments used for soil decompaction. Tilling (step 2 above) should not be performed within the drip line of any existing trees or over utility installations that are within 24 inches of the surface.

Compost Specifications

Compost shall be aged, from plant derived materials, free of viable weed seeds, have no visible free water or dust produced when handling, pass through a half inch screen and have a pH suitable to grow desired plants.

Maintenance

A simple maintenance agreement should identify where Soil Restoration is applied, where newly restored areas are/cannot be cleared, who the responsible parties are to ensure that routine vegetation improvements are made (i.e., thinning, invasive plant removal, etc.). Soil compost amendments within a filter strip or grass channel should be located in a public right of way, or within a dedicated stormwater or drainage easement.

Figure 5.17 Soil aerator implement

First year maintenance operations includes:

- Initial inspections for the first six months (once after each storm greater than a half inch)
- Reseeding to repair bare or eroding areas to assure grass stabilization
- Water once every three days for the first month, and then provide a half inch of water per week during the first year. Irrigation plan may be adjusted according to the rain event.
- Fertilization may be needed in the fall after the first growing season to increase plant vigor
- Ongoing Maintenance:

  Two points help ensure lasting results of decompaction:

  1) Planting the appropriate ground cover with deep roots to maintain the soil structure
  2) Keeping the site free of vehicular and foot traffic or other weight loads. Consider pedestrian footpaths. (Sometimes it may be necessary to de-thatch the turf every few years)

Section 5.2 Planning for Runoff Reduction: Reduction of Impervious Cover

Once sensitive resource areas and site constraints have been avoided, the next step is to minimize the impact of land alteration by reducing impervious areas. Reduction of impervious cover includes methods to reduce the amount of rooftops, parking lots, roadways, sidewalks and other surfaces that do not allow rainfall to infiltrate into the soil, in order to reduce the volume of stormwater runoff, increase groundwater recharge, and reduce pollutant loadings that are generated from a site. See **Table 5.3** for a list of the impervious cover reduction techniques described in the detailed practice sheets in this section.

Table 5.3 Planning Practices for Reduction of Impervious Cover

Practice	Description
Roadway Reduction	Minimize roadway widths and lengths to reduce site impervious area
Sidewalk Reduction	Minimize sidewalk lengths and widths to reduce site impervious area
Driveway Reduction	Minimize driveway lengths and widths to reduce site impervious area
Cul-de-sac Reduction	Minimize the number of cul-de-sacs and incorporate landscaped areas to reduce their impervious cover.
Building Footprint Reduction	Reduce the impervious footprint of residences and commercial buildings by using alternate or taller buildings while maintaining the same floor to area ratio.
Parking Reduction	Reduce imperviousness on parking lots by eliminating unneeded spaces, providing compact car spaces and efficient parking lanes, minimizing stall dimensions, using porous pavement surfaces in overflow parking areas, and using multi-storied parking decks where appropriate.

5.2.1 Roadway Reduction

Description

Roadway lengths and widths should be minimized on a development site where possible to reduce overall imperviousness.

Key Benefits

- Reduces the amount of impervious cover and associated runoff and pollutants generated
- Reduces the costs associated with road construction and maintenance

Typical Perceived Obstacles and Realities

- Local codes may not permit shorter or narrower roads – *Meet with local officials to discuss waivers for alternative designs that will address concerns of access, snow stockpiling, and parking*
- The public may view narrow roads as unsafe – *Narrower roads in fact reduce the speeds at which vehicles drive; many maintenance and emergency vehicles can in fact access narrow roads*
- Narrow and shorter roads do not have enough parking – *Provisions can be made in the design of a site to accommodate off-street parking*

Using this Practice

- Consider different site and road layouts that reduce overall street length
- Minimize street width by using narrower street designs that are a function of land use, density and traffic demand
- Use smaller side-yard setbacks to reduce total road length
- Consult with local highway and planning officials to determine if narrower roads and smaller setbacks are accepted or whether waivers or variances will be needed

Discussion

The use of alternative road layouts that reduce the total length of roadways can significantly reduce overall imperviousness of a development site. Site designers are encouraged to analyze different site and roadway layouts to see if they can reduce overall street length.

In addition, residential streets and private streets within commercial and other development should be designed for the minimum required pavement width needed to support travel lanes, on-street parking and emergency access. **Figure 5.18** shows options for narrower street designs. In many instances, on-street parking can be reduced to one lane or eliminated on local access roads with less than 200 average daily traffic (ADT) and on short cul-de-sacs street. One-way, single-lane, loop roads are another way to reduce the width of lower-traffic streets.

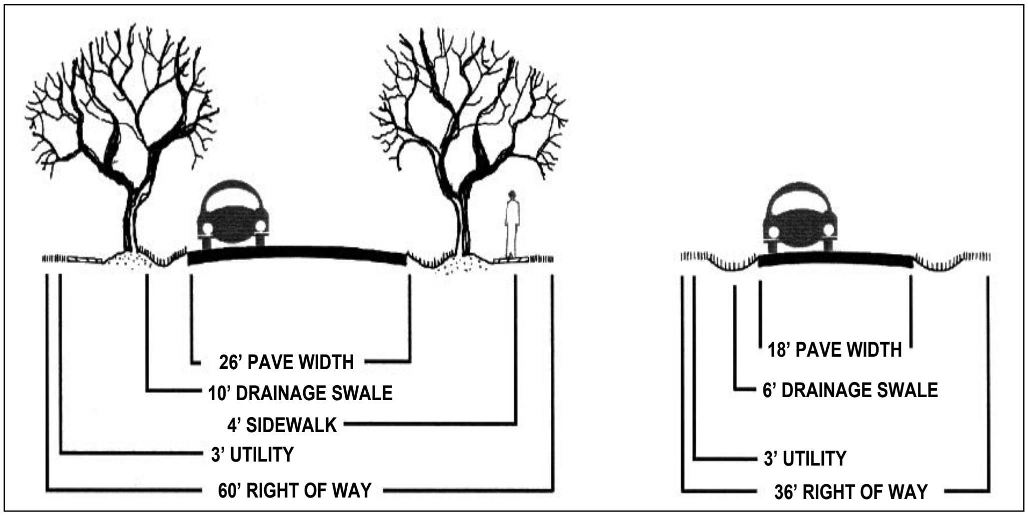


Figure 5.18 Potential design options for narrower roadway widths

County public works and highway departments in New York State as well as the New York State Department of Transportation use the American Association of State Highway Transportation Officials (AASHTO) recommendations for road design. AASHTO recommends that for low volume local roads with less than 400 average daily trips and design speeds of 40 mph or less, the width of the traveled way can be as little as 18 ft. Adding two-ft shoulders on either side, the total would be 22 ft. For larger volume roads, widths would be increased accordingly. See **Table 5.4**. Further, reducing side yard setbacks and using narrower frontages can reduce total street length, which is especially important in cluster and open-space designs.

Table 5.4 Minimum Width of Traveled Way (Ft) for Specified Design Volume				
Design speed (miles per hour)	Under 400	400 to 1500	1500 to 2000	Over 2000
15	18	20 [1]	20	22
20	18	20 [1]	22	24[3]
25	18	20 [1]	22	24[3]
30	18	20 [1]	22	24[3]
40	18	20 [1]	22	24[3]
45	20	22	22	24[3]
50	20	22	22	24[3]
55	22	22	24[3]	24[3]
60	22	22	24[3]	24[3]
	Width of graded shoulder on each side of road (ft)			
All speeds	2	5[1,2]	6	8

[1] For roads in mountainous terrain with design volume of 400 to 600 vehicles/day, use 18-ft traveled way width and 2-ft shoulder width.

[2] May be adjusted to achieve a minimum roadway width of 30 ft for design speeds greater than 40 mph.

[3] Where the width of the traveled way is shown as 24 ft, the width may remain at 22 ft on reconstructed highways where alignment and safety records are satisfactory.

From: *A Policy on Geometric Design of Highways and Streets,* (Exhibit 5-5. Minimum Width of Traveled Way and Shoulders) 2004, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

5.2.2 Sidewalk Reduction

Description

Sidewalk lengths and widths should be minimized on a development site where possible to reduce overall imperviousness.

Key Benefits

- Reduces the amount of impervious cover and associated runoff and pollutants generated
- Reduces the costs associated with construction and maintenance
- Reduces the individual homeowner’s responsibility for maintenance, such as snow clearance

Typical Perceived Obstacles and Realities

- Sidewalks on only one side of the street may be perceived as unsafe – *Accident research shows sidewalks on one side are nearly as safe as sidewalks on both*
- Homebuyers are perceived to want sidewalks on both sides – *Some actually prefer not to have a sidewalk in front of their home, and there is no market difference between homes with and without sidewalks directly in front.*
- Local codes may not permit narrower, alternative, or the elimination of a sidewalk – *Meet with local officials to discuss waivers for alternative designs that will address concerns of accessibility and safety issues.*

Using this Practice

- Locate sidewalks on only one side of the street where applicable (may not apply in downtown and village areas where walkability is important)
- Provide common walkways linking pedestrian areas
- Use alternative sidewalk and walkway surfaces
- Shorten front setbacks to reduce walkway lengths
- Consult with local highway and planning officials to determine if alternative sidewalk designs and paving materials are allowed or whether waivers or variances will be needed

Discussion

Most local codes require that sidewalks be placed on both sides of residential streets (e.g., double sidewalks) and be constructed of impervious concrete or asphalt. For state and federally funded projects, the standard width of a sidewalk is 5 ft. Many subdivision codes also require sidewalks to be 4 to 6 ft wide and 2 to 10 ft from the street. These codes are enforced to provide sidewalks as a safety measure.

Figure 5.19 Sidewalk with common walkways linking pedestrian areas (Source: MA EOEA, 2005)

Developers may wish to consider allowing sidewalks on only one side of the street or eliminating them where they don't make sense. Sidewalks should be designed with the goal of improving pedestrian movement and diverting it away from the street. Developers may also consider reducing sidewalk widths and placing them farther from the street. In addition, sidewalks should be graded to drain to front yards rather than the street, or planters could be used as filters placed between sidewalk and road.

Alternative surfaces for sidewalks and walkways should be considered to reduce impervious cover (**Figure 5.19**). In addition, building and home setbacks should be shortened to reduce the amount of impervious cover from entry walks.

5.2.3 Driveway Reduction

Description

Driveway lengths and widths should be minimized on a development site where possible to reduce overall imperviousness.

Key Benefits

Reduces the amount of impervious cover and associated runoff and pollutants generated

Typical Perceived Obstacles and Realities

- Alternative driveway surfaces make snow removal more difficult – *Careful site design, material selection and homeowner education can help alleviate the concern*
- Developers perceive alternative surfaces as less marketable – *"Green" development projects are increasingly being sought by consumer.*
- Homeowners have concerns regarding access with shared driveways – *Proper site design, shared driveway agreements and homeowner education will alleviate access issues*
- Local codes may not permit shorter or narrower driveways or driveways with porous surfaces – *Meet with local officials to discuss waivers for alternative designs*

Using this Practice

- Use shared driveways that connect two or more homes
- Use alternative driveway surfaces
- Use smaller lot front building setbacks to reduce total driveway length
- Use shared driveway agreements for maintenance
- Consult with local highway and planning officials to determine if alternative driveway designs and paving materials are allowed or whether waivers or variances will be needed

Discussion

Most local subdivision codes are not very explicit as to how driveways must be designed. Most simply require a standard apron to connect the street to the driveway but don't specify width or surface material. Typical residential driveways range from 12 ft wide for one-car driveways to 20 ft for two. While shared driveways are discouraged or prohibited by many communities, they can reduce impervious cover and should be encouraged with enforceable maintenance agreements and easements (**Figure 5.20**).

The typical 400-800 square ft of impervious cover per driveway can be minimized by using narrower driveway widths, reducing the length of driveways, or using alternative surfaces such as double-tracks, reinforced grass or permeable paving materials (**Figure 5.21**).

Figure 5.20 Reduced driveway lengths by using shared driveways (Source: MA EOEA, 2005)

Figure 5.21 Permeable pavers as an alternative driveway surface

Building and home setbacks should be shortened to reduce the amount of impervious cover from driveways and entry walks. A setback of 20 ft is more than sufficient to allow a car to park in a driveway without encroaching into the public right of way and reduces driveway and walk pavement by more than 30 percent compared with a setback of 30 ft (see **Figure 5.22**).

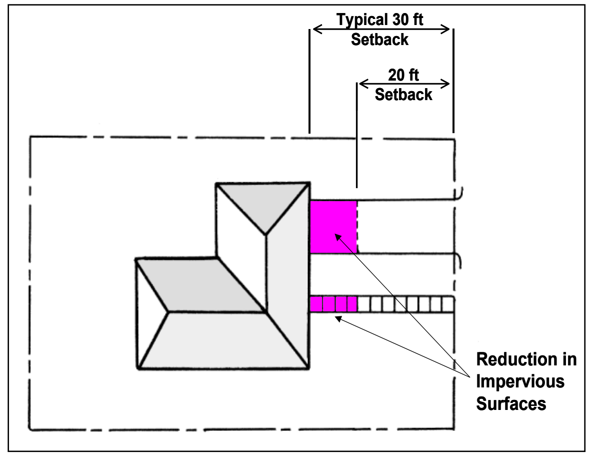


Figure 5.22 Reduced driveway and walkway lengths by using reduced setbacks (Adapted from: MPCA, 1989)

5.2.4 Cul-de-sac Reduction

Description

Minimize the number of cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of a cul-de-sac should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should also be considered.

Key Benefits

- Reduces the amount of impervious cover, associated runoff and pollutants generated
- Increases aesthetics by allowing for natural or landscaped areas rather than pavement

Typical Perceived Obstacles and Realities

- Emergency and maintenance vehicles require a large turning radius – *Many newer vehicles are available with small turning radii*
- School buses require a large turning radius - *Verify school bus pick-up plans. Not every cul-de-sac will need to accommodate school bus turning radii*
- Homeowners like the "end of the road" appeal of cul-de-sacs – *This appeal can be accommodated using loop roads or lots that back onto open space areas*
- Local codes may not permit smaller or alternative cul-de-sac designs – *Meet with local officials to discuss waivers for alternative designs that will address concerns of access*

Using this Practice

- Reduce the radius of the turnaround bulb or consider alternative cul-de-sac design, such as "tee" turn-a-rounds or looping lanes
- Apply site design strategies that minimize dead-end streets
- Create a pervious island or a stormwater bioretention area in the cul-de-sac center to reduce impervious area
- Consult with local highway and planning officials to determine if alternative cul-de-sac designs are allowed or whether waivers or variances will be needed

Discussion

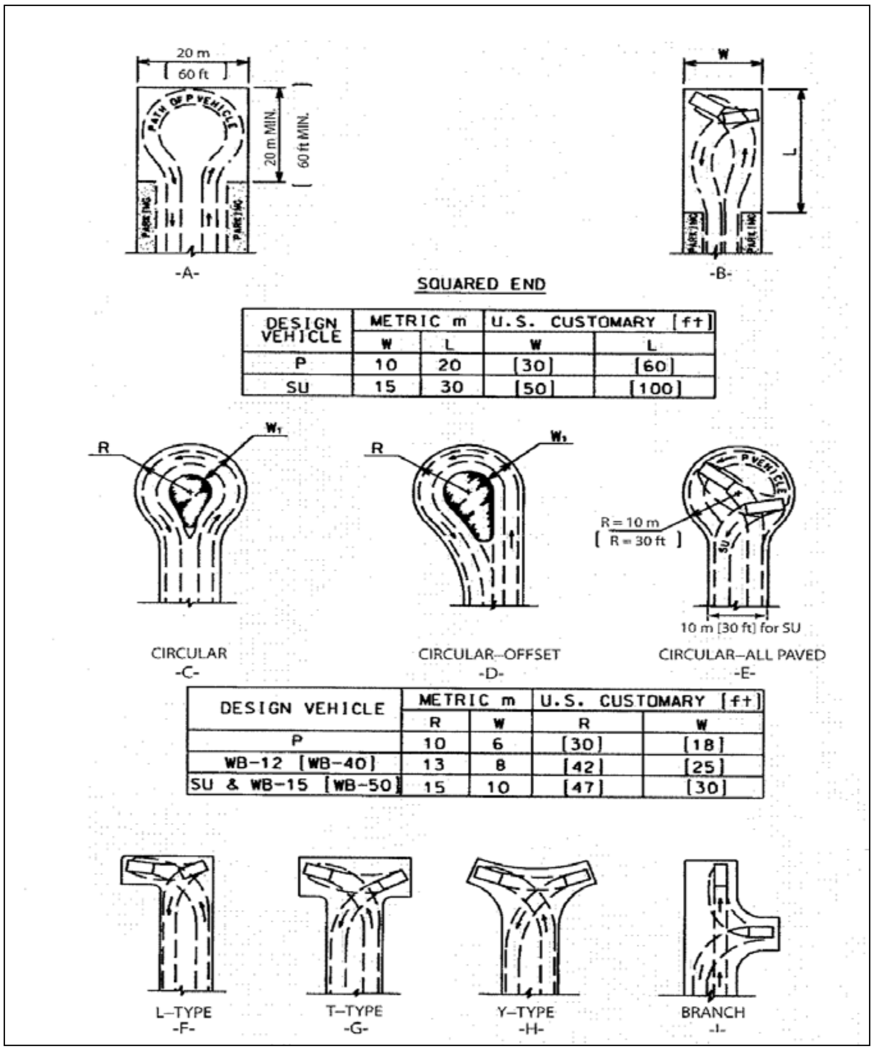
Alternative turnarounds are end of the street designs that replace fully paved cul-de-sacs and reduce the amount of impervious cover created in developments. Cul-de-sacs are local access streets with a closed circular end that allows for vehicle turnarounds. Many of these cul-de-sacs can have a radius of more than 40 ft. From a stormwater perspective, cul-de-sacs create a huge bulb of impervious cover, increasing the amount of runoff. For this reason, reducing the size of cul-de-sacs through the use of alternative turnarounds or eliminating them altogether can reduce the amount of impervious cover created at a site. Numerous alternatives create less impervious cover than the traditional 40-ft cul-de-sac. These alternatives include reducing cul-de-sacs to a 30-ft radius and creating hammerheads, loop roads and pervious islands in the cul-de-sac center (see **Figure 5.23**, **Figure 5.24** and **Figure 5.25**).

Figure 5.23 T-shaped turnaround option (Source: Center for Watershed Protection, 2005)

Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering the cul-de-sac should be considered. Fire trucks, service vehicles and school buses are often cited as needing large turning radii. However, some fire trucks are designed for smaller turning radii. In addition, many newer large service vehicles are designed with a triaxle (requiring a smaller turning radius), and many school buses usually do not enter individual cul-de-sacs. Another option for designing cul-de-sacs involves the placement of a pervious island in the center. Vehicles only travel along the outside of the cul-de-sac when turning, leaving an unused “island” of pavement in the center. These islands can be attractively landscaped and also designed as bioretention areas to treat stormwater (see **Section 6.4** of this Manual).

Figure 5.24 Loop road option (Source: Center for Watershed Protection, 2005)

The most recent AASHTO guidelines should be used for cul-de-sac and alternative turnaround designs, and the design should create no more impervious surface than specified in the AASHTO guidelines.



DESIGN VEHICLE	METRIC m		U.S. CUSTOMARY [ft]	
	W	L	W	L
P	10	20	[30]	[60]
SU	15	30	[50]	[100]

DESIGN VEHICLE	METRIC m		U.S. CUSTOMARY [ft]	
	R	W	R	W
P	10	6	[30]	[18]
WB-12 [WB-40]	13	8	[42]	[25]
SU & WB-15 [WB-50]	15	10	[47]	[30]

From: A Policy on Geometric Design of Highways and Streets, 2004, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

P = Passenger Car

SU = Single-Unit Truck

WB = Wheel Base - applies to semitrailer

Figure 5.25 Types of cul-de-sacs and dead-end streets

5.2.5 Building Footprint Reduction

Description

The impervious footprint of residences and commercial buildings can be reduced by using alternate or taller buildings while maintaining the same floor-to-area ratio.

Key Benefits

- Reduces the amount of impervious cover and associated runoff and pollutants generated

Typical Perceived Obstacles and Realities

- Taller buildings are perceived to have higher construction and maintenance costs – *Costs for taller buildings and associated parking may be offset by reduced land and construction and maintenance costs*
- Local codes may not permit taller buildings – *Consider alternative locations that do allow taller buildings, or meet with local officials to discuss waivers for alternative designs*

Using this Practice

- Use alternate or taller building designs to reduce the impervious footprint of buildings.
- Consolidate functions and buildings or segment facilities to reduce footprints of structures.
- Reduce directly connected impervious areas.
- Consult with local planning officials to determine allowed building heights and whether variances will be needed for alternative designs.

Discussion

In order to reduce the imperviousness associated with the footprint and rooftops of buildings and other structures, alternative and/or vertical (taller) building designs should be considered. Consolidate functions and buildings, as required, or segment facilities to reduce the footprint of individual structures. **Figure 5.26** shows the reduction in impervious footprint by using a taller building design, and **Figure 5.27** and **Figure 5.28** show residential examples of reduced footprints.

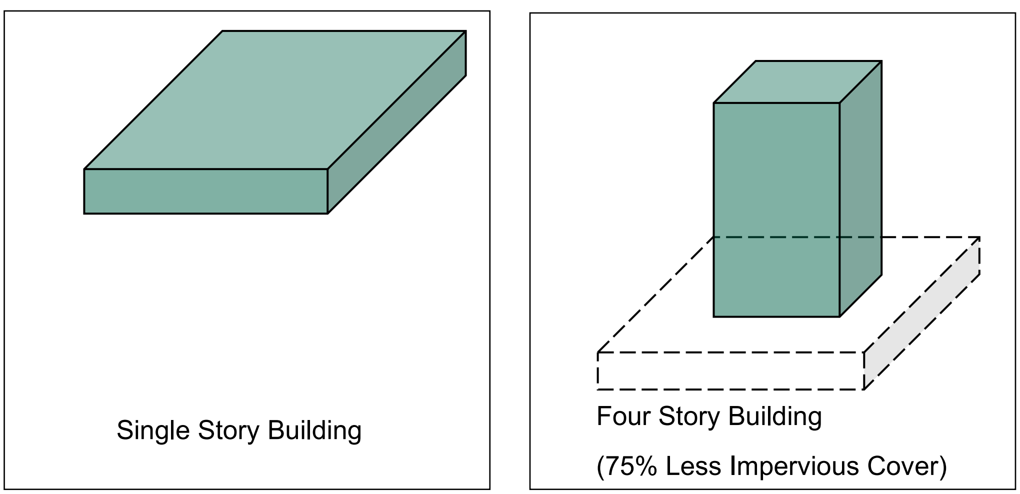


Figure 5.26 Reduction of impervious cover by building up rather than out
(Source: Georgia Stormwater Manual, 2001)

Figure 5.27 Taller apartments create a smaller impervious footprint
(Source: City of Portland, OR, 2001)

Figure 5.28 Taller houses create a smaller impervious footprint
(Source: Center for Watershed Protection, 2005)

5.2.6 Parking Area Reduction

Description

Reduce the overall imperviousness associated with parking lots by eliminating unneeded spaces, providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, using multi-storied parking decks and using porous paver surfaces or porous concrete in overflow parking areas where feasible.

Key Benefits

- Reduces the amount of impervious cover, associated runoff and pollutants generated
- Reduces construction costs, long-term operation and maintenance costs, and the need for larger stormwater facilities
- Improves aesthetics of an area by increasing vegetative surfaces and reducing the feeling of a large, paved urban area

Typical Perceived Obstacles and Realities

- Developers desire excess parking and fear losing customers during peaks – *Potential loss of customers due to reduced parking is unknown however, often times parking areas are not full during peak periods*
- Parking may spill over into residential or commercial areas when full – *Include preferential parking provisions for residents or parking enforcement with meters*
- Trend to larger vehicles such as SUVs – *Stall width requirements in most local parking codes are much larger than the widest SUVs*
- Structured parking is more expensive than surface lots – *Costs for structured parking may be offset by land costs or by constructing garages above or below an actual building*
- Porous pavement surfaces are more expensive to install and maintain – *Alternative surfaces may reduce the need for deicing treatments as well as alleviate the need for larger stormwater treatment elsewhere on the site*

Using this Practice

- Reduce the number of unnecessary parking spaces by examining minimum parking ratio requirements, and set a maximum number of spaces
- Reduce the number of un-needed parking spaces by examining the site's accessibility to mass transit
- Minimize individual parking stall dimensions, consulting local codes to determine if a waiver or variance is required
- Examine the traffic flow of the parking lot design to eliminate un-needed lanes / drive aisles

- Consider parking structures and shared parking arrangements between non-competing uses
- Use alternative porous surface for overflow areas or main parking areas if not a high-traffic parking lot
- Use landscaping or vegetated stormwater practices in parking lot islands
- Provide incentives for compact and hybrid cars

Discussion

Setting maximums for parking spaces, minimizing stall dimensions, using structured parking, encouraging shared parking, using alternative porous surfaces can all reduce parking footprint and site imperviousness. Some Planning Boards require that only a portion of the minimum parking spaces be constructed, and that space be provided to construct the remaining required spaces if needed.

Many parking lot designs result in far more spaces than actually required. This problem is exacerbated by a common practice of setting parking ratios to accommodate the highest hourly parking during the peak season. By determining average parking demand instead, a lower maximum number of parking spaces can be set to accommodate most of the demand. **Table 5.5** provides examples of conventional parking requirements and compares them to average parking demand. In addition, the number of parking spaces needed may be reduced by a site's accessibility to public transportation.

Table 5.5 Conventional Minimum Parking Ratios (Source: CWP, 1998; modified NYSDEC, 2010)

Land Use	Parking Requirement			Actual Average Parking Demand
	Parking Ratio	Typical Range	New York Example*	
Single family homes	2 spaces per dwelling unit	1.5–2.5	2 spaces per dwelling unit, plus 1 per auxiliary unit	1.11 spaces per dwelling unit
Shopping center	5 spaces per 1000 sf GFA	4.0–6.5	5.5 for > 2000 sf Net Floor Area	3.97 per 1000 sf GFA
Convenience store	3.3 spaces per 1000 sf GFA	2.0–10.0	7 per for < 2000 sf Net Floor Area	--
Industrial	1 space per 1000 sf GFA	0.5–2.0	1 space per employee	1.48 per 1000 sf GFA
Medical/dental office	5.7 spaces per 1000 sf GFA	4.5–10.0	6.7 per 1000 sf of net floor area	4.11 per 1000 sf GFA

GFA = Gross floor area of a building without storage or utility spaces,

*Town of Amherst Zoning Ordinance, net floor area is 0.75 to 0.9 of GFA, allows for alternate parking plans (http://www.amherst.ny.us/pdf/planning/compplan/zcrc/p7.pdf)

Another technique to reduce the parking footprint is to minimize the dimensions of the parking spaces. This can be accomplished by reducing both the length and width of the parking stall. Parking stall dimensions can be further reduced if compact spaces are provided. Another method to reduce the parking area is to incorporate efficient parking lanes such as using one-way drive aisles with angled parking rather than the traditional two-way aisles.

Structured parking decks are another method for significantly reducing the overall parking footprint by minimizing surface parking. **Figure 5.29** shows a parking deck used for a commercial development.

Shared parking in mixed-use areas and structured parking are techniques that can further reduce the conversion of land to impervious cover. A shared parking arrangement could include usage of the same parking lot by an office space that experiences peak parking demand during the weekday with a church that experiences parking demands during the weekends and evenings. Provide a written agreement for the parties to sign that specifies usage and maintenance.

Using alternative surfaces such as porous pavers or porous concrete is an effective way to reduce the amount of runoff generated by parking lots. They can replace conventional asphalt or concrete in both new developments and redevelopment projects. **Figure 5.31** is an example of grass pavers used at an overflow lot. Alternative pavers can also capture and treat runoff from other areas on the site.

When possible, expanses of parking should be broken up with landscaped islands at or below the grade of the parking area, with curb cuts. These islands could include shade trees and shrubs (see **Figure 5.30**) or landscaped stormwater management “islands” such as filter strips, swales and bioretention areas (see **Section 5.3.2**, **Section 5.3.3**, **Section 5.3.5**, **Section 6.4** and **Section 6.5** of this Manual).

Figure 5.29 Structured parking at an office park
(Source: Georgia Stormwater Manual, 2001)

Figure 5.31 Grass pavers for parking
(Source: Georgia Stormwater Manual, 2001)

Figure 5.30 Expanses of parking area “Broken-Up” with Landscape Features

Section 5.3 Runoff Reduction Techniques

Runoff Reduction is best achieved through the reduction of the effective impervious surface area of the catchment and minimization of disturbed area. This is particularly the case where pre-development soils demonstrate significant infiltration capacity. This section presents a series of runoff reduction principles and practices that can be incorporated in the site design to allow for micromanagement of runoff, promote groundwater recharge, increase losses through evapotranspiration and emulate the preconstruction hydrology, resulting in reduced water quality treatment volume.

Runoff Reduction (RR) techniques utilize the natural features of the site and promote runoff reduction. By using these principles, the techniques in this Chapter provide an opportunity for distributed runoff control from individual sources, flow routing, infiltration, treatment and reduction of total water quality volume. Acceptable RR techniques are explained in this section of the Manual. Deviation from these requirements must be documented and justified. Refer to the **Fact Sheets** at the end of each practice section in **Chapter 5** for key considerations of each runoff reduction technique, including performance criteria, practice suitability, implementation considerations, pollutant removal capability, and runoff reduction credit.

The computation runoff reduction fall under two general methods. The first group of practices includes site design techniques that a designer could factor in by subtracting conserved areas from the total site area, resulting in reduced WQ_v and CPv. The second group of practices provide runoff reduction by storage of volume runoff and are computed accordingly. The following basic principles must be applied to all RR technique design applications:

- Must be appropriately sized for its contributing area (pervious and impervious cover).
- Contributing areas, depending on final grading, flow path, impervious cover disconnection, and varying levels of micromanagement of the flow, may require subcatchment delineation.
- For all RR techniques that involve infiltration, soil testing is required to confirm soil permeability and depth to seasonal high water table/bedrock. Testing must be performed within the limits of the proposed practice and follow the requirements in **Appendix D**.
- If any other calculation methods are utilized (e.g. TR-55), all the contributing areas and related practices must be modeled according to the requirements of the selected method.
- Must be designed with an overflow sized to safely pass the 100-year 24-hour storm event and convey storm flows to facilities designed for quantity control, if required.
- A stone drainage layer shall be incorporated in most practices to enhance structural integrity, storage, drainage, and infiltration.

The following table allows designers to evaluate each standard SMP and determine which practice(s) are feasible for application to a specific site. Feasibility is based on thresholds that shall be met for four key site conditions:

1. *Soil Permeability*: This column outlines the permeability requirements for underlying soils at the location of a proposed SMP. The designer should perform an initial investigation of the NRCS hydrologic soil groups at the site to determine soil characteristics. Please note that more detailed geotechnical tests are usually required, in accordance with **Appendix D**.
2. *Depth to Seasonal High Water Table*: This column indicates the minimum depth to the seasonally high water table from the bottom elevation of the SMP section.
3. *Contributing Area*: This column indicates the minimum or maximum contributing area that is considered optimal for a practice. The minimum contributing area shall not be reduced, and the maximum shall not be increased, except where specific design criteria are met or additional engineering analysis is performed to support an adjusted area.
4. *Max Site Slope*: This column indicates the preferred maximum slope of the area proposed for installation of a practice. Existing slopes may exceed these values with proper engineering to ensure slope stability and non-erosive runoff velocities from the contributing area.

Table 5.6 Runoff Reduction Feasibility Matrix				
GI Design	**Underlying Soils**	**Depth to Water Table (ft)**	**Contributing Area**	**Max Site Slope**
Conservation of Natural Areas	No Restriction	No Restrictions	10,000 sf (min)	No Restrictions
Sheet Flow to Riparian Buffers or Filter Strips	No Restriction	No Restrictions	150 ft (pervious) 75 ft (impervious)	5% / 10%
Tree Planting	No Restriction	2	No Restrictions	10%
Tree Pit	Underdrains required for $f_c < 0.5$ inch/hr	2	No Restrictions	10%
Tree Trench	$f_c \geq 0.5$ inch/hr	2	No Restrictions	10%
Disconnection of Rooftop Runoff	No Restriction	No Restrictions	1,000 sf/filter path (max)	No Restrictions
Vegetated Swale	No Restriction	No Restrictions	5 ac (max)	0.5% - 4% and 3:1 (h:v)
Filtration Rain Garden	Underdrains required for $f_c < 0.5$ inch/hr	2[1]	1,000 sf/garden (max)	No Restrictions
Infiltration Rain Garden	$f_c \geq 0.5$ inch/hr	2[1]	1,000 sf/garden (max)	No Restrictions
Filtration Stormwater Planter	Underdrains required for $f_c < 0.5$ inch/hr	2[1]	15,000 sf/planter (max)	No Restrictions
Infiltration Stormwater Planter	$f_c \geq 0.5$ inch/hr	2[1]	15,000 sf/planter (max)	No Restrictions
Rainwater Harvesting System	NA	NA	No Restrictions	NA
Porous Pavement	$f_c \geq 0.5$ inch/hr	2[1]	No Restrictions	10%
Green Roof	NA	NA	Roof Size	10% / 25%

[1]When in sole source aquifer increase to 4 ft

NA = Not Applicable

5.3.1 Conservation of Natural Areas (RR-1)

Conservation of natural areas is an area reduction practice designed to retain the pre-development hydrologic and water quality characteristics of undisturbed natural areas by permanently conserving these areas on a site. Undisturbed natural areas include: forest retention areas; reforestation areas; stream and river corridors; shorelines; wetlands, vernal pools, and associated vegetated buffers; and undisturbed open space.

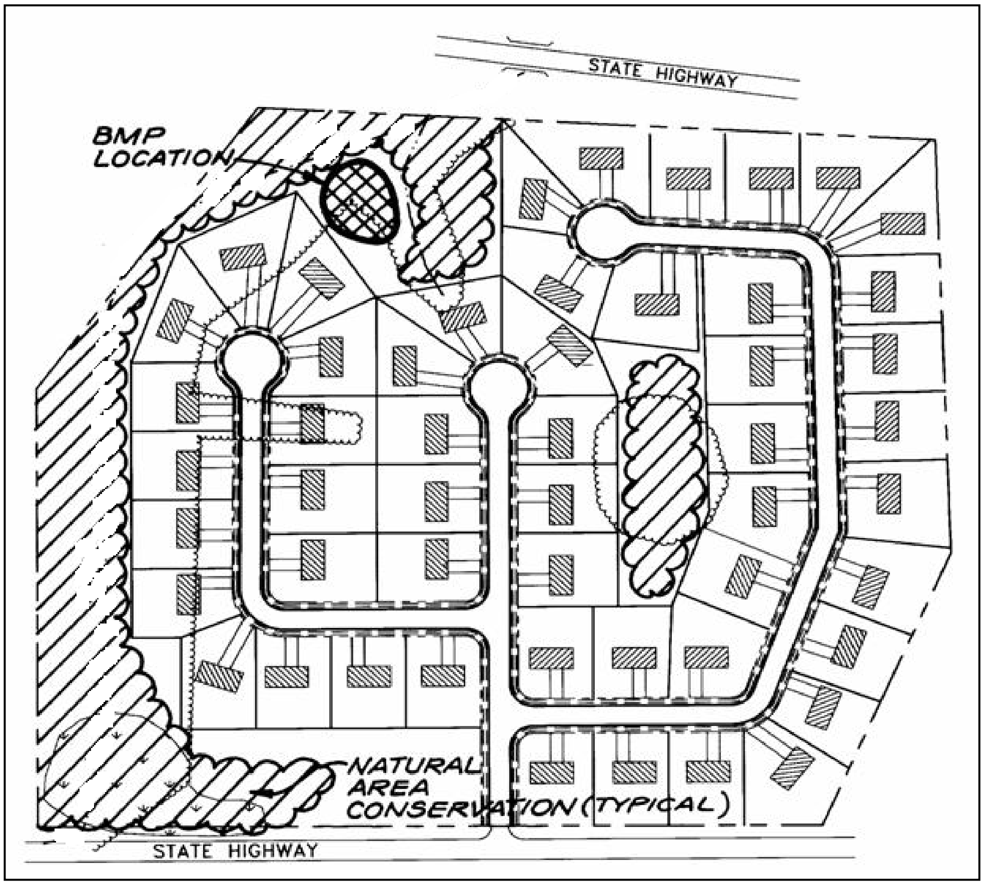


Figure 5.32 Schematic Diagram of Conservation of Natural Area. Areas with cross-hatching are being designated as a permanent conservation area and shall be removed from the total contributing site area when calculating water quality volume.

5.3.1.1 Feasibility

- Natural conservation areas must be delineated and permanently protected through establishment of a legal conservation easement.
- Managed turf including, but not limited to, playgrounds, parks, athletic fields, and cemeteries are not acceptable for conservation.

5.3.1.2 Treatment

5.3.1.2.1 Design Criteria

- Conservation areas shall have a minimum contiguous area of 10,000 sf. If multiple, separate conservation areas are provided on the same site, then each area must meet the minimum contiguous area. Delineation of conservation areas shall be performed to maximize contiguous land area and avoid fragmentation.
- Conservation areas shall be permanently protected through establishment of a legal conservation easement that clearly specifies how the natural area vegetation shall be managed. Boundaries of a conservation area must be delineated with permanent physical markers.
- Conservation areas cannot be disturbed and shall be protected throughout construction with appropriate structural barriers. The limits of disturbance along conservation areas shall be clearly shown on all construction drawings, staked out in the field and delineated by orange construction fencing prior to commencing construction activities.

5.3.1.2.2 Sizing Criteria

- When computing water quality volume, the area to be designated as a conservation area is subtracted from the total contributing area to a given design point. This reduction shall only be applied for undisturbed natural areas that are located within the property boundaries of the site, are solely controlled by the property owner, and contribute runoff to the design point. The area reduction credit shall only be applied towards the required RR_v for the design point to which the conservation area is tributary.
- This practice is not applicable if credit for Sheet flow to Riparian Buffer, or another area reduction practice, is already being taken for the same area.
- Conservation areas shall not receive runoff from impervious area. Contributing areas that contain existing or new impervious surfaces shall be designed according to Sheet flow to Riparian Buffer requirements.
- When calculating peak discharge rates or volumes, the total contributing area associated with conservation areas must be included in the hydrologic/hydraulic analyses and an appropriate curve number must be applied. If the conservation area is tributary to a downstream SMP, then the practice must be sized to accommodate the total flow generated from the entire tributary watershed.

5.3.1.2.3 Design Example

Base Data

Total contributing area = 10 acres

Contributing impervious area = 3 acres

90% Rainfall Event Number = 1.0 inch

Area to be protected as natural conservation area = 3 acres.

**In this scenario the conservation area is not receiving runoff from upstream areas and is subtracted from the contributing area to the design point: 10-3=7 acres*

- First, compute the required WQ_v, per **Chapter 4**:

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{3\ acres}{10\ acres}\ x\ 100$$

$$I = 30\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 30)$$

$$R_V = 0.32$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.00\ inches\ x\ 0.32\ x\ 10\ acres}{12}$$

$$\boldsymbol{WQ_V = 0.267\ af}$$

- Next compute the Area Reduction WQ_v, accounting for the area reduction from the natural conservation area. When calculating the Area Reduction WQv, the previously calculated Rv (0.32) remains unchanged:

$$R_V = 0.32$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.00\ inches\ x\ 0.32\ x\ 7\ acres}{12}$$

$$\boldsymbol{WQ_V = 0.187\ af}$$

- Then compute the RR_v Provided, taking into account the natural conservation area:

$$RR_V\ Provided = Required\ WQ_V - Area\ Reduction\ WQ_V$$

$$RR_V\ Provided = 0.267\ af - 0.187\ af$$

$$\boldsymbol{RR_V\ Provided = 0.080\ af}$$

Fact Sheet: Conservation of Natural Areas (RR-1)

Description: Area reduction practice designed to maintain pre-development hydrologic and water quality characteristics of undisturbed natural areas by permanently conserving them.

Key Considerations

FEASIBILITY

- Natural conservation areas require legal conservation easement
- Areas must not be disturbed during construction

TREATMENT

- Minimum area = 10,000 sf
- Delineate boundaries of conservation area with permanent physical marker
- Conservation areas shall not receive runoff from impervious areas
- Area to be designated as a conservation area is subtracted from the total contributing area to a given design point when computing WQv
- Total contributing area associated with conservation areas must be included in the hydrologic/hydraulic analyses when calculating peak discharge rates/volumes

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- L Maintenance Burden
- L Safety Risk
- NA Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- Phosphorus
- Nitrogen
- Metals
- Pathogens
- Total Suspended Solids

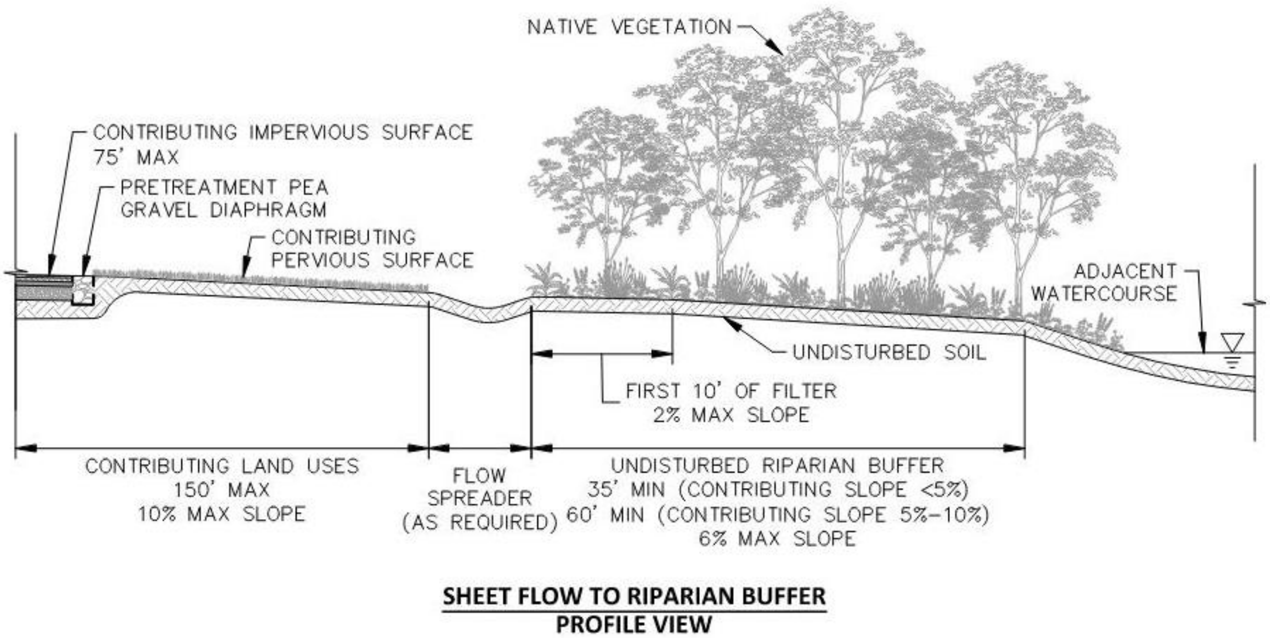
G = Good **F** = Fair **P** = Poor
★ = May provide partial benefits

RUNOFF REDUCTION CREDIT

- 100% area reduction towards RRv

5.3.2 Sheet Flow to Riparian Buffers or Filter Strips (RR-2)

An area reduction practice where runoff is directed towards natural riparian buffers and vegetated filter strips for source control treatment, infiltration, reduction in velocity, and pollutant removal. Riparian buffers are natural or reforested vegetated areas along streams, rivers, and other waterbodies that protect water quality through bank stabilization, erosion and sediment control, reduced flood impacts, and filtration of nutrients. Vegetated filter strips are areas of permanent vegetation designed to treat sheet flow from adjacent surfaces and remove pollutants through filtration and infiltration.



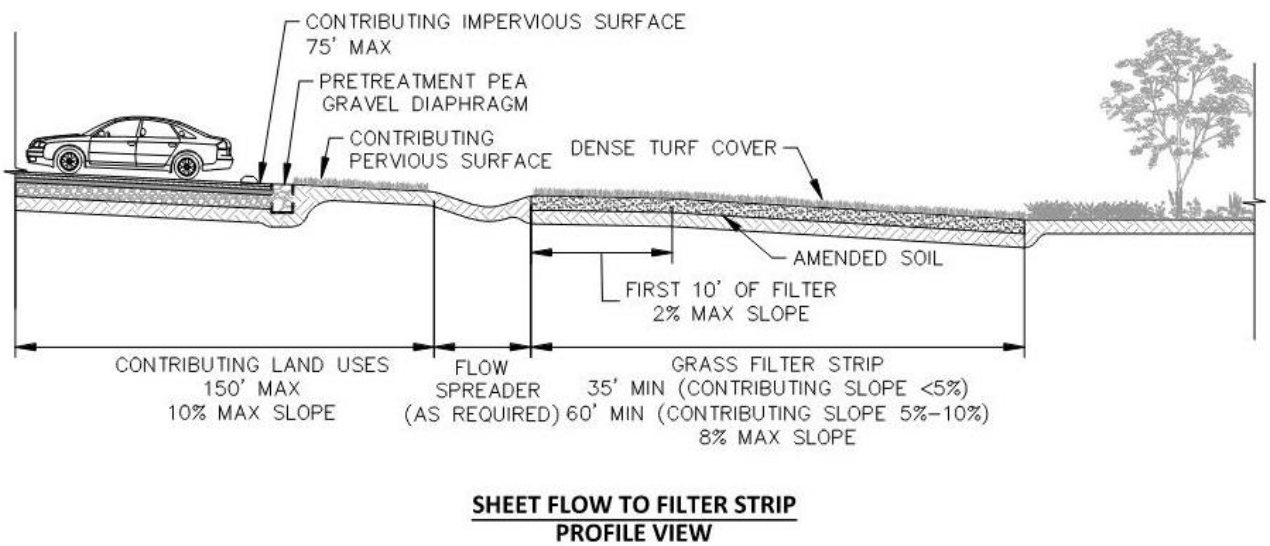


Figure 5.33 Sheet Flow to Riparian Buffers of Filter Strips (RR-2)

5.3.2.1 Feasibility

- Riparian buffers and vegetated filter strips must be delineated and permanently protected through establishment of a legal conservation easement.

5.3.2.2 Conveyance

- Intercept stormwater runoff near the source before it becomes concentrated and then distribute this flow evenly (as sheet flow) to the buffer or filter strip to promote natural infiltration. Install an upgradient level spreader to establish sheet flow, if necessary, as seen in **Figure 5.33**.
- A mechanism for the bypass of higher-flow events should be provided to reduce erosion or damage to a buffer or filter strip. Recommended buffer widths for various uses are indicated in **Figure 5.34**.
- Carefully constructed berms can be placed around natural depressions and below undisturbed vegetated areas with porous soils to provide for additional runoff storage and/or infiltration of flows.

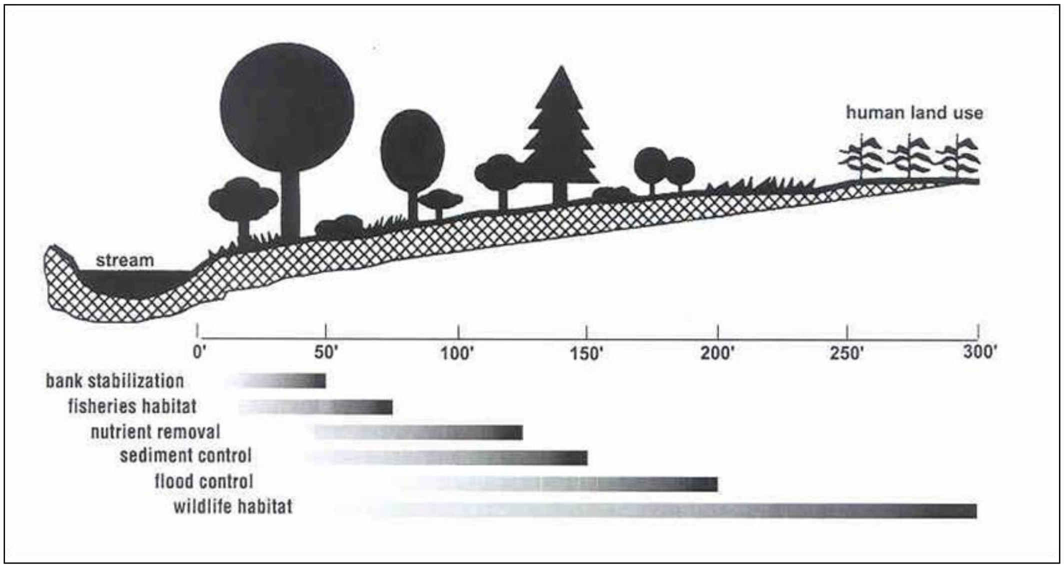


Figure 5.34 Preservation of buffers for various environmental quality goals

5.3.2.3 Pretreatment

- Pretreatment shall be provided through a pea gravel diaphragm installed upgradient of the buffer or filter strip. If runoff is being conveyed via sheet flow from a surface level impervious area, then the pea gravel diaphragm shall be installed along the downgradient edge of the impervious area. The pea gravel diaphragm shall have the minimum dimensions 12 inch width by 24 inch depth.

5.3.2.4 Treatment

5.3.2.4.1 Design Criteria

- Runoff shall enter the buffer or filter strip as overland sheet flow. If sheet flow cannot be achieved due to upgradient slopes, then a flow spreader shall be installed upgradient of the practice.
- Siting and sizing of this practice must address runoff reduction requirements and cannot result in overflow to undesignated areas.
- The NYS Freshwater Wetlands Act regulates the 100-ft adjacent area of NYS designated wetlands. If the regulated stream or adjacent wetland area conforms to the treatment criteria defined herein, then credit can be taken for the area.
- Riparian buffers cannot be disturbed and shall be protected throughout construction with appropriate structural barriers. The limits of disturbance along the riparian buffer shall be clearly shown on all construction drawings, staked out in the field and delineated by orange construction fencing prior to commencing construction activities.

- The design, installation, and management shall be in accordance with **Table 5.7**.

Table 5.7 Design Criteria for Sheet Flow to Riparian Buffer & Sheet Flow to Vegetated Filter Strip

Design Criteria	**Sheet Flow to Riparian Buffer**	**Sheet Flow to Vegetated Filter Strip**
Soil and Ground Cover	Undisturbed soils and native vegetation	Amended soils and dense turf cover
Typical Application	Adjacent drainage to natural stream buffer or conservation area	Source control treatment of directly adjacent impervious area
Compost Amendments	No	Yes
Maximum Length of Contributing Flow Path	150 ft total length with 75 ft total from impervious surfaces	
Maximum Slope of Contributing Area	5% without upgradient flow spreader >5 to 10% with upgradient flow spreader >10% practice not permitted	
Maximum Slope, First 10 Ft of Filter	Less than 2%	Less than 2%
Maximum Overall Slope	6%	8%
Minimum Flow Length through Buffer or Filter Strip	35 ft for contributing area slope of 0% to < 5% 60 ft for contributing area slope of 5% to 10%	
Protection During Construction Stage	Locate outside the limits of disturbance and protect with ESC practices	
*See the NYS Standards and Specifications for Erosion and Sediment Control for the design of flow spreaders		

5.3.2.4.2 Sizing Criteria

- When computing the required water quality volume to a given design point, subtract the area contributing by sheet flow to a riparian buffer or filter strip from the total area tributary to the design point. If the contributing area contains impervious cover, then the impervious area is subtracted from the total contributing area to the buffer or filter strip and the total impervious area. This reduction may only be applied for buffers or filter strips that are located within the property boundaries of the site, are solely controlled by the property owner, and contribute runoff to the design point. The area reduction credit can only be applied towards the required RRv for the design point to which the buffer or filter strip is tributary.
- Reduced areas are not deducted when calculating quantity controls for larger storms.
- In HSG C and D, buffer or filter strip length shall be increased by 15% and 20%, respectively.
- The buffer or filter strip length shall be determined using the below equation for filter length based on the SCS TR-55 travel time equation. If the calculated buffer or filter strip length is less than the minimum flow length through the buffer or filter strip, in **Table 5.7**, the minimum length must be used.

$$L = \frac{T^{1.25} * {P_2}^{0.625} * S^{0.5}}{0.338n}$$

L = length of filter strip parallel to flow path (ft)
T = travel time through filter strip (6 minutes min. based on TR-55)
P_2 = 2-yr 24-hr rainfall depth (inches)
S_L = filter strip slope (ft/ft)
n = Manning's coefficient for buffer or filter strip

5.3.2.4.3 Design Example

Base Data

Total contributing area = 3.40 acres

Contributing impervious area = 0.20 acres

90% Rainfall Event Number = 1.00 inches

Contributing area slope = 5.5%

Contributing area width = 50 ft

HSG Group = C

Travel time = 6 minutes

2-yr 24-hr rainfall depth = 3.43 inches

Overall filter strip slope = 8%

Manning's coefficient = 0.24

- First, compute the required WQv, per **Chapter 4**:

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{0.20\ acres}{3.40\ acres}\ x\ 100$$

$$I = 6\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 6)$$

$$R_V = 0.10$$

$$WQv = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQv = \frac{1.00\ inches\ x\ 0.10\ x\ 3.40\ acres}{12}$$

$$\boldsymbol{WQv = 0.028\ af}$$

- Next, determine the filter strip width. The filter strip minimum width must equal the contributing area width. The filter strip width is 50 ft.
- Then, calculate the filter strip based on the proposed design conditions:

$$L = \frac{T^{1.25} * {P_2}^{0.625} * S^{0.5}}{0.338n}$$

$$L = \frac{6^{1.25} * 3.43^{0.625} * 0.08^{0.5}}{0.338 * 0.24}$$

$$\boldsymbol{L = 70.7\ ft}$$

- The calculated filter length is 70.7 ft. Based on **Table 5.7**, the minimum filter strip length required is 75 ft for contributing area slopes between 5% and 10%. **The filter strip length proposed is 75 ft.**
- In addition, the filter strip is in HSG C soils and must be increased by an additional 15%. Therefore, the proposed filter strip **length is increased from 75 ft to 86.25 ft.**
- Assuming all other feasibility and design requirements have been met, the designed filter strip receives 100% RRv credit of **0.028 af.**

Fact Sheet: Sheet Flow to Riparian Buffers or Filter Strips (RR-2)

Description: Area reduction practice designed to direct runoff towards natural riparian buffers and vegetated filter strips. This practice acts as source control, provides treatment, promotes infiltration, reduces velocity, and removes pollutants.

(Photo Source: Fund for Lake Michigan)

Key Considerations

FEASIBILITY

- Riparian buffers and vegetated filter strips require the establishment of a legal conservation easement
- Areas must not be disturbed during construction

CONVEYANCE

- Intercept runoff near source and distribute as sheet flow to buffer or filter strip
- High flow bypass should be utilized to reduce damage to buffer/filter strip

PRETREATMENT

- Gravel diaphragm on upgradient side of buffer/filter strip

TREATMENT

- Runoff should enter as sheet flow
- The maximum slope for the contributing area is 5% without an upgradient flow spreader, and 10% with an upgradient flow spreader. The slope of the contributing area shall not exceed 10%
- The maximum length of contributing flow path is 150 ft total length with 75 ft total from impervious surfaces
- The maximum slope, for the first 10 ft of the filter, shall be less than 2%
- The maximum overall slope of a riparian buffer is 6%. The maximum overall slope for a vegetated filter strip is 8%
- The minimum flow length through the buffer or filter strip is 35 ft for contributing area slope of 0% to < 5%, and 60 ft for contributing area slope of 5% to 10%
- Not applicable if credit for Disconnection of Rooftop Runoff, or another area reduction practice, is already being taken for the same area
- Buffer length shall be increased by 15%-20% in HSG C and D respectively

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- L Maintenance Burden
- L Safety Risk
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- G Phosphorus
- F Nitrogen
- P Metals
- P Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

5.3.3 Tree Planting/Tree Pit/Tree Trench (RR-3)

Tree plantings are existing or newly planted trees in a natural setting that can be applied as an RR Technique for Area Reduction.

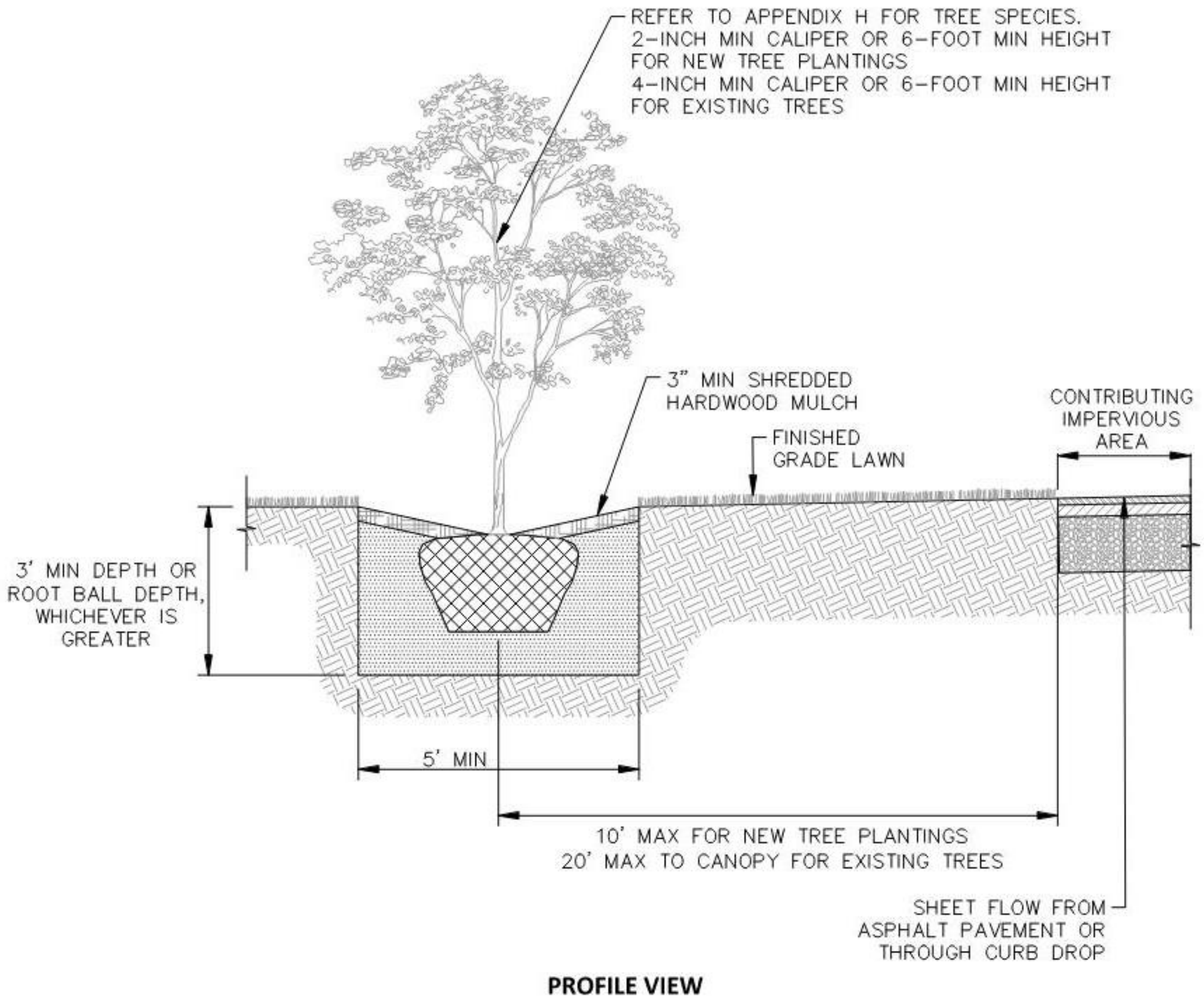


Figure 5.35 Tree Planting (RR-3)

Tree pits refer to individually planted trees in contained areas, such as street trees within sidewalks or curbed islands, that can be applied as an RR Technique for Volume Reduction.

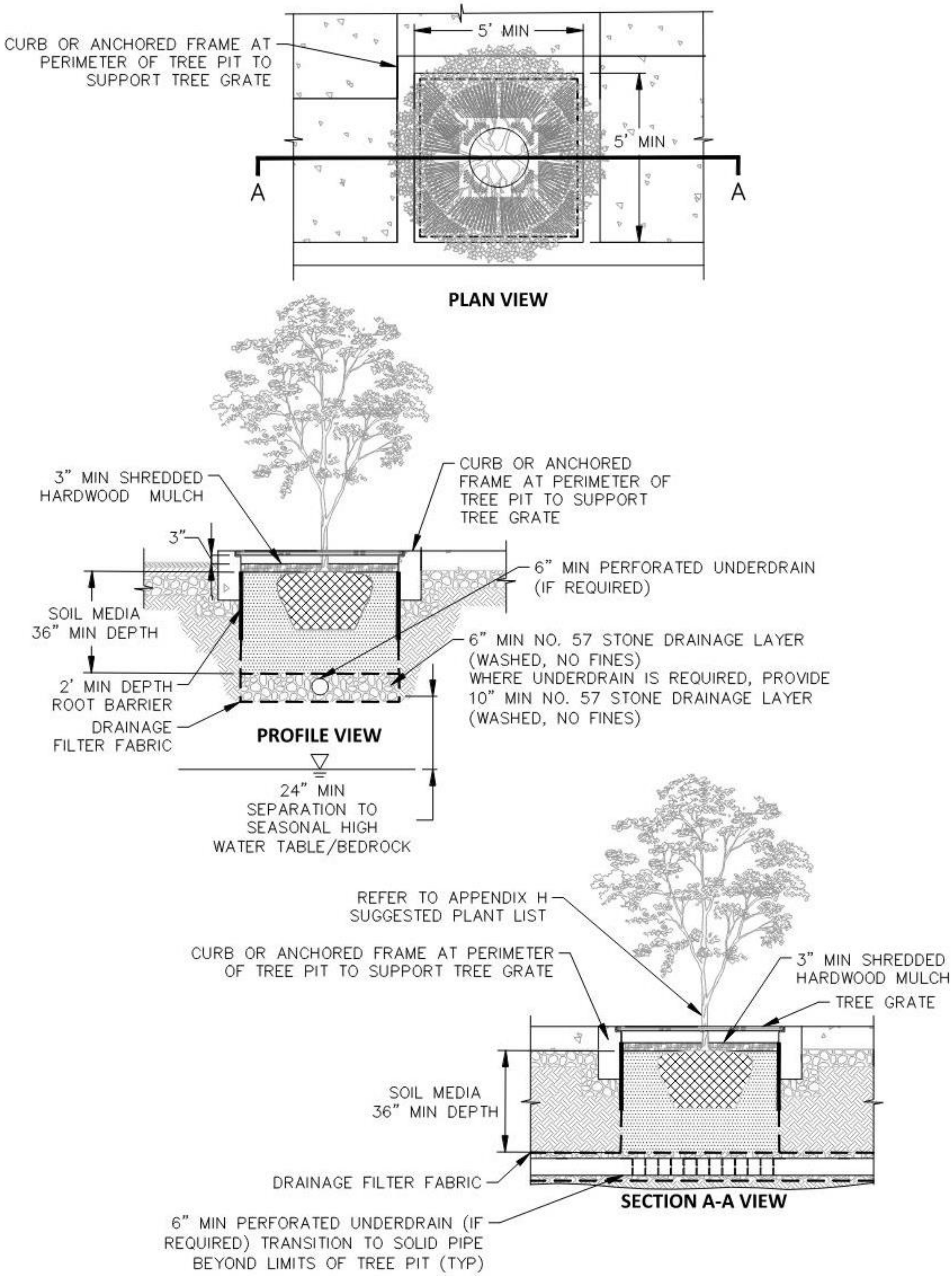


Figure 5.36 Tree Pit (RR-3)

Tree trenches are linearly planted trees along an impervious surface, such as roads or sidewalks, that capture surface flow and are connected by an underground stone reservoir with perforated pipe to maximize infiltration for credit as an RR Technique for Volume Reduction. Tree trenches can support surface or subsurface flow.

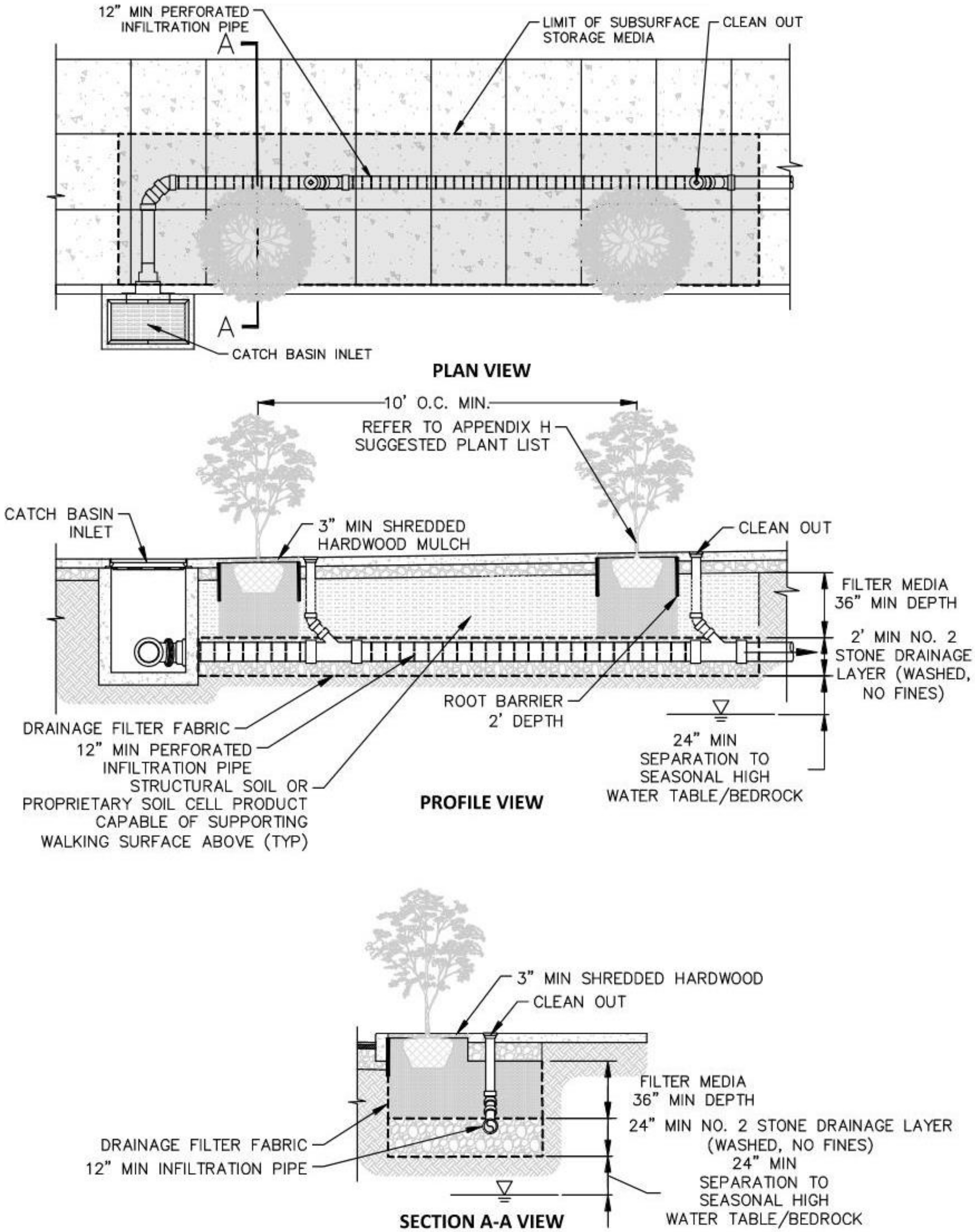


Figure 5.37 Tree Trench Subsurface Flow (RR-3)

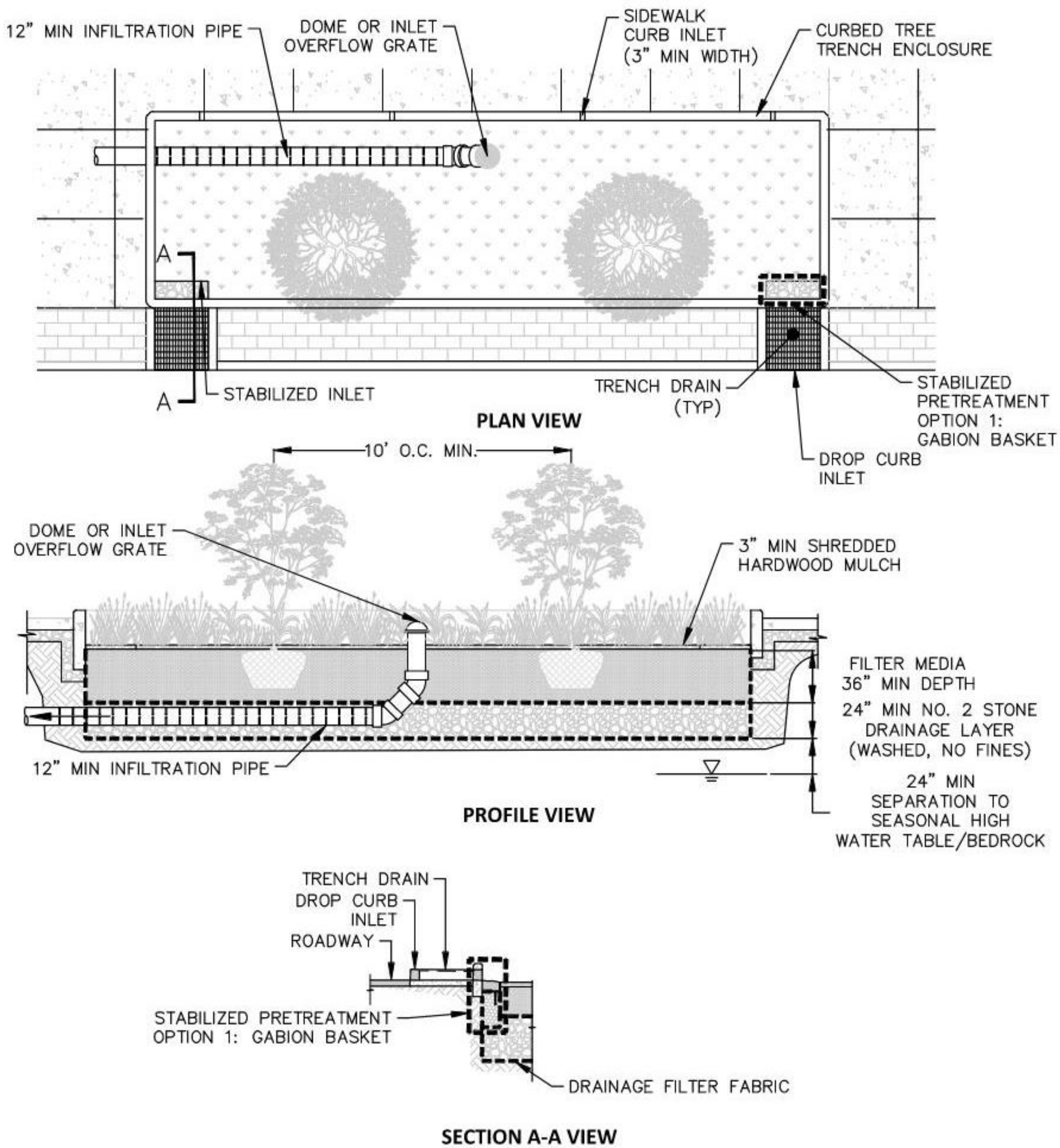


Figure 5.38 Tree Trench Surface Flow (RR-3)

5.3.3.1 Feasibility

- Tree species selection shall take overhead and underground utilities into consideration, where applicable.
- Tree pits and tree trenches may be applied as practices for urban stormwater management (see **Chapter 8**).
- Conserved existing trees shall be non-invasive, healthy trees with a root system that will not be impacted by the proposed development.
- Tree pits shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr, as confirmed by required geotechnical testing (see **Appendix D**), unless underdrains are provided.
- Tree trenches shall not be used unless the underlying soils have an infiltration rate greater than or equal to 0.50 inch/hr, as confirmed by required geotechnical testing (see **Appendix D**).
- Tree trenches and tree pits shall have a 2 ft min. separation to the seasonal high water table and bedrock, including sound bedrock, fractured bedrock or karst geology.
- Tree trenches, tree pits and tree plantings shall not be used to treat stormwater hotspots.
- In areas of known contamination, or if contamination is discovered during excavation, contaminant levels must be evaluated by a qualified professional and state remediation program to determine if infiltration is permitted.
- Tree plantings are not applicable if credit for another area reduction practice is already being taken for the same area.
- Tree pits designed adjacent to public or private roadways shall have a maximum spacing of 30 ft on center.
- Tree trenches shall meet the separation requirements as listed in **Table 5.8**. Vertical separation shall be taken from the bottom of the stone drainage layer. Horizontal separation shall be taken from the closest side of the filter media.

Table 5.8 Tree Trench Minimum Separation Requirements

	Vertical Separation		Horizontal Separation			
Design Variant	**Seasonal High Water Table[1,2]**	**Bedrock[1,2]**	**Structures Without Foundation Waterproofing**	**Structures With Foundation Waterproofing**	**Water Supply Well/Reservoir**	**Septic System[3]**
Tree Trench	2 ft	2 ft	10 ft	0 ft	100 ft	50 ft

[1]Sound bedrock, fractured bedrock or karst geology as documented by on-site soil testing.
[2]4 ft in sole source aquifers.
[3]Septic systems are inclusive of distribution boxes and absorption fields.

5.3.3.2 Conveyance

- Stormwater runoff shall be intercepted near the source and conveyed to the practice as sheet flow or concentrated flow with a flow dissipater upon entrance into the practice.
- Runoff from adjacent building roofs can be captured and directed into tree trenches. Roof drains shall discharge at the surface of the tree trench or connect to a storm sewer structure for flow dissipation, prior to entering the tree trench. Direct connections to the subsurface infiltration pipe are not permitted. Adequate pretreatment shall be provided.
- Tree pit underdrain systems shall be designed to create an internal water storage using one of the following methods:
    - Provide an upturned elbow, set 10 inches above the bottom of practice (**Refer to Appendix C)**;
    - Set the outlet pipe invert, at the outlet control structure, 10 inches above the bottom of practice; or
    - Increase the drainage layer depth to provide 8 inches of stone below the underdrain.

- Tree trenches shall be equipped with a subsurface infiltration reservoir, below the soil media, consisting of a 12 inch minimum perforated pipe (infiltration pipe) embedded within a stone drainage layer. The stone drainage layer shall be extended a minimum of 12 inches on all sides of the infiltration pipe. Alternatively, approved proprietary underground infiltration systems, meeting the design criteria in **Section 6.3**, may be used in place of the infiltration pipe.
- Tree trenches shall have a subsurface emergency overflow pipe within an outlet control structure and the invert shall be set at or above the top of the infiltration pipe.

5.3.3.3 Treatment

5.3.3.3.1 Design Criteria

- Flush curbs shall only be used around tree pits and tree trenches if pedestrian protection fencing is installed around the perimeter of the practice.
- For tree pits and tree trenches, where the open surface area does not meet the filter media minimum width or length requirements, the filter media shall extend to meet the minimum dimensions beneath the adjacent hardscape. The portion of the filter media that extends beneath hardscape surfaces shall be substituted with a structural filter media meeting the requirements in **Table 5.9**.
- Tree plantings, pits and trenches shall meet the following design requirements:

Table 5.9 Design Criteria for Tree Plantings, Pits and Trenches

Design Criteria	Tree Trenches	Tree Pits	Tree Plantings
Maximum Slope of Contributing Area	10%		
Tree Species	Species shall be chosen from **Chapter 11** or a local list of native species		
Minimum Size – New Trees	Deciduous trees: 2-inch caliper Evergreen trees: 6 ft. height		
Minimum Size – Existing Trees	Deciduous trees: 2-inch caliper Evergreen trees: 6 ft. height		
Minimum Tree Spacing	10 ft. o.c.	N/A	N/A
Maximum Horizontal Separation from Contributing Impervious Area – New Trees	10 ft		
Maximum Horizontal Separation from Contributing Impervious Area – Existing Trees	Canopy within 20 ft		

- Tree pits and Tree Trenches shall consist of the following design specifications:

Table 5.10 Tree Pit & Tree Trench Design Specifications

		Tree Trenches	Tree Pits	Tree Planting
Ponding[1]	**Depth**	6 inch max. below lowest inlet		
Surface Layer[1]	**Depth**	3 inch min. for new plantings		
	Material	Shredded Hardwood Mulch		
Structural Filter Media	**Applicability**	As Required	N/A	N/A
	Depth	Per Manufacturer	N/A	
	Material	CU-Structural Soil® or demonstrated equivalent		
Filter Media[1]	**Depth**	36 inches min.		
	Width	5 ft min.		
	Length	Determined by available space	5 ft min.	
	Material	ASTM C-33 Sand: 60%-75% Topsoil[3]: 25%-40%		Common planting soil
Drainage Layer	**Applicability**	Required	Required	N/A
	Depth	24 inch min.	6 inch min. without underdrain 10 inch min. with underdrain	N/A
	Material	No. 2 stone, washed, no fines	AASHTO No. 57 stone, washed, no fines	N/A
Drainage Filter Fabric	**Applicability**	Required	Required	N/A
	Material[2]	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)		
Infiltration Pipe	**Applicability**	Required	N/A	N/A
	Material	12” min. perforated PVC or HDPE laid level or approved underground proprietary practice		
Underdrain	**Applicability**	N/A	As Required	N/A
	Material	6” perforated PVC or HDPE laid at 0.5% slope min. at 30 ft max. O.C.		

Footnotes:
[1]Required for all Design Variants
[2]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel
[3]Topsoil shall conform to NYSDOT Standard Specification 713-01 for Roadside Mix or Specialty Planting Mix.

Construction Requirements

- Heavy equipment traffic must be limited in the vicinity of both existing and proposed tree planting areas.
- Where existing trees are proposed as tree plantings, the design development and construction process must:
  - Inventory existing trees on-site;
  - Identify trees to be protected;
  - Protect the identified trees and surrounding soils during construction by limiting clearing, grading and compaction within the drip line of the canopy; and
  - Protect and maintain identified trees post-construction.

5.3.3.3.2 Sizing Criteria

Area Reduction (Tree Planting)

- Credit for impervious area reduction shall be the following:
    - Mature tree canopy less than 16 ft diameter: half the area of the tree canopy.
    - Mature tree canopy greater than or equal to 16 ft diameter: 100 SF per tree.
- When computing the required water quality volume to a given design point, subtract the impervious area contributing by sheet flow, to an existing or new tree, from the total contributing impervious area.
- Reduced areas are not deducted when calculating quantity controls for larger storms.

Volume Reduction (Tree Pit/Tree Trench)

- Depth of stone reservoir shall be designed to account for the total tributary area, in-situ soil characteristics, as well as water quality volume and quantity control requirements. Systems shall be designed to ensure that the peak water surface elevation for the 10-year, 24-hr design storm does not overtop the system and shall safely convey runoff from greater storm events.
- The depth of soil media shall be sized, based on the principles of Darcy's Law, to treat the WQv for the surface discharge tributary to each tree pit/trench. The filter area shall be sized based on the principles of Darcy's Law. Calculate the minimum bottom area:

$$A_f = \frac{WQ_v d_f}{k(h_f + d_f)t_f}$$

Where:

A_f = Filter area (sf)

WQ_v = Water Quality Volume (cf)

d_f = Depth of filter (ft)

k = Permeability flow rate of filter media (1 ft/day)

h_f = Average height of ponding (ft) (0.5 ft max.)

t_f = Maximum filter bed drain time (2 days)

5.3.3.4 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Tree Planting/Tree Pit/Tree Trench (RR-3)

Description: Tree planting is an area reduction practice using existing or newly planted trees. Tree pits are a volume reduction practice using trees planted in contained areas.

Key Considerations

FEASIBILITY

- Tree plantings are not applicable if credit for another area reduction practice is already being taken for the same area
- Trees shall be non-invasive and not be disturbed during construction
- Tree pits shall have underlying soils with an infiltrate greater than or equal to 0.50 inch/hr, unless underdrains are provided
- Tree trenches shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr
- Tree trenches and tree pits shall have a 2 ft min. separation to the seasonal high water table and bedrock
- Overhead clearance shall be taken into consideration when selecting tree species

CONVEYANCE

- Tree pit underdrain systems shall be designed to create an internal water storage
- Tree trenches shall be equipped with a subsurface infiltration reservoir
- Stormwater runoff shall be intercepted near the source and conveyed to the practice as sheet flow

TREATMENT

- The maximum slope of the contributing area is 10%
- The maximum horizontal separation from the contributing impervious area is 10 ft (new trees) or within 20 ft of the canopy (existing trees)
- Drainage filter fabric shall separate and wrap the soil media and stone drainage layer of tree trenches
- For area reduction subtract the total area contributing by sheet flow to an existing or new tree from the total area when computing WQv
- For volume reduction, systems should ensure that the peak water surface elevation for the 10-year, 24-hr design storm does not overtop the system

STORMWATER MANAGEMENT SUITABILITY

	Water Quality
	Channel Protection
	Overbank Flood Protection
	Extreme Flood Protection
✓	Runoff Reduction
	Treatment of Hotspots
✓	Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

H	Capital Cost
M	Maintenance Burden
L	Safety Risk
L	Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.4***)

G	Phosphorus
F	Nitrogen
G	Metals
G	Pathogens
G	Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% area reduction towards RRv (plantings)
- 100% RRv provided (trenches and pits)
- 40% RRv provided (tree pits with underdrains)

5.3.4 Disconnection of Rooftop Runoff (RR-4)

Direct runoff from rooftop areas to designated filter area(s) to reduce runoff rates. When disconnection of rooftop runoff meets the design requirements, the practice provides an impervious area reduction when computing the water quality volume requirements.

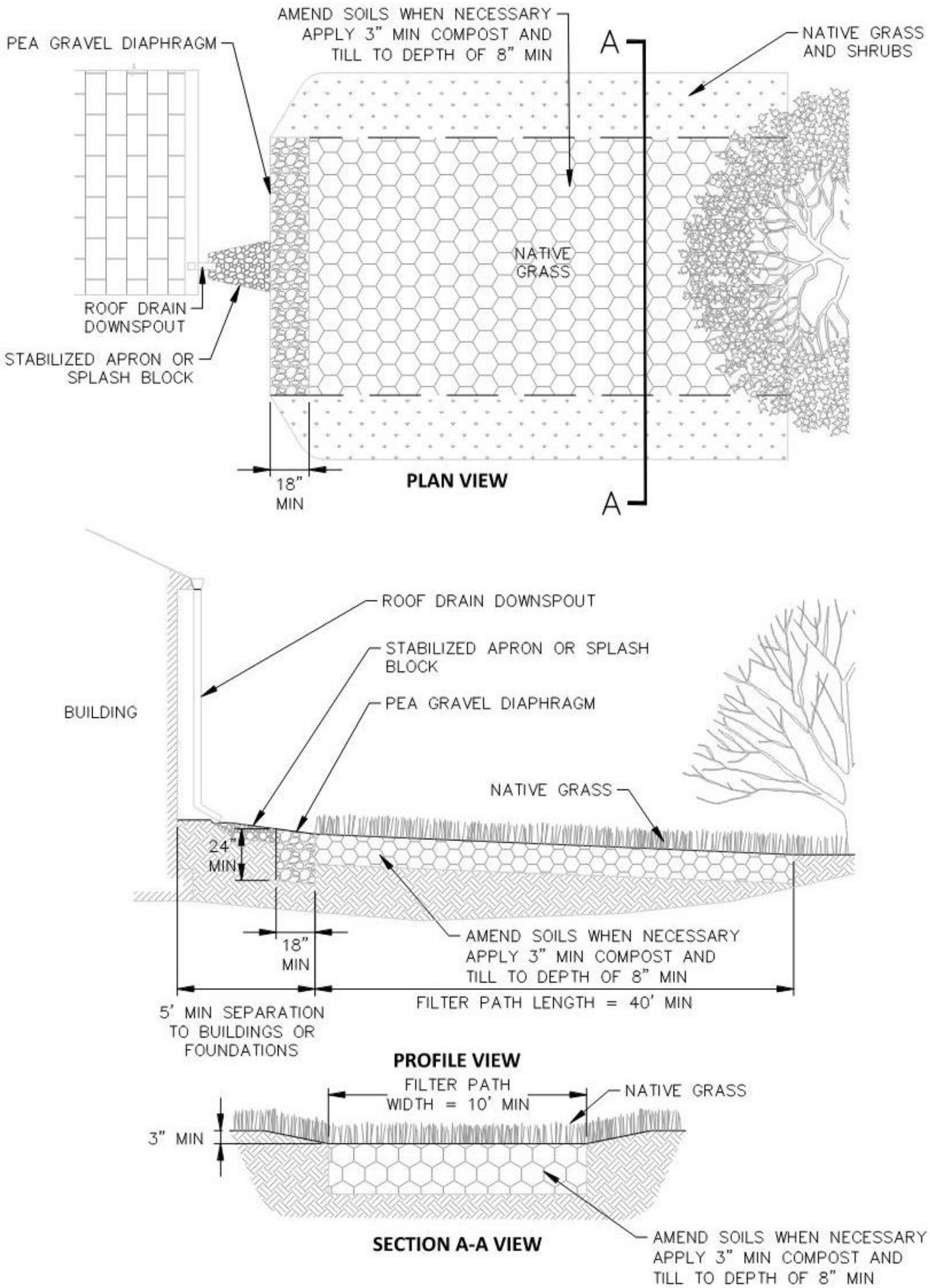


Figure 5.39 Disconnection of Rooftop Runoff (RR-4)

5.3.4.1 Feasibility

- Disconnect shall be designed such that redirected runoff drains away from buildings and foundations.
- Disconnection can be used on any post-construction Hydrologic Soil Group. However, the erodibility of the soils must be considered. For Soil Groups C or D, disconnection shall include amended soil within the filter path, as defined in **Section 5.3.4.3.2** below**.**
- Disconnection cannot result in overflow to areas not designated as the filter path.
- For disconnections draining directly to a buffer, either the disconnection of rooftop runoff or sheet flow to riparian buffer runoff reduction method shall be used, but not both.

5.3.4.2 Conveyance

- Flow from the downspout shall be spread over a filter path, extending down-gradient from the structure.
- A pea gravel diaphragm shall be installed at the downspout outlet to distribute flows evenly across the filter path.

5.3.4.3Treatment

5.3.4.3.1 Design Criteria

- The filter path shall be a minimum of 3 inches lower than the surrounding area in order to keep flow in the path. Similarly, filter path shall be level perpendicular to flow to discourage flow concentration.
- Rooftop disconnection shall meet the following design criteria:

Table 5.11 Design Criteria for Rooftop Disconnection

Design Criteria	Required Elements
Maximum tributary rooftop area	1,000 sf per disconnection filter path
Filter path geometry	Width = minimum 10 ft Length = minimum 40 ft
Filter path slope	< 2%, or < 5% with turf reinforcement
Filter path separation to buildings or foundations	5 ft
Amended soils within filter path	Apply 3 inches of compost over entire area of filter path and till to a depth of 8 inches (HSG C or D)

5.3.4.3.2 Material Specification

- Compost shall be derived from plant material and meet the general criteria set forth by the U.S. Composting Seal of Testing Assurance (STA) program.
- The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the following criteria:
    - 100% of the material shall pass through a ½ inch screen;
    - The pH of the material shall be between 5.5 and 8.5;
    - Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0% by weight;
    - The organic matter content shall be > 35%;
    - Soluble salt content shall be less than 6.0 mmhos/cm;

- Shall be mature and stable per the appropriate test(s) as specified by STA;
- Carbon/nitrogen ratio shall be less than 25:1;
- Must meet USEPA part 503 levels for heavy metals;
- The compost should have an optimum dry bulk density ranging from 40 to 50 lbs/cf. However, certain fully mature coarse textured composts may be lower; and
- Compost shall not include manure.

5.3.4.3.3 Sizing Criteria

- When computing the required water quality volume to a given design point, subtract the total disconnected area contributing by sheet flow to the filter path from the total area.
- Disconnected impervious areas are not deducted when calculating quantity controls for larger storms.

5.3.4.3.4 Design Example

Base Data

(9) 1,000 sf homes proposed for rooftop disconnection

Total site area = 8.54 acres

Total impervious area = 3.17 acres

90% Rainfall Event Number = 1.00 inch

- First, compute the required WQ_v, per **Chapter 4**:

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{3.17\ acres}{8.54\ acres}\ x\ 100$$

$$I = 37\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 37)$$

$$R_V = 0.38$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.00\ inches\ x\ 0.38\ x\ 8.54\ acres}{12}$$

$$\boldsymbol{WQ_V = 0.270\ af}$$

- Next compute the area reduction WQ_v, accounting for the area reduction from disconnected roofs.

$$Area\ to\ be\ disconnected = \frac{(9\ houses\ x\ 1{,}000\ sf)}{43{,}560\ sf/acre}$$

$$Area\ to\ be\ disconnected = 0.21\ acres$$

$$Reduced\ impervious\ area = 3.17\ acres - 0.21\ acres$$

$$Reduced\ impervious\ area = 2.96\ acres$$

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{2.96\ acres}{8.54\ acres}\ x\ 100$$

$$I = 35\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 35)$$

$$R_V = 0.37$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.00\ inches\ x\ 0.37\ x\ 8.54\ acres}{12}$$

$$\boldsymbol{WQ_V = 0.263\ af}$$

- Then compute the RR_v Provided, taking into account the rooftop disconnection:

$$RR_V\ Provided = Required\ WQ_V - Area\ Reduction\ WQ_V$$

$$RR_V\ Provided = 0.270\ af - 0.263\ af$$

$$\boldsymbol{RR_V\ Provided = 0.007\ af}$$

Fact Sheet: Disconnection of Rooftop Runoff (RR-4)

Description: Area reduction practice that directs rooftop runoff to designated filter areas.

(Photo Source: Harford County, Maryland)

Key Considerations

FEASIBILITY

- Redirected runoff shall drain away from buildings and foundations
- Erodibility of soils shall be considered
- For HSG C or D, disconnection shall include amended soil within the filter path
- For disconnections draining directly to a buffer, either the disconnection of rooftop runoff or sheet flow to riparian buffer runoff reduction method shall be used, but not both

CONVEYANCE

- Flow from the downspout shall be spread over a filter path, extending down-gradient from the structure

TREATMENT

- Maximum tributary rooftop area is 1,000 sf per disconnection filter path
- Maximum flow length of tributary rooftop is 75 ft
- Filter paths shall be a minimum of 10 ft wide and 40 ft long
- Maximum filter path slope is < 2% without turf reinforcement and <5% with turf reinforcement
- Minimum filter path separation to buildings or foundations is 5 ft
- Filter path should be 2 to 4 inches below surrounding grade and level perpendicular to flow path

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- L Capital Cost
- L Maintenance Burden
- L Safety
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- G Phosphorus
- ★ Nitrogen
- ★ Metals
- ★ Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor
★ = May provide partial benefits

RUNOFF REDUCTION CREDIT

- 100% RRv provided

5.3.5 Vegetated Swale (RR-5)

Vegetated swales are a volume reduction practice designed to convey stormwater, in a maintained, turf-lined swale, at a low velocity, to promote natural treatment and infiltration. A properly designed, constructed, and maintained swale (or, in some cases natural drainage path) can be used in both residential and non-residential areas to treat and convey runoff from roadways and other impervious surfaces. A vegetated swale can be an alternative to underground storm sewers or lined open channels.

IMPORTANT NOTE: CONVENTIONAL GRASSED OR LINED WATERWAYS USED FOR CONVEYANCE OR DIVERSION SHALL BE STABILIZED IN ACCORDANCE WITH THE NYSDEC STANDARDS AND SPECIFICATIONS FOR EROSION AND SEDIMENT CONTROL, LATEST EDITION. CONVENTIONAL WATER QUALITY TREATMENT (WET AND DRY SWALES) SHALL BE DESIGNED IN ACCORDANCE WITH **CHAPTER 6**.

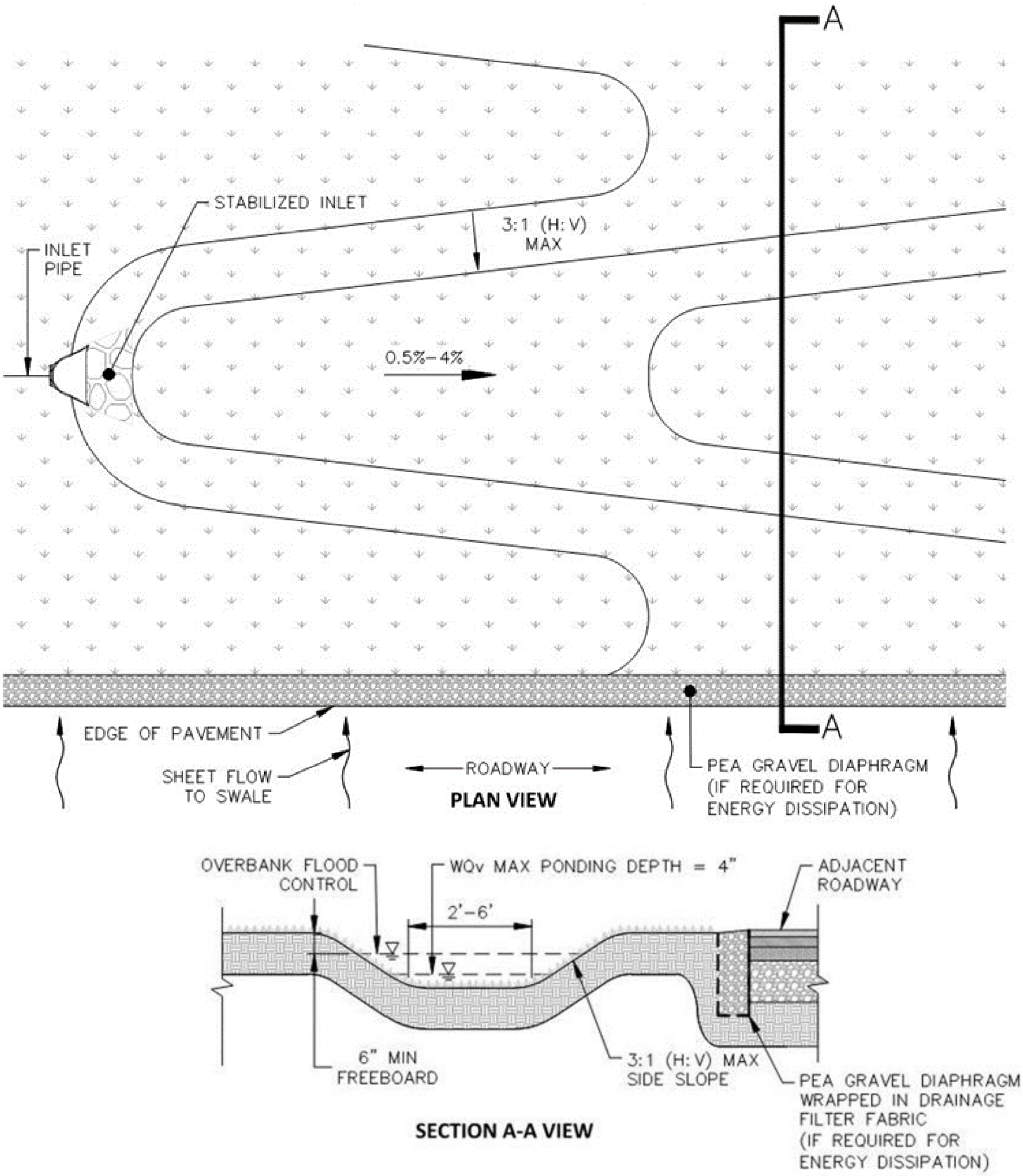


Figure 5.40 Vegetated Swale (RR-5)

5.3.5.1 Feasibility

- Local codes may not allow swales instead of curb gutter or closed drainage pipes – *Meet with local officials to discuss waivers for alternative designs.*

5.3.5.2 Treatment

5.3.5.2.1 Design Criteria

- Vegetated swales shall have a trapezoidal or parabolic shape.
- The design, installation, and management shall be in accordance with the following Table.

Table 5.12 Design Criteria for Vegetated Swales

Design Criteria	Required Elements
Maximum Contributing Area	5 acres
Maximum WQ_v Peak Discharge Rate	3 cfs
Bottom Width	2 ft minimum, 6 ft maximum
Maximum Side Slopes	3 horizontal: 1 vertical
Longitudinal Slope	0.5% minimum, 4% maximum
Minimum Swale Length	100 ft (inclusive of driveway culverts)
Manning's Coefficient	0.03 to 0.15 (Refer to **Appendix G**)
Conveyance of WQ_v Peak Discharge	4 in maximum flow depth at a velocity ≤ 1 fps (Check dam(s) may be required to achieve criteria)
Conveyance of 10-Year Peak Discharge	6 in of freeboard at a velocity ≤ 5 fps
Required WQ_v Retention	10 minutes for point discharge at the inlet 5 minutes for sheet flow or multi-point discharge along swale length

5.3.5.2.2 Sizing Criteria

The WQ_v for a vegetated swale is computed in accordance with the uniform sizing criteria methods outlined in **Chapter 4**. Design flows are calculated using small storm hydrology (**Appendix B**), and conventional hydrology methods (**Chapter 8**) in conjunction with Manning's equation for open channel flow.

- First, calculate the required WQv, per **Chapter 4.**
- Then, use the Water Quality Peak Flow Rate Calculation (**Appendix B**) to compute the peak discharge.
- Next using the proposed swale geometry, calculate the swale top width:

$$W_{Top} = b + (2\ x\ Side\ Slope)\ x\ d$$

Where:

W_{Top} = Channel top width (ft)

b = Bottom width (ft)

d = WQv flow depth (ft)

- Using the calculated swale top width and WQv flow depth as the height, calculate the wetted perimeter:

$$P_w = b + (d^2 + (Side\ Slope\ x\ d)^2)^{1/2}\ x\ 2$$

Where:

P_w = Wetted perimeter (ft)

- Using the calculated swale top width, calculate the Area (A) of the swale in square feet:

$$A = \frac{d\ x\ (b + W_{Top})}{2}$$

- Using the calculated area and WQ_F, calculate the WQv peak discharge velocity (V):

$$V = \frac{WQ_F}{A}$$

- Calculate the required swale length. Proposed swale length must be greater than or equal to the required swale length:

$$L_r = WQv\ Retention\ Time\ x\ 60\ x\ V$$
$$L_p \geq L_r$$

Where:

L_r = Required swale length (ft)

L_p = Provided swale length (ft)

- If the WQv peak discharge velocity is greater than 1 fps, calculate the required check dam spacing within the swale using the proposed check dam height and slope:

$$C_S = \frac{C_H}{S_L}$$

Where:

C_S = Check dam spacing (ft)

C_H = Check dam height (ft)

- If the WQv peak discharge velocity is greater than 1 fps, Calculate the number of check dams required using the proposed swale length and calculated spacing:

$$C = \frac{L_p}{C_S}$$

Where:

C = Number of check dams required

- Using computer modeling to determine the 10-year 24-hr flow depth, determine the available freeboard and calculate the 10-yr 24-yr velocity:

$$V_{10} = \frac{1.49}{n}\ x\ d_{10}{}^{2/3}\ x\ S_L{}^{1/2}$$

Where:

V_{10} = 10-year peak discharge velocity (fps)

- If all criteria have been met, calculate the RRv provided based on the HSG:

$$(HSG\ A\ or\ B)\ Volume\ Reduction\ WQ_V = WQ_V\ x\ 20\%$$
$$(HSG\ C\ or\ D)\ Volume\ Reduction\ WQ_V = WQ_V\ x\ 10\%$$
$$(HSG\ Modified\ C)\ Volume\ Reduction\ WQ_V = WQ_V\ x\ 15\%$$
$$(HSG\ Modified\ D)\ Volume\ Reduction\ WQ_V = WQ_V\ x\ 12\%$$
$$RR_V\ Provided = WQ_V - Volume\ Reduction\ WQ_V$$

5.3.5.3 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Vegetated Swale (RR-5)

Description: Volume reduction practice designed to convey stormwater at a low velocity to promote treatment and infiltration.

Key Considerations

FEASIBILITY

- Local codes may not allow swales instead of curb gutter or closed drainage pipes. Meet with local officials to discuss waivers for alternative designs.

TREATMENT

- Maximum contributing area is 5 acres
- Maximum WQv peak discharge rate is 3 cfs
- Swale bottom width shall be 2 ft minimum and 6 ft maximum
- Swale side slopes shall be a maximum of 3 horizontal: 1 vertical
- Swale longitudinal slope shall be 0.5% minimum and 4% maximum
- Swale length shall be 100 ft, inclusive of driveway culverts
- During the WQv event, the maximum flow depth is 4 inches with a maximum velocity of 1 fps. Check dam(s) may be required to meet this criteria
- During the 10-year event, the swale shall have a minimum freeboard of 6 inches at a maximum velocity of 5 fps
- The required WQv retention time within the swale is 10 minutes for point discharge at the inlet and 5 minutes for sheet flow or multi-point discharge along the swale length

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- L Capital Cost
- L Maintenance Burden
- L Safety
- M Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- G Phosphorus
- F Nitrogen
- F Metals
- P Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 20% RRv provided in HSG A or B
  10% RRv provided in HSG C or D
  15% RRv provided in Modified HSG C
  12% RRv provided in Modified HSG D

5.3.6 Rain Gardens (RR-6)

A rain garden is intended to manage and treat small volumes of stormwater runoff from impervious surfaces. Treatment is achieved using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. Rain gardens are designed as a passive filtration system without an underdrain system connected to the storm drain system. A stone drainage layer is used for dispersed infiltration. The system consists of an inflow component, a shallow ponding area over a planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism to convey larger rain events to the storm drain system or receiving waters.

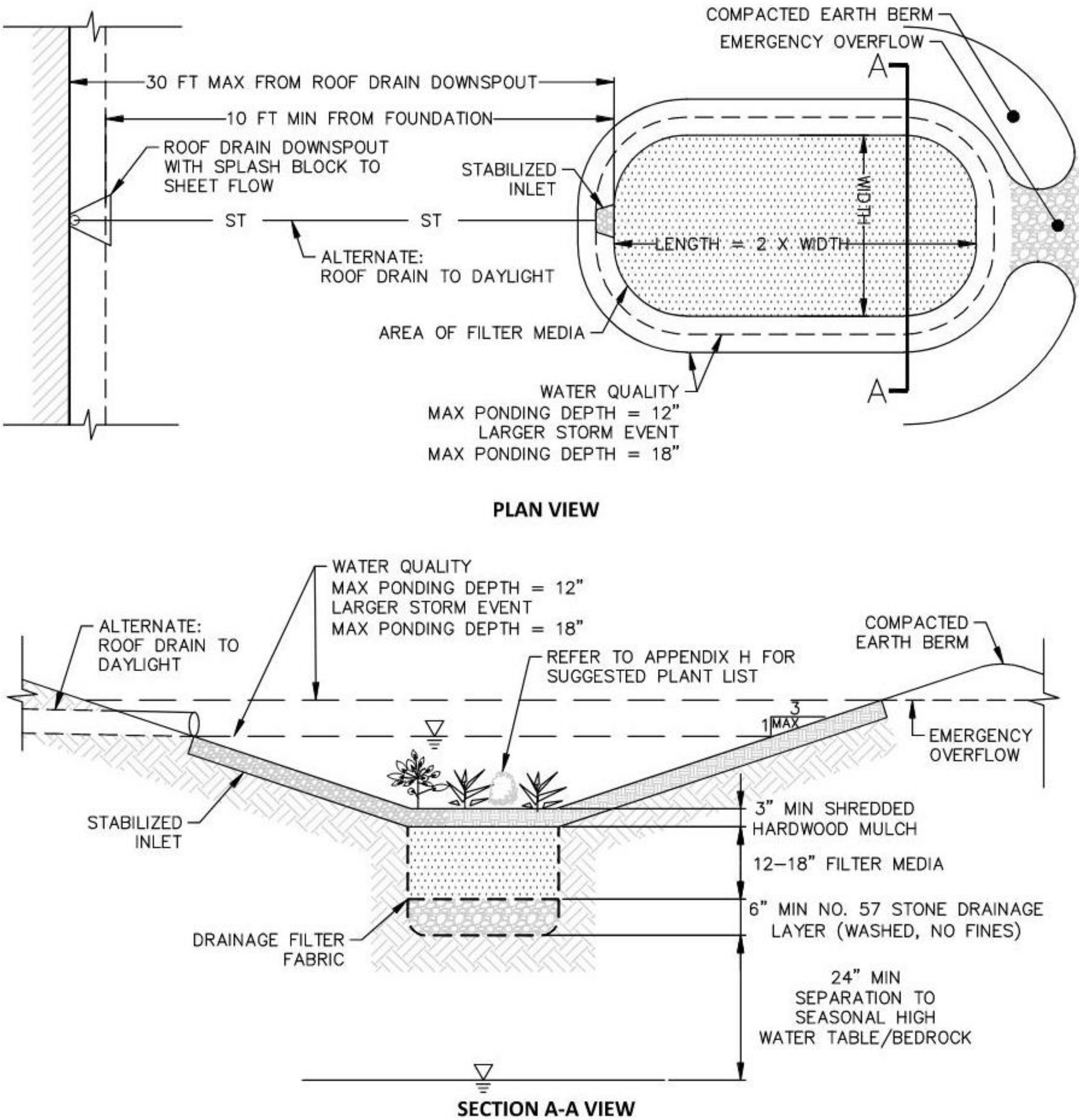


Figure 5.41 Infiltration Rain Garden (RR-6)

A rain garden is intended to manage and treat small volumes of stormwater runoff from impervious surfaces. Treatment is achieved using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. Rain gardens are designed as a passive filtration system with an underdrain system connected to the storm drain system. A stone drainage layer is used for dispersed infiltration. The system consists of an inflow component, a shallow ponding area over a planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism to convey larger rain events to the storm drain system or receiving waters.

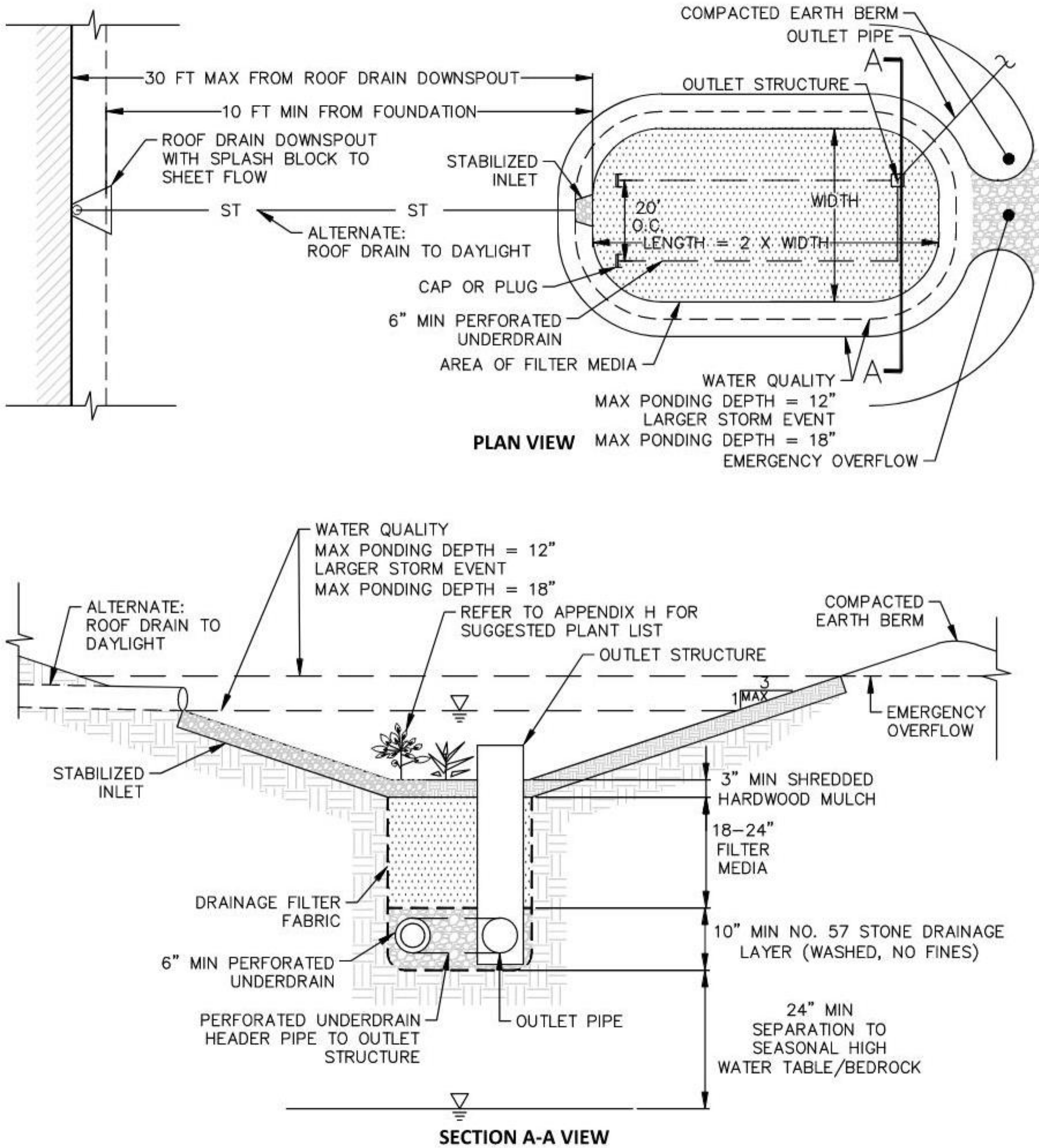


Figure 5.42 Filtration Rain Garden (RR-6)

5.3.6.1 Feasibility

- The practice shall not be located in areas with heavy tree cover.
- The surface area of rain gardens shall be designed and constructed with no longitudinal or lateral slope.
- Infiltration rain gardens shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr, as confirmed by required geotechnical testing (see **Appendix D**). If the infiltration rate is less than 0.50 inch/hr or geotechnical testing is not provided the practice shall be designed as a filtration rain garden with underdrains.
- In areas of known contamination, or if contamination is discovered during excavation, contaminant levels must be evaluated by a qualified professional and state remediation program to determine if infiltration is permitted. Filtering practices can be used to treat stormwater runoff in areas of known or discovered contamination; however, an impermeable liner shall be provided below the stone drainage layer and on all sides.
- The maximum contributing area shall be 1,000 sf per rain garden.
- Rain gardens may be applied as a practice for urban stormwater management (see **Chapter 8**).
- Rain gardens shall be located a maximum of 30 ft from the downspout or impervious area treated. Parking lot or roadway runoff shall not be directed to rain gardens for treatment.
- Rain gardens shall be located down gradient and meet the separation requirements as listed in **Table 5.13**. Vertical separation shall be taken from the bottom of the stone drainage layer. Horizontal separation shall be taken from the maximum water surface elevation (Extreme Flood peak water surface elevation). Where 2 ft separation cannot be met, an impermeable liner shall be provided at the bottom of the stone drainage layer and all sides.

Table 5.13 Rain Garden Minimum Separation Requirements

	Vertical Separation		Horizontal Separation			
Design Variant	**Seasonal High Water Table[1,2]**	**Bedrock[1,2]**	**Structures Without Foundation Waterproofing**	**Structures With Foundation Waterproofing**	**Water Supply Well/Reservoir**	**Septic System[3]**
Infiltration Rain Garden	2 ft	2 ft	10 ft	0 ft	100 ft	50 ft
Filtration Rain Garden	2 ft	2 ft	10 ft	0 ft	100 ft	50 ft

[1]Sound bedrock, fractured bedrock or karst geology as documented by on-site soil testing.
[2]4 ft in sole source aquifers.
[3]Septic systems are inclusive of distribution boxes and absorption fields.

5.3.6.2 Conveyance

- Runoff must enter at the surface of the soil media. Runoff shall be directed to rain gardens at a non-erosive rate through downspouts, shallow swales or short distances of sheet flow. To prevent erosion, an energy dissipater, such as riprap or splash blocks, shall be placed below downspouts or where stormwater enters the rain garden.
- Except where a liner is provided, underdrain systems shall be designed to create an internal water storage using one of the following methods:
    - Provide an upturned elbow, set 10 inches above the bottom of practice;
    - Set the outlet pipe invert, at the outlet control structure, 10 inches above the bottom of practice; or
    - Increase the drainage layer depth to provide 8 inches of stone below the underdrain.
- Outlet(s) shall be designed to ensure non-erosive outlet conditions.
- An emergency spillway or overflow device shall be provided to safely convey stormwater exceeding the Extreme Flood.

5.3.6.3 Treatment

5.3.6.3.1 Design Criteria

- Rain gardens shall consist of the following treatment components:

Table 5.14 Rain Garden Design Specifications

		Infiltration Rain Garden	Filtration Rain Garden
Ponding[1]	**Depth**	12 inch max. (WQv) 18 inch max. (Extreme Flood)	
Surface Layer[1]	**Depth**	3 inch min.	
	Material	Shredded Hardwood Mulch	
Filter Media[1]	**Depth**	12 inches min. 18 inches max.	18 inches min. 24 inches max.
	Material	ASTM C-33 Sand: 60%-75% Topsoil[3]: 25%-40%	
Drainage Layer[1]	**Depth**	6 inches min.	10 inches min.
	Material	AASHTO No. 57, stone washed, no fines	
Drainage Filter Fabric[1]	**Material[2]**	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)	
Impermeable Liner	**Applicability**	N/A	As Required
	Material	12 - 24 inch of clay soil (min. 50% passing #200 sieve and max. permeability 1 x 10^{-5} cm/sec) or 40 mil HDPE geomembrane	
Underdrain	**Applicability**	N/A	Required
	Material	6” perforated PVC or HDPE laid at 0.5% slope min. at 30 ft max. O.C.	

Footnotes:
[1]Required for all Design Variants
[2]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel
[3]Topsoil shall conform to NYSDOT Standard Specification 713-01 for Roadside Mix or Specialty Planting Mix.

5.3.6.3.2 Sizing Criteria

- The required WQv is to be provided above the top of the filter media.
- Infiltration and filtration rain gardens shall be sized based on the principles of Darcy’s Law. Calculate the minimum bottom area:

$$A_f = \frac{WQ_v d_f}{k(h_f + d_f)t_f}$$

Where:

A_f = Surface area of filter bed (sf)
WQ_v = Water Quality Volume (cf)
d_f= Filter bed depth (ft)
k = Permeability flow rate of filter media (1 ft/day)
h_f = Average height of ponding (ft) (0.5 ft max.)
t_f = Design filter bed drain time (2 days)

5.3.6.4 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Rain Garden (RR-6)

Description: Passive filtration system to manage and treat small volumes of stormwater runoff from impervious surfaces. The system consists of an inflow component, a shallow ponding area over a planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism to convey larger rain events to the storm drain system or receiving waters.

Key Considerations

FEASIBILITY

- Surface area of rain gardens shall be designed and constructed with no longitudinal or lateral slope
- Infiltration rain gardens shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr
- Filtration rain gardens shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr, unless underdrains are provided
- Surface area shall not exceed a loading ratio of 5:1 (drainage area to rain garden, where drainage area is assumed to be 100% impervious)
- Maximum contributing area shall be 1,000 sf per rain garden
- Rain gardens shall be located 30 ft maximum from the downspout or impervious area treated
- Parking lot or roadway runoff shall not be directed to rain gardens

CONVEYANCE

- Runoff must enter at the surface of the soil media
- Runoff shall be directed to rain gardens at a non-erosive rate through downspouts, shallow swales o short distances of sheet flow
- Underdrain systems shall be designed to create an internal water storage
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow device shall be provided to safely covey stormwater exceeding the Extreme Flood

TREATMENT

- Maximum ponding depth shall be 12 inches during the WQv event and 18 inches during the Extreme Flood event
- Infiltration rain gardens shall have a 12 inch minimum and 18 inch maximum filter media depth
- Filtration rain gardens shall have an 18 inch minimum and 24 inch maximum filter media depth
- Infiltration rain gardens shall have a 6 inch minimum stone drainage layer
- Filtration rain gardens shall have a 10 inch minimum stone drainage layer
- Underdrains are required for filtration rain gardens

STORMWATER MANAGEMENT SUITABILITY

- ● Water Quality
- ● Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection
- ✓ Runoff Reduction
- ● Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- L Capital Cost
- M Maintenance Burden
- L Safety
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.4***)

- G Phosphorus
- ▞ Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

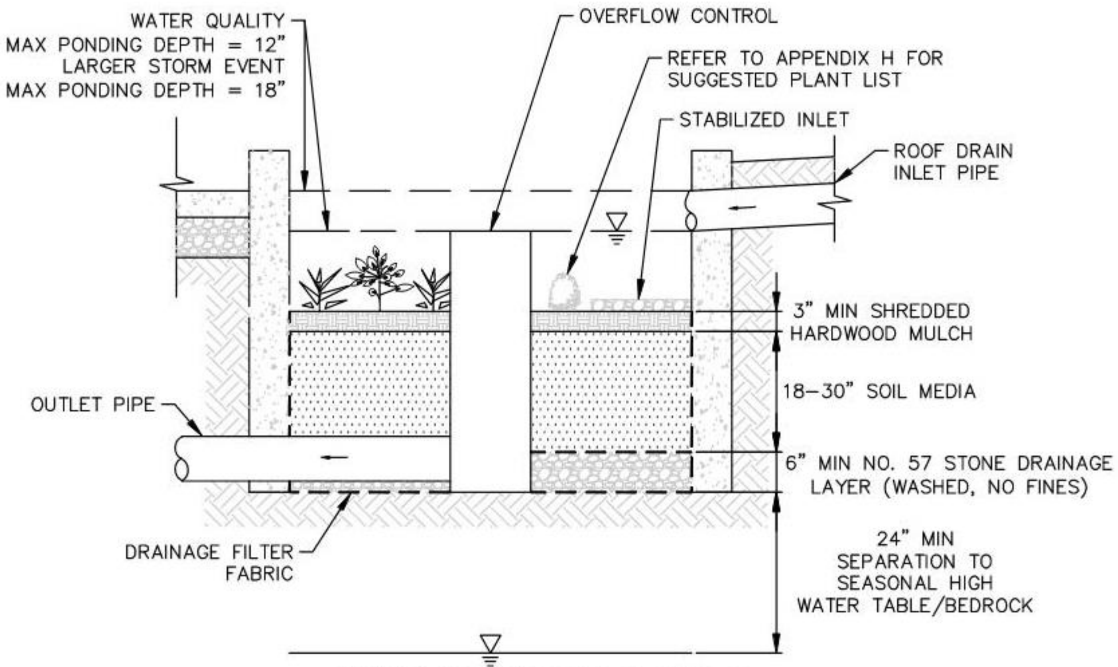
G = Good **F** = Fair **P** = Poor ▞ = Fair/Good

RUNOFF REDUCTION CREDIT

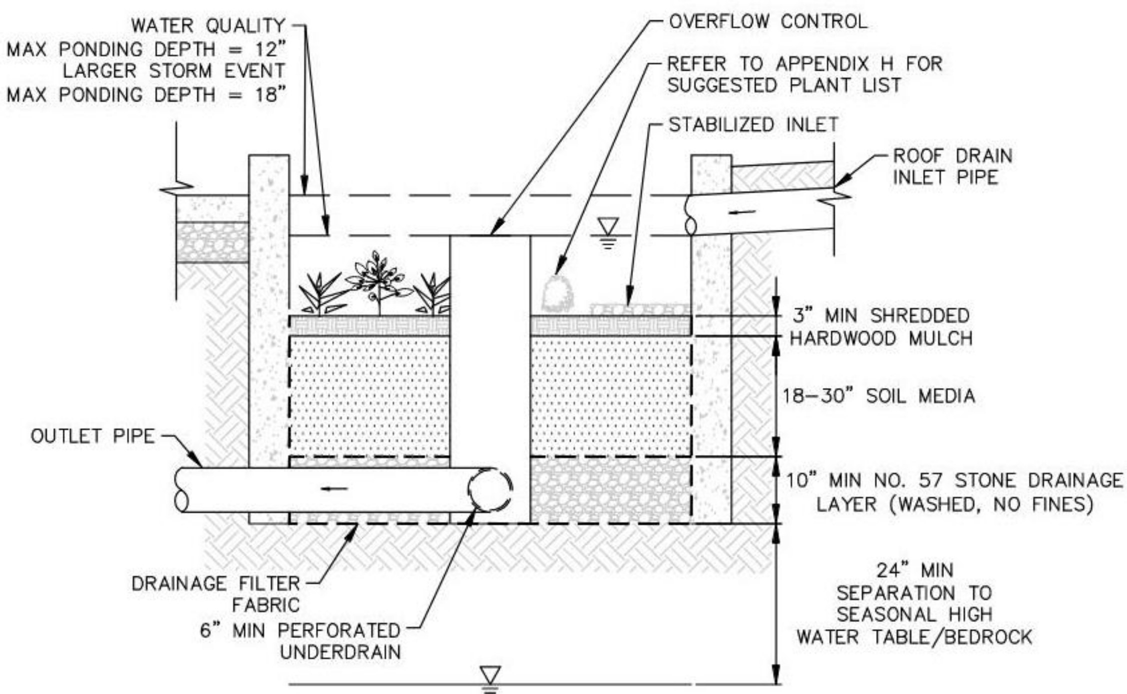
- 100% RRv provided without underdrains
  40% RRv provided with underdrains

5.3.7 Stormwater Planter (RR-7)

A stormwater planter is intended to manage and treat small to moderate volumes of stormwater runoff from adjacent impervious surfaces. Treatment is achieved using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. Stormwater planters are designed as a passive filtration system without an underdrain system or with an underdrain connected to the storm drain system. The system consists of an inflow component, a shallow ponding area over a planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism to convey larger rain events to the storm drain system.



INFILTRATION STORMWATER PLANTER
SECTION VIEW



FILTRATION STORMWATER PLANTER
SECTION VIEW

Figure 5.43 Stormwater Planters (RR-7)

5.3.7.1 Feasibility

- Materials suitable for stormwater planter walls include stone, concrete, brick, clay, plastic, wood, or other durable material. Treated wood shall not be used.
- Stormwater planters shall be designed and constructed with no longitudinal or lateral slope.
- The maximum contributing area shall be 15,000 sf per stormwater planter.
- Stormwater planters may be applied as a practice for urban stormwater management (see **Chapter 8**).
- Parking lot or roadway runoff shall not be directed to stormwater planters for treatment.
- Infiltration stormwater planters shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr, as confirmed by required geotechnical testing (see **Appendix D**).
- Filtration stormwater planters shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr, as confirmed by required geotechnical testing (see **Appendix D**), unless underdrains are provided.
- In areas of known contamination, or if contamination is discovered during excavation, contaminant levels must be evaluated by a qualified professional and state remediation program to determine if infiltration is permitted. Filtering practices can be used to treat stormwater runoff in areas of known or discovered contamination however an impermeable liner shall be provided at bottom of stone drainage layer and all sides.
- Stormwater planters shall be located down gradient and meet the separation requirements as listed in **Table 5.15**. Vertical separation shall be taken from the bottom of the stone drainage layer. Horizontal separation shall be taken from the maximum water surface elevation (Extreme Flood peak water surface elevation). Where 2 ft separation cannot be met, an impermeable liner shall be provided at the bottom of the stone drainage layer and all sides.

Table 5.15 Stormwater Planter Minimum Separation Requirements

	Vertical Separation		Horizontal Separation			
Design Variant	**Seasonal High Water Table[1,2]**	**Bedrock[1,2]**	**Structures Without Foundation Waterproofing**	**Structures With Foundation Waterproofing**	**Water Supply Well/Reservoir**	**Septic System[3]**
Infiltration Stormwater Planter	2 ft	2 ft	10 ft	0 ft	100 ft	50 ft
Filtration Stormwater Planter						

[1]Sound bedrock, fractured bedrock or karst geology as documented by on-site soil testing.
[2]4 ft in sole source aquifers.
[3]Septic systems are inclusive of distribution boxes and absorption fields.

5.3.7.2 Conveyance

- Runoff must enter at the surface of the soil media. Runoff shall be directed to stormwater planters at a non-erosive rate through shallow swales, drainpipe, or short distances of sheet flow. To prevent erosion an energy dissipater, such as riprap or splash blocks, shall be placed below downspouts or where stormwater enters the planter.
- Except where a liner is provided, underdrain systems shall be designed to create an internal water storage using one of the following methods:
    - Provide an upturned elbow, set 10 inches above the bottom of practice (See **Appendix C**)
    - Set the outlet pipe invert, at the outlet control structure, 10 inches above the bottom of practice; or
    - Increase the drainage layer depth to provide 8 inches of stone below the underdrain.

- Outlet(s) shall be designed to ensure non-erosive outlet conditions.
- An emergency spillway or overflow device shall be provided to safely convey stormwater exceeding the Extreme Flood.

5.3.7.3 Treatment

5.3.7.3.1 Design Criteria

- Stormwater planters shall consist of the following treatment components:

Table 5.16 Stormwater Planter Design Specifications

		Infiltration Stormwater Planter	Filtration Stormwater Planter
Ponding[1]	**Depth**	12 inch max. (WQv) 18 inch max. (Extreme Flood)	
Surface Layer[1]	**Depth**	3 inch min.	
	Material	Shredded Hardwood Mulch	
Filter Media[1]	**Depth**	18 inches min. 30 inches max.	
	Material	ASTM C-33 Sand: 60%-75% Topsoil[3]: 25%-40%	
Drainage Layer[1]	**Depth**	6 inches min.	10 inches min.
	Material[2]	AASHTO No. 57 stone, washed, no fines	
Drainage Filter Fabric[1]	**Material**	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)	
Impermeable Liner	**Applicability**	N/A	As Required
	Material	12 - 24 inch of clay soil (min. 50% passing #200 sieve and max. permeability 1×10^{-5} cm/sec) or 40 mil HDPE geomembrane	
Underdrain	**Applicability**	N/A	Required
	Material	6" perforated PVC or HDPE laid at 0.5% slope min. at 30 ft max. O.C.	

Footnotes:
[1]Required for all Design Variants
[2]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel
[3]Topsoil shall conform to NYSDOT Standard Specification 713-01 for Roadside Mix or Specialty Planting Mix.

5.3.7.3.2 Sizing Criteria

- The required WQv is to be provided above the top of the filter media.
- Infiltration and filtration stormwater planters shall be sized based on the principles of Darcy's Law. Calculate the minimum bottom area:

$$A_f = \frac{WQ_v d_f}{k(h_f + d_f)t_f}$$

Where:

A_f = Surface area of filter bed (sf)
WQ_v = Water Quality Volume (cf)
d_f = Filter bed depth (ft)
k = Permeability flow rate of filter media (1 ft/day)
h_f = Average height of ponding (ft) (0.5 ft max.)
t_f = Design filter bed drain time (2 days)

5.3.7.4 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Stormwater Planters (RR-7)

Description: Passive filtration system to manage and treat small to moderate volumes of stormwater runoff from adjacent impervious surfaces. The system consists of an inflow component, a shallow ponding area over a planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism to convey larger rain events to the storm drain system.

Key Considerations

FEASIBILITY

- Stormwater planters shall be designed and constructed with no longitudinal or lateral slope
- Maximum contributing area shall be 15,000 sf per stormwater planter
- Parking lot or roadway runoff shall not be directed to stormwater planters
- Infiltration stormwater planters shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr
- Filtration stormwater planters shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr, unless underdrains are provided

CONVEYANCE

- Runoff must enter at the surface of the soil media
- Runoff shall be directed to stormwater planters at a non-erosive rate through shallow swales, drainpipe, or short distances of sheet flow
- Underdrain systems shall be designed to create an internal water storage
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow device shall be provided to safely convey stormwater exceeding the Extreme Flood

TREATMENT

- Maximum ponding depth shall be 12 inches during the WQv event and 18 inches during the Extreme Flood event
- Stormwater planters shall have a 18 inch minimum and 30 inch maximum filter media depth
- Infiltration stormwater planters shall have a 6 inch minimum stone drainage layer
- Filtration stormwater planters shall have a 10 inch minimum stone drainage layer
- Underdrains are required for filtration stormwater planters

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- L Capital Cost
- M Maintenance Burden
- L Safety
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- G Phosphorus
- ▞ Nitrogen
- NA Metals
- NA Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor ▞ = Fair/Good

**NA = Not enough data available, more research needed*

RUNOFF REDUCTION CREDIT

- 100% RRv provided without underdrains
  40% RRv provided with underdrains

5.3.8 Rainwater Harvesting System (RR-8)

A rainwater harvesting system captures and stores stormwater runoff, to be used for irrigation or filtered and reused for non-potable water activities. The storage system is located either above or below ground and constructed on-site, or delivered as a prefabricated system. The basic components of a rainwater harvesting system include: a watertight storage tank, secure cover, a debris/mosquito screen, a coarse inlet filter with a clean-out, a valve, an overflow pipe, a manhole or access hatch, a drain for cleaning, and an extraction system (tap or pump). Additional features might include: a water level indicator, a bubbler and/or a heater to prevent freezing, a sediment trap, a connector pipe to an additional tank for increased storage, etc. If located above ground, the storage system is typically placed on riser blocks or a gravel pad to aid in gravity drainage of collected runoff and to prevent the accumulation of overflow water around the system. A rain barrel is a small above ground tank, usually between 50 and 100 gallons, that can be installed directly next to a downspout, most commonly for residential applications. A cistern is a larger tank that can be installed above ground or below ground, depending on the structural capacity of the material, most commonly used for commercial applications.

Figure 5.44 Rainwater Harvesting System (RR-8)

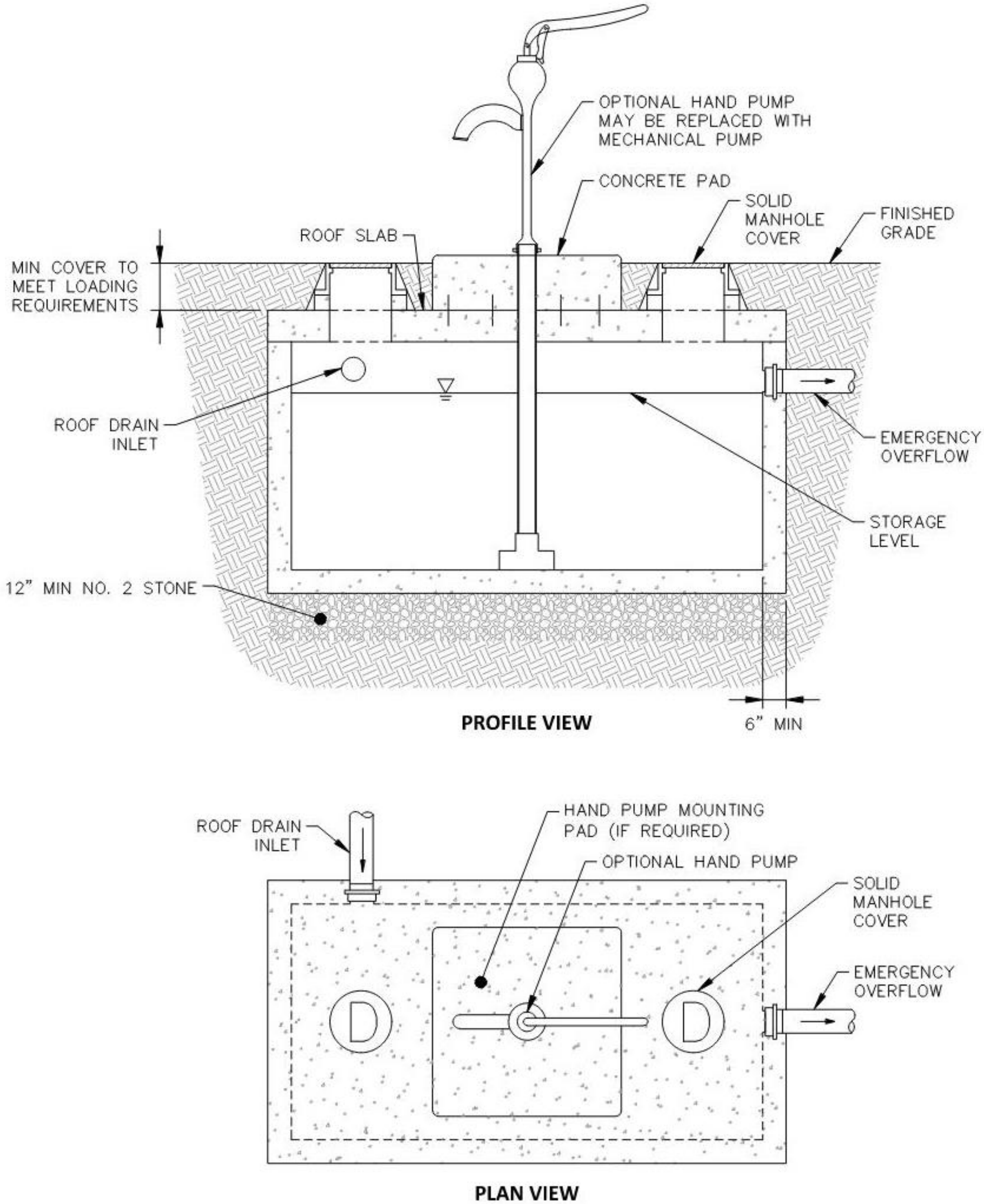


Figure 5.45 Underground Concrete Rainwater Harvesting Tank (RR-8)

5.3.8.1 Feasibility

- The contributing area to rainwater harvesting systems is limited by the calculated water demand established for the proposed reuse application(s). It is critical that a detailed water demand analysis be performed to size the system appropriately.
- RWH systems and the water reuse program shall be actively monitored to ensure that stored water is used on a consistent basis, such that the system is emptied between storm events to allow for subsequent capture of rooftop runoff. If water cannot be utilized in advance of predicted heavy rainfall, then the tank shall be drained to accommodate necessary storage.
- Harvested rainwater shall not be used for drinking or watering food plants. Pipes or storage units shall be clearly marked "not for consumption".
- Systems shall be located indoors, buried below the frost line, or winterized to withstand seasonal temperature fluctuations, unless the system is drained and decommissioned prior to the cold weather season. Winterization methods include perimeter insulation, insulation of the inlet/outlet pipe and lining with heat tape, and/or an aeration system. If the system is used year-round, then the water level in the system must be lowered at the beginning of winter to prevent possible ice damage and provide necessary storage for capturing rooftop runoff from the spring snow melt.
- For small rain barrels, it is recommended that the system be disconnected from the roof gutters and placed indoors during the winter months. In this case, downspout piping must be temporarily extended to the ground and directed away from the structure foundation.
- Consideration shall be given to minimize thermal fluctuations and algae growth by locating system in shade, providing fence or landscape screen, or providing an aeration system.
- The system shall be maintained periodically to ensure effective storage of stormwater while reducing the growth of algae and limiting the potential for mosquito breeding.

5.3.8.2 Conveyance

- The conveyance system shall keep reused stormwater or greywater separate from potable water piping systems.
- An emergency overflow shall be provided to discharge stormwater, if the storage capacity is exceeded, at a non-erosive velocity. The overflow shall be conveyed to a stabilized outfall.

5.3.8.3 Treatment

- To obtain runoff reduction credit, at a minimum, the information below must be provided in the SWPPP:
  - Identify the rooftop area(s) proposed for capture in the rain barrel or cistern collection system;
  - Provide calculations verifying the WQ_v sizing criteria;
  - Identify the material specifications or manufacturer/model for the selected rain barrel or cistern;
  - Identify installation techniques;
  - Identify maintenance requirements for continued operation of the practices;
  - Provide a water budget analysis; and
  - Identify how water will be used to ensure that the system will be available for subsequent rainfall events.

5.3.8.3.1 Sizing and Design Criteria

- Rainwater harvesting (RWH) systems shall be sized to provide adequate storage for the design storm, which is either the Extreme Flood, or a smaller event if a portion of stormwater is bypassed around the system. The storage volume shall be dictated by the water demand, which is the quantity of water that can reasonably be reused for on-site non-potable or irrigation applications.
- A detailed water demand analysis shall be performed to ensure that the system is appropriately sized for periods of consecutive wet-weather or drought conditions. If water is being reused for non-potable applications, a mechanism shall be in-place to provide a supplementary water source, during periods of system maintenance or drought conditions.
- Runoff reduction credit is applied if the storage volume within the system, and correlated water demand, are equal to or greater than the WQ_V.

5.3.8.3.2 Design Example

Base Data

Total tributary area = 3,000 sf

Percent impervious area = 100%

90% Rainfall Event Number = 1.0 inch

- First, compute the required WQ_V, per **Chapter 4**:

$$I = \frac{A_{imp}}{A} \; x \; 100$$

$$I = \frac{0.07 \; acres}{0.07 \; acres} \; x \; 100$$

$$I = 100\%$$

$$R_V = 0.05 + (0.009 \; x \; I)$$

$$R_V = 0.05 + (0.009 \; x \; 100)$$

$$R_V = 0.95$$

$$WQ_V = \frac{P \; x \; R_V \; x \; A}{12}$$

$$WQ_V = \frac{1.00 \; inches \; x \; 0.95 \; x \; 0.07 \; acres}{12}$$

$$\boldsymbol{WQ_V = 0.006 \; af \; (241 \; cf)}$$

- Next compute the required storage volume in gal/cf:

$$Vol = WQ_V \; x \; 7.5 \frac{gal}{cf}$$

$$Vol = 241 \; cf \; x \; 7.5 \frac{gal}{cf}$$

$$\boldsymbol{Vol = 1,808 \; gal}$$

- Therefore, to provide RR_V for the area draining to the practice, a cistern/rain barrel that can hold at least 1,808 gallons is required.

Fact Sheet: Rainwater Harvesting Systems (RR-8)

Description: Practice to capture and store stormwater runoff to be used for irrigation or filtered and reused for non-potable water applications. The storage systems are located either above or below ground and are either constructed on-site or pre-fabricated of various materials. The basic components of a rainwater harvesting system include: a watertight storage container, secure cover, a debris/mosquito screen, a coarse inlet filter with a clean-out, a valve, an overflow pipe, a manhole or access hatch, a drain for cleaning, and an extraction system (tap, pump, or valve).

Key Considerations

FEASIBILITY

- Contributing area is limited by the calculated water demand established for the proposed reuse application(s). A water demand analysis shall be performed to size the system
- Harvested rainwater shall not be used for drinking or watering food plants. Pipes or storage units shall be clearly marked “not for consumption”
- Systems shall be located indoors, buried below the frost line or winterized, unless the system is drained and decommissioned prior to the cold weather season
- Thermal fluctuations and algae growth shall be minimized by locating the system in the shade, providing fence or landscape screening, or providing an aeration system

CONVEYANCE

- Conveyance system shall keep reused stormwater or greywater separate from potable water piping systems.
- Emergency overflow shall be provided to discharge stormwater, if the story capacity is exceeded, at a non-erosive velocity.
- The overflow shall be conveyed to a stabilized outfall

TREATMENT

- Shall be sized to provide adequate storage for the design storm, which is either the Extreme Flood, or a smaller event if a portion of stormwater is bypassed around the system.
- The storm volume shall be dictated by the water demand, which is the quantity of water than can reasonably be reused for on-site non0potable or irrigation applications.
- A detailed water demand analysis shall be performed
- If water is being reused for non-potable applications, a mechanism shall be in-place to provide a supplementary water source, during periods of system maintenance or drought conditions
- Storage volume within the system, and correlated water demand, shall be greater than or equal to the WQv to receive RRv credit

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- H Maintenance Burden
- L Safety
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- G Phosphorus
- ★ Nitrogen
- ★ Metals
- ★ Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor
★ = May provide partial benefits

RUNOFF REDUCTION CREDIT

- 100% RRv provided

5.3.9 Porous Pavement (RR-9)

Porous pavement is a broadly defined group of pervious surfaces that can be applied as an alternative to typical impervious surfaces for road, driveway, sidewalk, or plaza applications. These systems are designed to convey rainfall through the surface into an underlying reservoir that provides structural support, filters pollutants, temporarily stores runoff, and promotes infiltration. Porous pavements are designed to reduce the effective impervious area on a site; thereby reducing design volumes and peak discharge rates. These systems must be designed to support applicable loading, and carefully constructed and maintained to ensure long-term function.

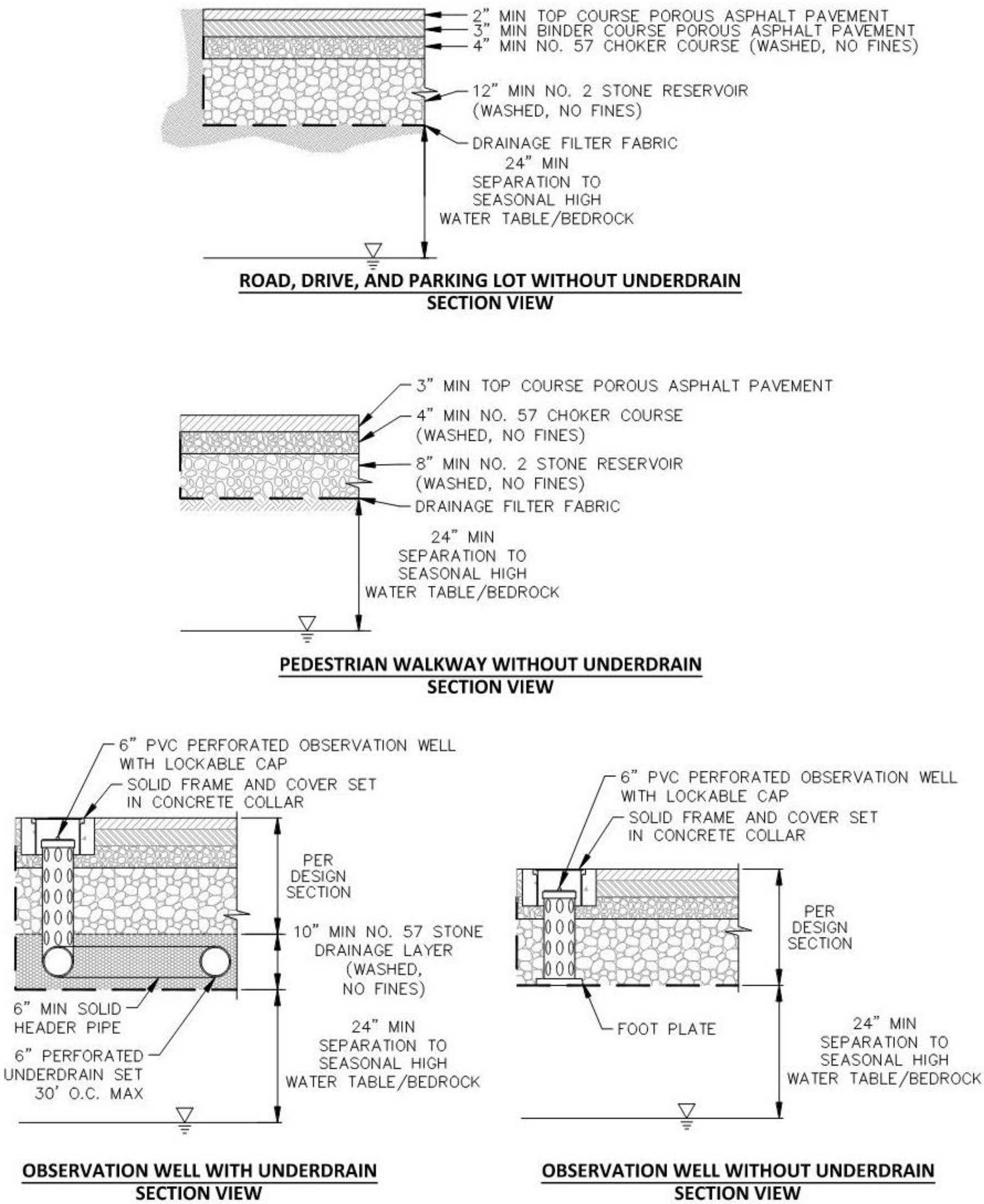
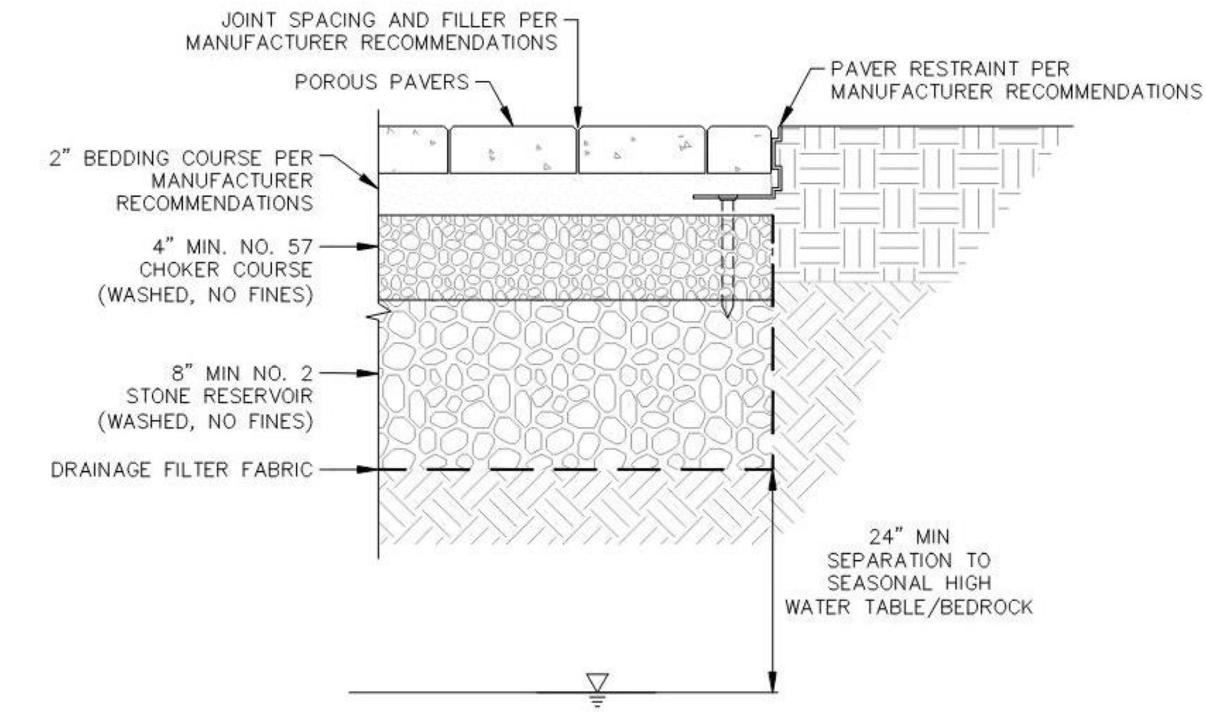
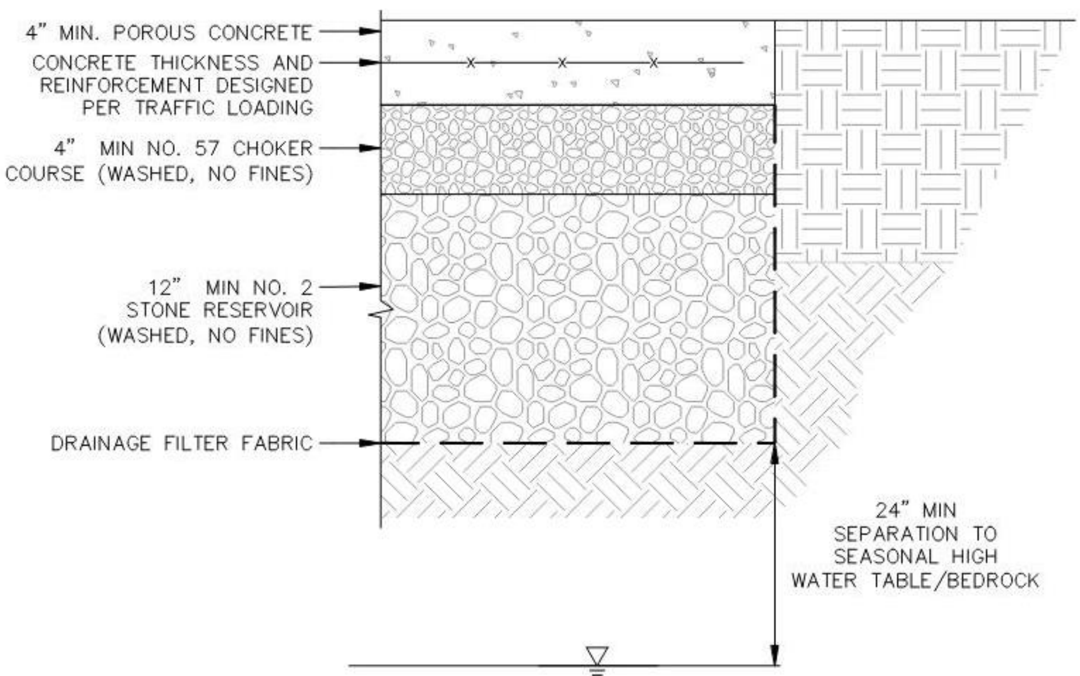


Figure 5.46 Porous Asphalt Pavement (RR-9)



POROUS PAVER WITHOUT UNDERDRAIN SECTION VIEW



POROUS CONCRETE WITHOUT UNDERDRAIN SECTION VIEW

Figure 5.47 Porous Pavers & Concrete (RR-9)

Design Variants

Porous pavement systems can be broken into two general design variants:

1. Porous Pavement Systems - Level 1 (Non-Vehicle Traffic):
    - Designed with a thin filter layer to support light-duty, non-vehicle traffic only.
    - Filter layer is typically sized to accommodate only rainfall that falls directly on the surface of the system.
    - Generally, consist of porous pavers and flexible porous pavement.

2. Porous Pavement Systems - Level 2 (Vehicle Traffic):
    - Designed with a thick filter layer to support heavy-duty structural load and/or accommodate storage of larger storm events.
    - Filter layer must be sized to store the entire WQv for the tributary area and can be sized to accept runoff from adjacent impervious areas.
    - Generally, consist of porous asphalt pavement, porous concrete, traffic-rated porous pavers, porous gravel with stabilization grid/cell, stabilized grass grid/cell and grass block pavers.

5.3.9.1 Feasibility

- Porous pavements shall be used in low dust areas and areas with low vehicle traffic volume. The systems shall be designed with the capability of bearing the anticipated vehicle and traffic loads.
- Porous pavements may be applied as practices for urban stormwater management (see **Chapter 8**).
- Sand and other winter traction materials shall not be used on porous pavement systems.
- Porous pavement systems shall not be used to treat stormwater hotspots.
- In areas of known contamination, or if contamination is discovered during excavation, contaminant levels must be evaluated by a qualified professional and state remediation program to determine if infiltration is permitted
- Slope across the finished surface shall not exceed 10%.
- Slope across the bottom of the stone reservoir shall not exceed 5%. Where surface slope exceeds 5%, the stone reservoir shall be stepped to meet this criteria and underdrains shall be used to distribute runoff through the reservoir evenly.
- The contributing area to porous pavements shall not exceed 3 times the surface area of the porous system.
- Porous pavements shall meet the separation requirements as listed in **Table 5.17**. Vertical separation shall be taken from the bottom of the stone drainage layer. Horizontal separation shall be taken from the closest side of the filter media.

Table 5.17 Porous Pavement Minimum Separation Requirements

	Vertical Separation		Horizontal Separation			
Design Variant	**Seasonal High Water Table[1,2]**	**Bedrock[1,2]**	**Structures Without Foundation Waterproofing**	**Structures With Foundation Waterproofing**	**Water Supply Well/Reservoir**	**Septic System[3]**
Level 1	2 ft	2 ft	10 ft	0 ft	100 ft	50 ft
Level 2			25 ft	10 ft		

[1]Sound bedrock, fractured bedrock or karst geology as documented by on-site soil testing.
[2]4 ft in sole source aquifers.
[3]Septic systems are inclusive of septic tanks, distribution boxes, and absorption fields.

- Porous pavement systems shall not be used unless the underlying soils have an infiltration rate greater than or equal to 0.50 inch/hr, as confirmed by required geotechnical testing (see **Appendix D**).
- Where underlying soils have an infiltration rate less than 2 inch/hr, underdrains shall be provided. If underlying soils have an infiltration rate greater than or equal to 2 inch/hr, underdrains are not required.
- If porous pavement systems are constructed in engineered fill soils, then the following criteria shall be met:
  - In-situ/natural soil layer below the porous pavement system shall have an infiltration rate greater or equal to the engineered fill soils, as determined by geotechnical testing (**Appendix D**);
  - Soils proposed for engineered fill shall be classified as suitable using **Table 5.18** and **Figure 5.48**;
  - Soils proposed for engineered fill shall have a minimum infiltration rate of 0.50 inch/hr and a material gradation similar to the in-situ/natural soils, as determined by geotechnical testing;
  - After placement of engineered fill, permeability testing (**Appendix D**) shall be performed to confirm the actual in place infiltration rate. If engineered fill material requirements are not met, the material shall be removed; and
  - The required vertical separation shall be measured from the existing grade of in-situ/natural soil. Engineered fill soils shall not be used to meet separation requirements.

Table 5.18 Hydrologic Soil Properties Classified by Soil Texture

Soil Texture Class	Hydrologic Soil Group	Minimum Infiltration Rate (inch/hr)	Suitability
Sand	A	8.27	Suitable for engineered fill for infiltration practice design
Loamy sand	A	2.41	
Sandy loam	B	1.02	
Loam	B	0.52	
Silt loam	C	0.27	Not suitable for engineered fill for infiltration practice design
Sandy clay loam	C	0.17	
Clay loam	D	0.09	
Silt clay loam	D	0.06	
Sandy clay	D	0.05	
Silty clay	D	0.04	
Clay	D	0.02	

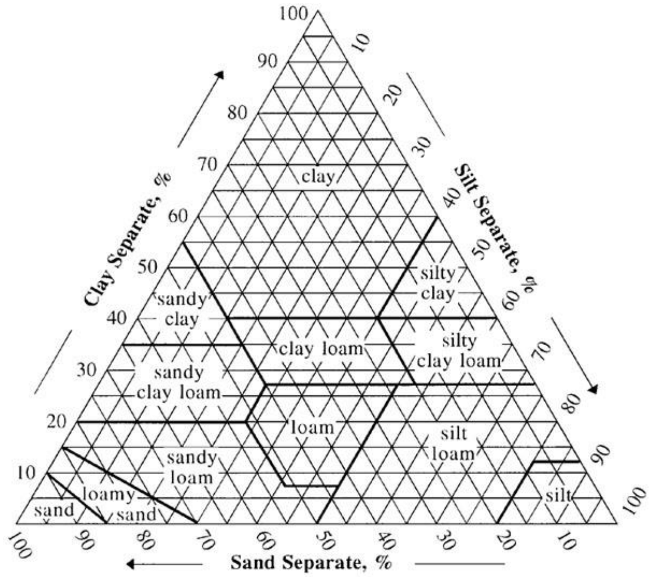


Figure 5.48 USDA Soil Textural Classification

- The following requirements shall be in place, during construction:
  - At the time of installation, extremely high or low temperatures shall be avoided.
  - System areas shall be clearly marked before any site work begins to avoid soil disturbance and compaction. Heavy equipment traffic shall be restricted from areas of existing or proposed porous pavements.
  - Construction of upstream areas shall be completed, and adequate vegetative cover shall be established over the entire tributary pervious area, before draining to the porous pavement system.
  - Subsurface area shall be excavated to the proposed depth of the porous pavement section. Existing subgrade shall not be compacted or subject to excessive construction equipment prior to placement of drainage filter fabric and stone reservoir. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed, and the underlying soils scarified to a minimum depth of 6 inches.
  - Place drainage filter fabric, or acceptable alternative, and stone drainage layer, immediately after approval of subgrade preparation to prevent accumulation of debris or sediment.
- To ensure proper management post-construction, the following activities shall be avoided:
  - Application of sand during winter months.
  - Only use plow or snow removal equipment that is suitable for the specific type of porous pavement.
  - Do not place dumpsters on or immediately upgradient of the pavement surface.
  - Do not store or place dirt, grit, mulch, sand, or other similar materials on or near the pavement surface.

5.3.9.2 Conveyance

- Runoff shall be conveyed to the practice via sheet flow.
- When designing porous pavement systems for treatment of adjacent areas, the stone reservoir shall be designed with additional capacity.

5.3.9.3 Pretreatment

- If pervious adjacent areas discharge to the porous pavement system, then pretreatment shall be provided by grass filter strip and minimum 24 inch wide by 12 inch deep pea gravel diaphragm for that area. Refer to Table 6.2 for pretreatment sizing criteria.

5.3.9.4 Treatment

5.3.9.4.1 Design Criteria

- Depth of stone reservoir shall be designed to account for the total contributing area, traffic load, in-situ soil characteristics, as well as water quality volume and quantity control requirements.

Table 5.19 Porous Pavement Design Specifications

		Porous Asphalt	Porous Concrete	Porous Paver
Surface Layer[1]	**Depth**	Level 1: 3 inch min. Level 2: 2 inch min.	4 inch min.	Per manufacturer specifications
	Material	NYSDOT Approved Top Course Porous Asphalt Pavement Specification	Portland Cement Type I or II (ASTM C 150), No. 8 (ASTM 33), Agg.:Cement Ratio 4:1 to 4.5:1 Water/Cement Ratio 0.28-0.35 Reinforcement designed per traffic loading	Per manufacturer specifications
Binder Course	**Applicability**	Level 1: N/A Level 2: Required	N/A	N/A
	Depth	3 inch min.		
	Material	NYSDOT Approved Binder Course Porous Asphalt Pavement Specification		
Bedding Course	**Applicability**	N/A	N/A	Required
	Depth	2 inch min. or per manufacturer specifications		
	Material	Per manufacturer specifications		
Choker Course[1]	**Depth**	4 inch min.		
	Material	AASHTO No. 57 stone, washed, no fines		
Stone Reservoir[1]	**Depth**	Level 1: 8 inch min. Level 2: 12 inch min. See **Section 5.3.9.4.2**		8 inch min. See **Section 5.3.9.4.2**
	Material	No.2 stone, washed, no fines		
Drainage Layer[1]	**Depth**	10 inch min.		
	Material	AASHTO No. 57 stone, washed, no fines		
Drainage Filter Fabric[1]	**Material[2]**	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)		
Underdrain	**Applicability**	As Required	As Required	As Required
	Material	6" perforated PVC or HDPE laid at 0.50% min. 30 ft max. O.C.		
Observation Well[1]	**Material**	6 inch min. perforated vertical PVC or HDPE pipe, with lockable cap installed flush with the surface.		

Footnotes:
[1]Required for all Design Variants
[2]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel

5.3.9.4.2 Sizing Criteria

- First, calculate the minimum depth of the stone reservoir needed to store the WQ_v storm event. Where underdrains are proposed, the invert of the underdrain shall be set at an elevation above the WQ_v.

$$d_p = \frac{\left(0.95\ x\ R\ x\ \frac{P}{12}\right) - \left(t_f x \frac{f_c}{2}\right)}{\Phi}$$

Where:

d_p = Depth of the stone reservoir (ft);
R (A_c/A_p) = Ratio of contributing area (A_c, including the porous pavement surface), to the porous pavement surface area (A_p);
t_f = Time to fill the reservoir layer (day) – 0.083 days;
P = 90% rainfall event (inches)
f_c = Underlying soils infiltration rate (ft/day); and
Φ = Porosity (assume 0.40)

- Next calculate the required total length of underdrain piping (L_T), then calculate the required number of underdrains (N), rounding up to the nearest whole number:

$$L_T = \frac{A_p}{S_P}$$

$$N = \frac{L_T}{L_U}$$

Where:

S_P = spacing between underdrain pipes (ft on-center) (max. 30 ft)
L_U = design length of underdrain pipe (ft)

Fact Sheet: Porous Pavement (RR-9)

Description: A broadly defined group of pervious surfaces that can be applied as an alternative to typical impervious surfaces for road, driveway, sidewalk, or plaza applications. Designed to convey rainfall through the surface into an underlying reservoir that provides structural support, filters pollutants, temporarily stores runoff, and promotes infiltration.

Key Considerations

FEASIBILITY

- Use in low dust areas and area with low traffic volume
- Shall be designed with the capability of bearing the anticipated vehicle and traffic loads
- Sand and winter traction materials shall not be used
- Maximum slope across the finished surface is 10%
- Maximum slope across the bottom of the stone reservoir is 5%.
- Where surface slope exceeds 5%, the stone reservoir shall be stepped with underdrains
- Minimum separation to bedrock/high water table is 2 ft
- Minimum infiltration rate of underlying soil is 0.50 inch/hr
- Where underlying soils have an infiltration rate less than 2 inch/hr, underdrains shall be provided
- Heavy equipment shall be restricted from area before, during and after construction
- Contributing area to porous pavements shall not exceed 3 times the surface area of the porous system

CONVEYANCE

- Runoff shall enter practice through sheet flow
- When designing systems for treatment of adjacent areas, the stone reservoir shall be designed with additional capacity

PRETREATMENT

- If pervious adjacent areas discharge to the system, a grass filter strip and minimum 24 inch wide by 12 inch deep pea gravel diaphragm shall be provided

TREATMENT

- Depth of stone reservoir shall be designed to account for the total contributing area, traffic load, in-situ soil characteristics and WQv and quantity control requirements
- System shall be designed to ensure the peak water surface elevation for the 10-year, 24-hr design storm does not rise above the stone reservoir
- Where underdrains are provided, the invert of the underdrain shall be set at an elevation above the required WQv storage

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H — Capital Cost
- M — Maintenance Burden
- L — Safety
- NA — Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.4***)

- G — Phosphorus
- F — Nitrogen
- G — Metals
- G — Pathogens
- G — Total Suspended Solids

G = Good **F** = Fair **P** = Poor

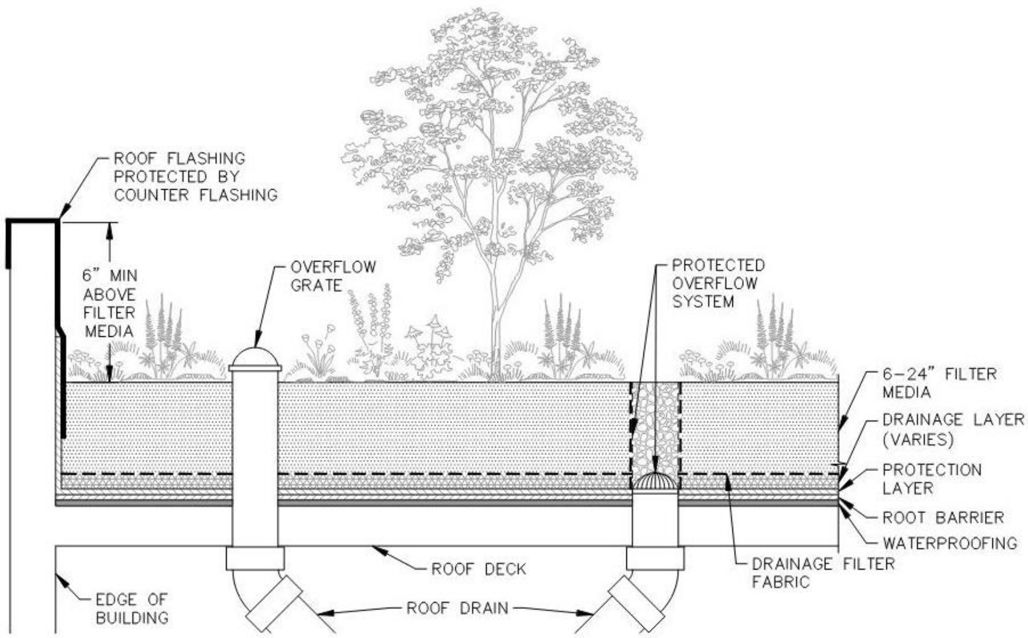
RUNOFF REDUCTION CREDIT

- 100% (*40%*) of the runoff reduction volume provided by this practice without underdrains (*with underdrains*)

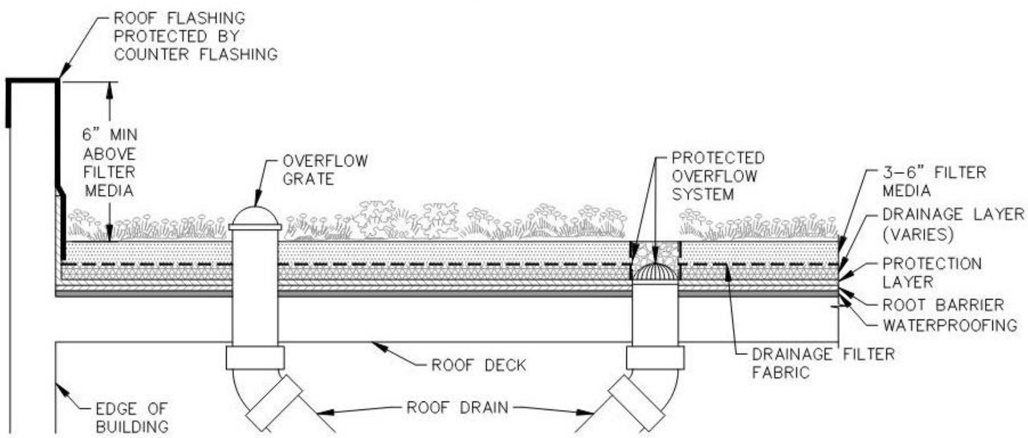
5.3.10 Green Roofs (RR-10)

Green roofs represent an alternative to traditional impervious roof surfaces. These systems consist of underlying waterproofing and drainage materials and an overlying soil media that is designed to support plant growth. Stormwater runoff is captured and temporarily stored in the soil media, where it is subjected to evaporation and transpiration, with any excess runoff conveyed back into the storm drain system.

There are two types of green roof systems: intensive green roof systems and extensive green roof systems. Intensive green roof systems have a thick layer of soil media that supports a diverse plant community that may include trees. Extensive green roof systems have a much thinner layer of soil media that supports a plant community that is comprised primarily of drought tolerant vegetation.



INTENSIVE GREEN ROOF PROFILE VIEW



EXTENSIVE GREEN ROOF PROFILE VIEW

Figure 5.49 Green Roofs (RR-10)

5.3.10.1 Feasibility

- Green roofs shall only be used to replace traditional impervious roof surfaces. They shall not be used to treat any stormwater runoff generated elsewhere on the development site.
- Intensive green roof systems shall be installed on flat or tiered roofs with a maximum slope of 10%.
- Extensive green roof systems shall be installed on flat roofs or roofs with a maximum slope of 10%. If strapping and drainage layer stabilization measures are installed, then the maximum slope shall be increased to 25%.
- The green roof waterproofing system shall have a warranty for repair due to water damage.
- Access to the green roof shall be provided for maintenance.

5.3.10.2 Conveyance

- An overflow system shall be designed to safely convey stormwater runoff out of the drainage layer and off the rooftop when the drainage layer becomes saturated and when larger storm events exceed the storage capacity. Typical overflow systems include:
    - Inlets set slightly above the surface elevation of the green roof;
    - Protected overflow system with the overflow grate set at the drainage layer elevation, covered by No. 2 stone and protected by a ballast guard wrapped in drainage filter fabric; or
    - Scuppers with downspouts.

5.3.10.3 Treatment

5.3.10.3.1 Design Criteria

- A licensed structural engineer must conduct a structural analysis of the system and any structural requirements necessary to support the additional load from soil, vegetation, water, snow and, where applicable, pedestrians.
- As a fire resistance measure, non-vegetative materials, such as stone or pavers shall be installed around all rooftop openings and at the base of all walls that contain openings.
- Green roof systems shall be designed to provide enough storage for the WQv storm event.
- Prior to construction of the drainage system, the waterproofing system must be fully tested to ensure watertight seal over a 24-hour period.

- Green roof systems shall consist of the following treatment components:

Table 5.20 Green Roof System Design Specifications

		Extensive	Intensive
Roof Flashing[1]	**Depth**	6 inches min. above filter media and protect by counter flashing	
Filter Media[1]	**Depth[2]**	3 – 6 inches	6 – 24 inches
	Material	Synthetic moisture retention material, or 80% lightweight inorganic material 15% organic material 5% sand	
Drainage Filter Fabric[1]	**Material[3]**	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)	
Drainage Layer[1]	**Depth**	Governed by the required storage capacity of the green roof system and the structural capacity of the rooftop	
	Material	Synthetic or inorganic materials (e.g. stone, polyethylene tray systems, drainage mat/board, geocomposite drain, flat drain) capable of both retaining water and providing efficient drainage when the layer becomes saturated. or, stone layer washed, no fines with perforated PVC or HDPE underdrain	
Protection Layer[1]	**Material**	A water-permeable, synthetic fiber with resistance to strains induced by point loads or puncture	
Root Barrier[1]	**Material**	Physical root barrier that has not been infused with pesticides, metals or leachable chemicals.	
Waterproofing[1]	**Material**	Synthetic rubber, modified bitumen or thermoplastic sheet membrane	

Footnotes:
[1]Required for all Design Variants
[2]For intensive green roofs, additional depth can be provided if roof is designed to support the load.
[3]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel

5.3.10.3.2 Sizing Criteria

Water Quality

- Calculate provided WQv, using assumed depth of soil media and drainage layer.

$$WQ_v = A_{GR}\ x\ [(D_{SM} x n_{SM}) + (D_{DL} x n_{DL})]$$

Where:

A_{GR} = Green roof surface area (sf)
D_{SM} = Depth of the soil media (ft)
D_{DL} = Depth of the drainage layer (ft)
n_{SM} = Maximum water retention of the soil media, as determined by ASTM E2399 (decimal)
n_{DL} = Maximum water retention of the drainage layer, as determined by ASTM E2393 (decimal)
WQ_v = Water Quality Volume (cf)

Water Quantity

- When designing green roof systems for water quantity, the system can be modeled one of two ways:
  - Assume a curve number of 98 to model the roof as an impervious surface, that discharges to the defined storage volume within the green roof system.
  - Calculate a modified curve number, using the NRCS (SCS) Rainfall-Runoff method, which accounts for storage volume within a green roof system and any additional runoff that would discharge to the design point.

$$CN = \frac{1{,}000}{B + 10}$$

$$B = (d_1 \; x \; \Phi_1) + (d_2 \; x \; \Phi_2) + \ldots (d_X \; x \; \Phi_X)$$

Where:

CN = Curve Number
B = Maximum basin retention (inches)
d = Depth of each component layer (inches)
Φ = Porosity of each component layer (decimal)

5.3.10.4 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Green Roofs (RR-10)

Description: Practice in which stormwater runoff is captured and temporarily stored in the soil media, where it is subjected to evaporation and transpiration, with any excess runoff conveyed back into the storm drain system. These systems consist of underlying waterproofing and drainage materials and an overlying soil media that is designed to support plant growth.

Key Considerations

FEASIBILITY

- Shall only be used to replace traditional impervious roof surfaces and shall not be used to treat any stormwater runoff generated elsewhere on the development site
- Systems shall be installed on flat or tiered roofs with a maximum slope of 10%. If strapping and drainage layer stabilization measures are installed, the maximum slope is increased to 25% for extensive green roof systems
- Waterproofing system shall have a warranty for repair due to water damage
- Access to the green roof shall be provided

CONVEYANCE

- Overflow system shall be designed to safely convey stormwater runoff

TREATMENT

- A licensed structural engineer must conduct a structural analysis of the system and any structural requirements necessary to support the additional load
- A non-vegetative fire resistance measure shall be installed around all rooftop openings and at the base of all walls that contain openings
- Systems shall be designed to provide enough storage for the WQv storm event
- Prior to construction of the drainage system, the waterproofing system must be fully tested to ensure watertight seal over 24-hr period
- Roof flashing shall be providing a minimum of 6 inches above the filter media and protected by counter flashing
- Extensive green roofs shall have a 3 inch minimum and 6 inch maximum filter media depth
- Intensive green roofs shall have a 6 inch minimum and 24 inch maximum filter media depth

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- L Maintenance Burden
- H Safety
- M Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- G Phosphorus
- F Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

5.3.11 Stream Daylighting (RR-11)

Stream Daylight previously culverted/piped streams to restore natural habitats, better attenuate runoff by increasing the storage size, promoting infiltration, and help reduce pollutant loads where feasible and practical. Stream daylighting may be credited as an Impervious Area Reduction practice for redevelopment projects in accordance with **Chapter 9**.

Stream daylighting involves uncovering a stream or a section of a stream that had been artificially enclosed in the past to accommodate development. The original enclosure of rivers and streams often took place in urbanized areas through the use of large culvert operations that often integrated the storm sewer system and combined sanitary sewers. The daylighting operation, therefore, often requires overhauls or updating of storm-drain systems and re-establishing stream banks where culverts once existed. When the operation is complete, what was once a linear pipe of heavily polluted water can become a meandering stream with dramatic improvements to both aesthetics and water quality.

Where combined sewer overflow (CSO) separation and other upgrades to storm-sewer systems are part of a daylighting project, significant water-quality improvements can be expected during wet-weather events. Also, as ultraviolet radiation is one of the most effective ways to eliminate pathogens in water, exposing these streams to sunlight could significantly decrease pathogen counts in the surface water.

Figure 5.50 Before and after daylighting Blackberry Creek in Berkeley, CA (Source: Stormwater Magazine, Nov/Dec 2001)

Stream daylighting can play an integral role in neighborhood restoration and site redevelopment efforts. Aside from improvements to infrastructure, stream daylighting can restore floodplain and aquatic habitat areas, reduce runoff velocities and be integrated into pedestrian walkway or bike- path design.

5.3.11.1 Feasibility

Limitations

- Daylighting a stream can be expensive - *Costs for daylighting streams are often comparable to costs for replacing culverts*
- Maintenance of daylighted stream areas can be intensive during the first years the stream is established –
- Finding the original stream channel may be difficult – examine historic records, soils, and up and *downstream channel characteristics.*
- Political backing and public support is more difficult for daylighting streams than for surface restoration because the culvert is not seen – Provide proper public education and outreach about the benefits and how safety issues will be addressed.

Applications

- Stream daylighting can generally be applied most successfully to sites with considerable open or otherwise vacant space. This space is required to: 1) Potentially reposition the stream in its natural stream bed; 2) Accommodate the meandering that will be required if a natural channel is being designed and 3) Provide adjacent floodplain area to store water in large storm-flow situations.
- Consider daylighting when a culvert replacement is scheduled
- Restore historic drainage patterns by removing closed drainage systems and constructing stabilized, vegetated streams, see **Figure 5.50**.
- Carefully examine flooding potential, utility impacts and/or prior contaminated sites.
- Consider runoff pretreatment and erosion potential of restored streams/rivers.

5.3.11.2 Treatment

5.3.11.2.1 Sizing and Design Criteria

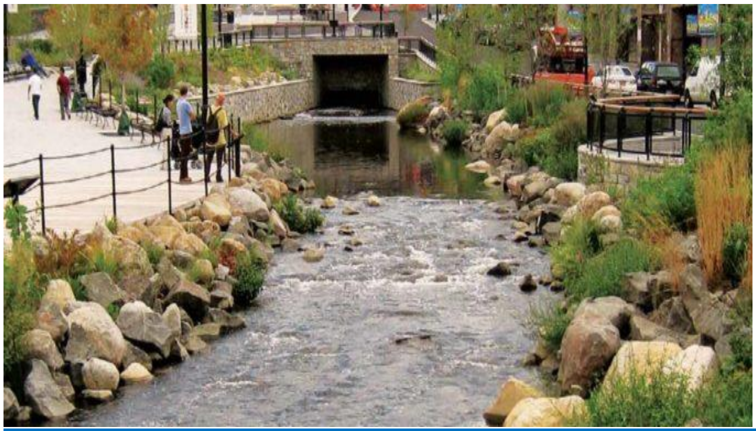
Stream daylighting is applicable only to redevelopment projects as an impervious area reduction type practice in accordance with **Chapter 9**. The sizing of the stream channel must, at minimum, equal or exceed the existing drainage capacity of the piped drainage system.

The impervious area reduction credited under **Chapter 9** would be equal to the area of imperviousness removed for streams buried and piped under impervious areas. For streams buried and piped under pervious areas, the impervious area reduction credited would be equal to the planar area of the bed and banks of the daylighted stream.

5.3.11.3 Landscaping

For planting guidance for stormwater management facilities, refer to **Chapter 11**.

Fact Sheet: Stream Daylighting



Description: A practice involving uncovering a stream or a section of a stream that had been artificially enclosed in the past to accommodate development. Stream daylighting previously culverted/piped streams restores natural habitats, better attenuates runoff, promotes infiltration, and helps reduce pollutant loads.

(Photo Source: Harford County, Maryland)

Key Considerations

FEASIBILITY

- Finding original stream channel can be difficult
- Consider this option when a culvert replacement is scheduled
- Consider: flood potential, proper contaminated sites, erosion potential

TREATMENT

- Only applicable as an impervious area reduction for redevelopment projects
- Sizing of channel must meet or exceed existing drainage capacity

STORMWATER MANAGEMENT SUITABILITY

- Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- Treatment of Hotspots
- Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- H Maintenance Burden
- H Safety
- M Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.4***)

- Phosphorus
- Nitrogen
- Metals
- Pathogens
- Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% impervious area reduction towards RRv

Chapter 6: Standard Stormwater Management Practices

This Chapter outlines performance criteria for five groups of standard stormwater management practices (SMPs) to meet water quality treatment goals. These include ponds, wetlands, infiltration practices, filtering practices and open channel systems. Each group of SMPs have six performance criteria:

1. *Feasibility:* Identify site considerations that may restrict use of a practice.
2. *Conveyance:* Convey runoff to and from the practice in a manner that is safe, minimizes erosion, maximizes pretreatment, mimics existing hydrology to the greatest extent practical, and prevents disruption to natural channels. Convey runoff through the practice in a manner that promotes maximum treatment, and detention/infiltration.
3. *Pretreatment:* Trap coarse sediments and debris before they enter the practice, to reduce the maintenance burden and ensure long-term performance of the practice.
4. *Treatment:* Provide water quality treatment through design elements that maximize pollutant removal.
5. *Landscaping:* Reduce secondary environmental impacts through landscaping design that minimizes disturbance of natural stream systems, complies with environmental regulations, and enhances the pollutant removal and aesthetic value of the practice. For planting guidance for stormwater management facilities, refer to **Chapter 11**.
6. *Maintenance:* Preserve the long-term performance of a practice through regular inspection and maintenance activities, as well as design elements that ease the maintenance burden. Refer to **Chapter 12** for guidance on inspection and maintenance activities.

IMPORTANT NOTES:

1. THIS CHAPTER PRESENTS REQUIRED PERFORMANCE CRITERIA BY USE OF DEFINITIVE LANGUAGE LIKE “SHALL” OR “MUST,” WHICH MEANS THAT THOSE CRITERIA SHALL BE USED IN ALL APPLICATIONS.
2. FACT SHEETS FOR EACH DESIGN VARIANT WITHIN THE FIVE SMP GROUPS ARE PRESENTED AT THE END OF EACH SECTION AND SUMMARIZE THE KEY PERFORMANCE CRITERIA FOR EACH PRACTICE. THESE FACT SHEETS ARE FOR REFERENCE AND MAY NOT BE INCLUSIVE OF ALL REQUIREMENTS.
3. ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* (**APPENDIX A**) AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY SECTION. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER PONDS OR WETLANDS CREATED BY A DAM.

The following table allows designers to evaluate each standard SMP and determine which practice(s) are feasible for application to a specific site. Feasibility is based on thresholds that shall be met for four key site conditions:

1. *Soil Permeability*: This column outlines the permeability requirements for underlying soils at the location of a proposed SMP. The designer should perform an initial investigation of the NRCS hydrologic soil groups at the site to determine soil characteristics. Please note that more detailed geotechnical tests are usually required, in accordance with **Appendix D**.
2. *Depth to Seasonal High Water Table*: This column indicates the minimum depth to the seasonally high water table from the bottom elevation of the SMP section.
3. *Contributing Area*: This column indicates the minimum or maximum contributing area that is considered optimal for a practice. The minimum contributing area shall not be reduced, and the maximum shall not be increased, except where specific design criteria are met or additional engineering analysis is performed to support an adjusted area.
4. *Max Site Slope*: This column indicates the preferred maximum slope of the area proposed for installation of a practice. Existing slopes may exceed these values with proper engineering to ensure slope stability and non-erosive runoff velocities from the contributing area.

Table 6.1 Standard SMP Feasibility Matrix

SMP Group	SMP Design	Soil Permeability	Separation to Water Table (ft)	Contributing Area (acres)	Max Site Slope
Ponds	Micropool ED	fc ≤0.014 inch/hr, unless impermeable liner provided (see **Section 6.1.4.1**)	0[1,2]	10 (min)[4]	15%
	Wet Pond			25 (min)[4]	
	Wet ED Pond				
	Multiple Pond				
Wetlands	Shallow Wetland	fc ≤0.014 inch/hr, unless impermeable liner provided (see **Section 6.2.4.1)**	0[1,2]	25 (min)	15%
	ED Shallow Wetland				
	Pond/Wetland System				
	Pocket Wetland		0[2]	5 (min)	
	Gravel Wetland		0[1,2]	5 (max)	
Infiltration	Infiltration Trench	f_c > 0.5 inch/hr	2[3]	5 (max)	15%
	Infiltration Basin			Varies (10/25/50 max)	
	Dry Well			1 (max)	
	Underground Infiltration			10 (max)	
Filters	Surface Sand Filter	No Restriction	2	10 (max)	10%
	Underground Sand Filter			2 (max)	
	Perimeter Sand Filter				
	Infiltration Bioretention	f_c > 0.5 inch/hr		5 (max)	
	Filtration Bioretention	No Restriction			
	Bioslope			150 ft (max)	3:1 (h:v)
Open Channels	Dry Swale	No Restriction	2	5 (max)	4% longitudinal
	Wet Swale		below water table		

[1] When treating stormwater hotspots, increase separation to 2 ft.

[2] When located in a sole source aquifer, increase separation to 2 ft.

[3] When located in a sole source aquifer, increase separation to 4 ft.

[4] Minimum contributing area for ponds can be reduced if a water balance analysis is performed in accordance with **Section 6.1.4.2**.

Section 6.1 Stormwater Ponds

Stormwater ponds are practices that have either a permanent pool of water, or a combination of a permanent pool and extended detention, and some elements of a shallow marsh with storage equivalent to the entire WQ_v. There are four design variants, which include:

P-1	Micropool Extended Detention Pond	(**Figure 6.1**)
P-2	Wet Pond	(**Figure 6.2**)
P-3	Wet Extended Detention Pond	(**Figure 6.3**)
P-4	Multiple Pond System	(**Figure 6.4**)

Refer to the **Fact Sheets** at the end of this section for key considerations of each pond design variant, including performance criteria, practice suitability, implementation considerations, pollutant removal capability, and runoff reduction credit.

IMPORTANT NOTES:

1. STORMWATER PONDS DESIGNED ACCORDING TO THIS MANUAL MAY ACT AS A COMMUNITY AMMENITY, AND MAY PROVIDE SOME LEVEL OF HABITAT VALUE. HOWEVER, THEY CANNOT BE ANTICIPATED TO FUNCTION AS NATURAL LAKES OR PONDS. TO ENSURE LONG-TERM FUNCTION AS INTENDED, THEY MUST BE PROPERLY MAINTAINED.
2. DRY EXTENDED DETENTION PONDS (WITHOUT A PERMANENT POOL) ARE NOT CONSIDERED AN ACCEPTABLE OPTION FOR MEETING WATER QUALITY TREATMENT OBJECTIVES.

Micropool Extended Detention Pond (P-1)

A micropool extended detention pond is a variation of a wet extended detention pond, where a small micropool is maintained at the outlet of the pond. The micropool prevents resuspension of previously settled sediments and prevents clogging of the low flow orifice. The outlet structure is sized to detain the water quality volume within the pond for 24-hrs, or 12-hrs when discharging to trout waters.

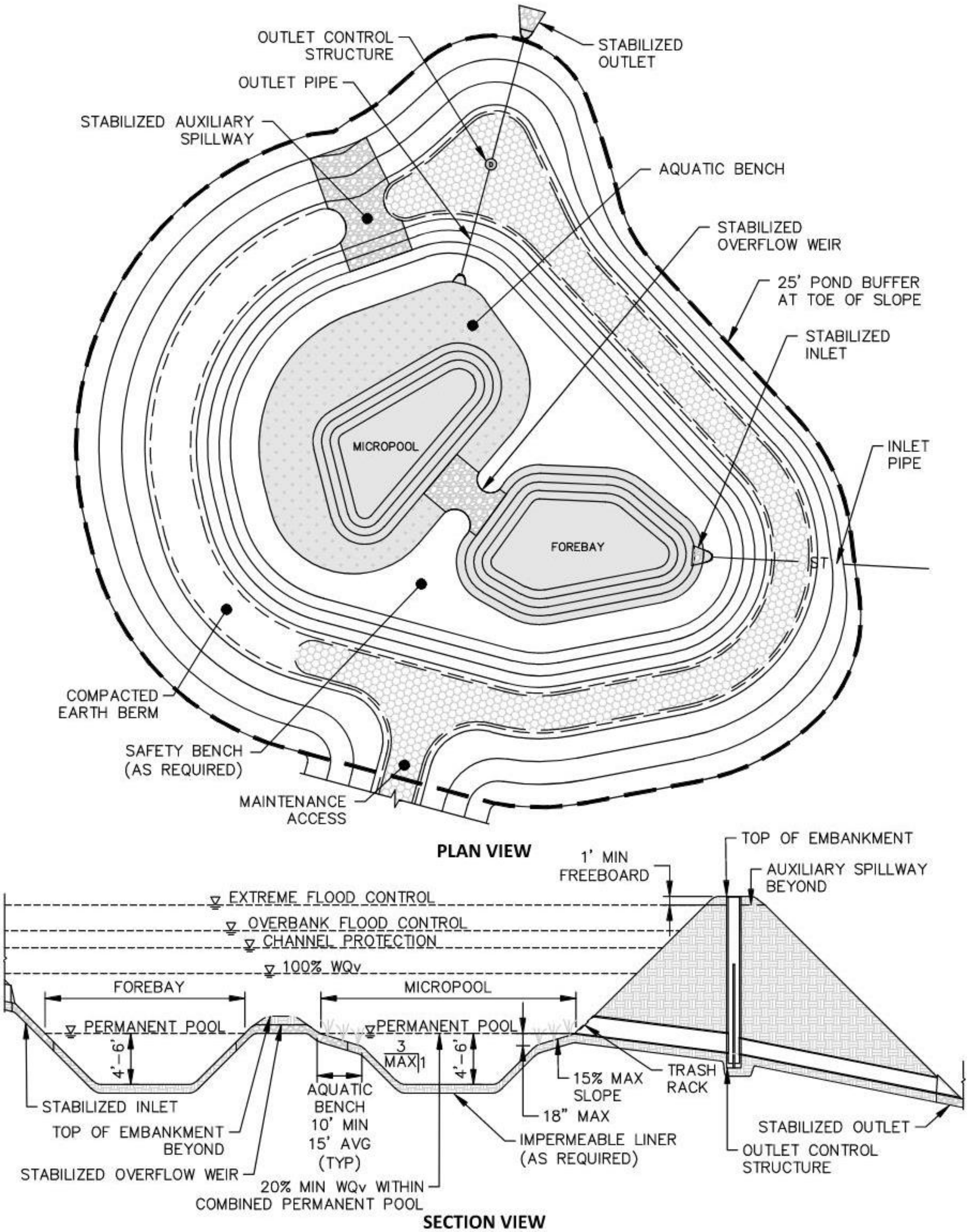


Figure 6.1 Micropool Extended Detention Pond (P-1)

Wet Pond (P-2)

A wet pond is a stormwater basin constructed of a permanent pool of water having a storage volume equal to the water quality volume. Stormwater runoff displaces the water already present in the pool. Temporary storage can be provided above the permanent pool elevation for larger flows.

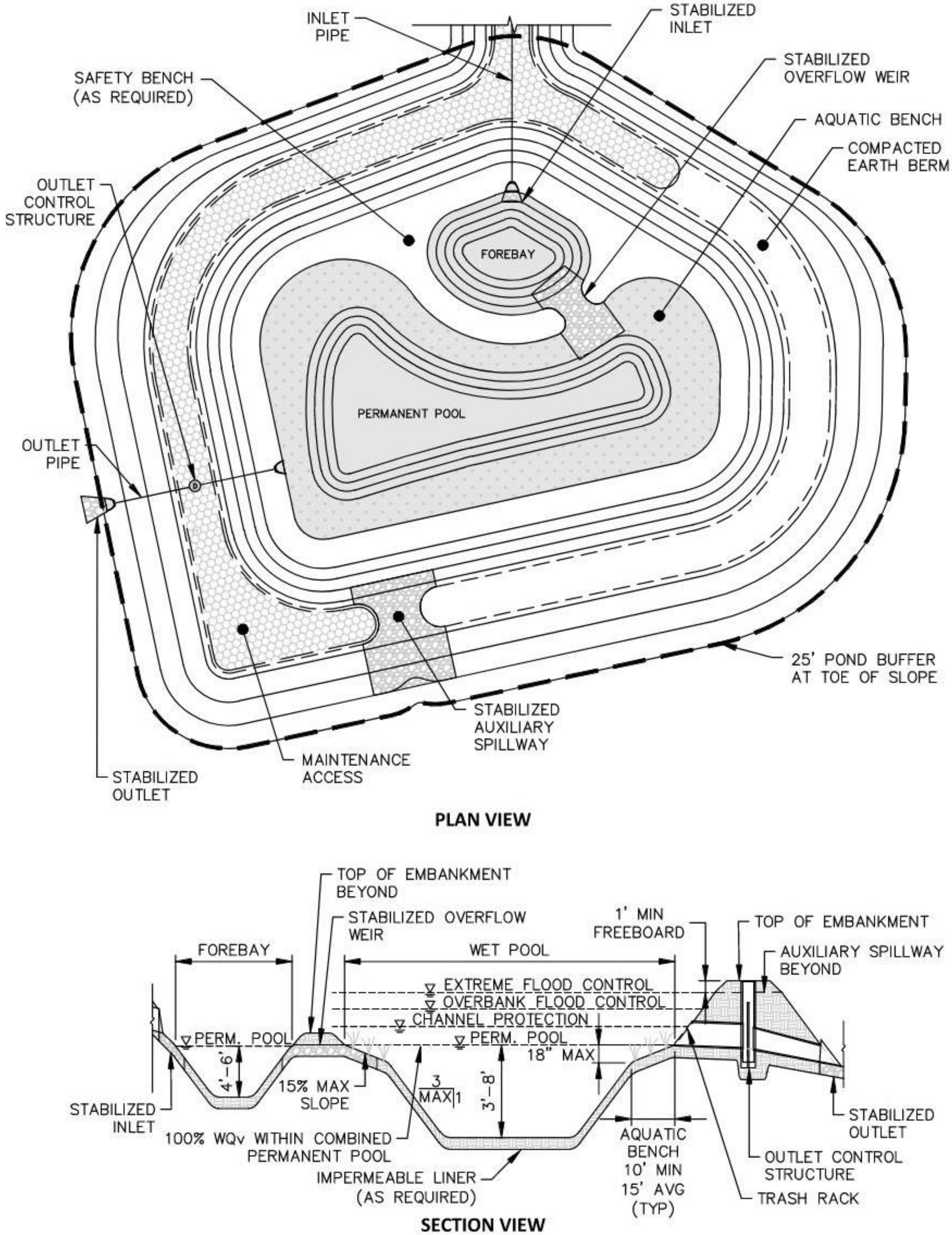


Figure 6.2 Wet Pond (P-2)

Wet Extended Detention Pond (P-3)

A wet extended detention pond is a wet pond where the water quality volume is split evenly between the permanent pool and extended detention storage above the permanent pool. During storm events, water is detained above the permanent pool and released over time.

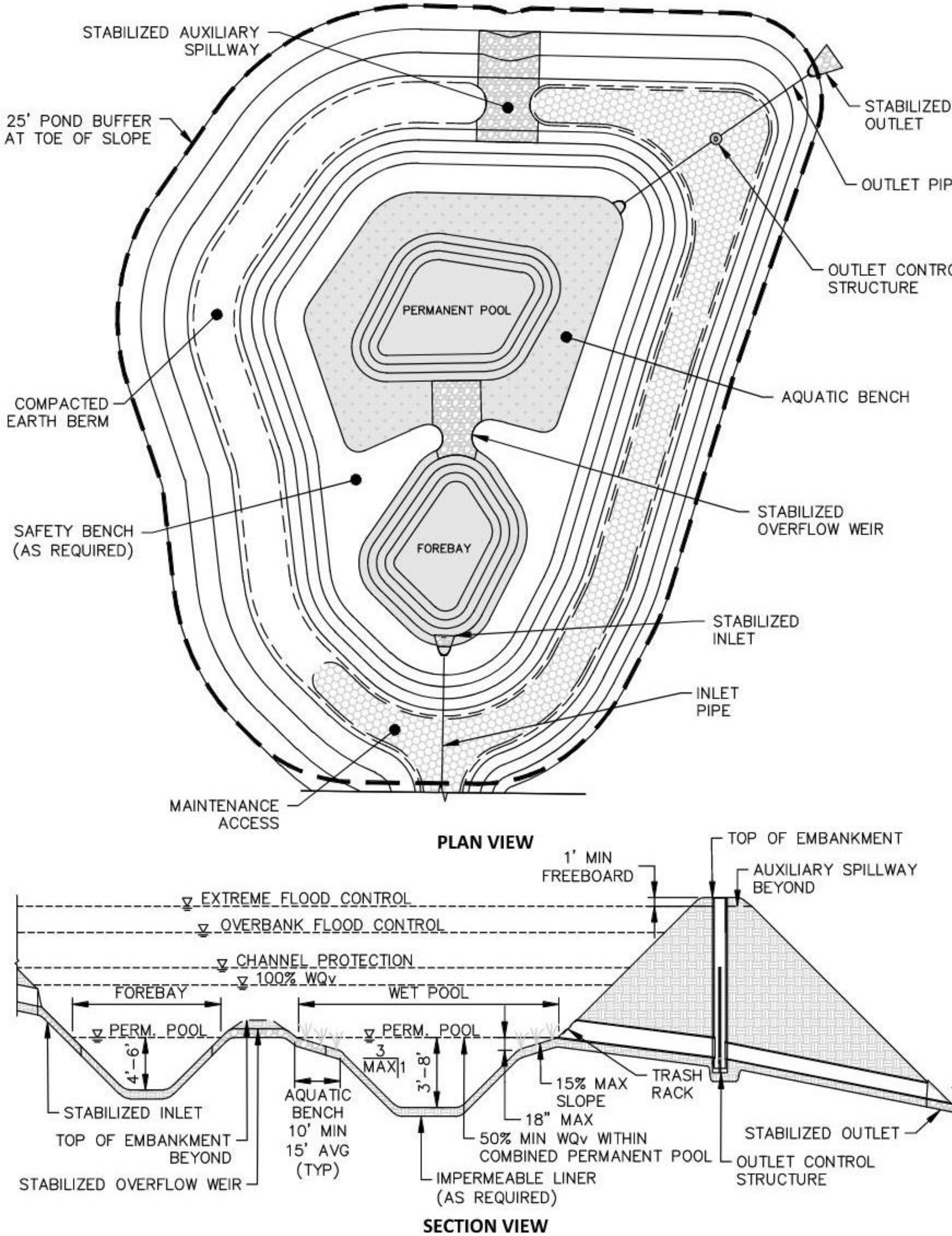


Figure 6.3 Wet Extended Detention Pond (P-3)

Multiple Pond System (P-4)

Multiple pond systems consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The multiple cells create high surface area to volume ratios, complex microtopography, longer pollutant removal pathways, and improved downstream protection.

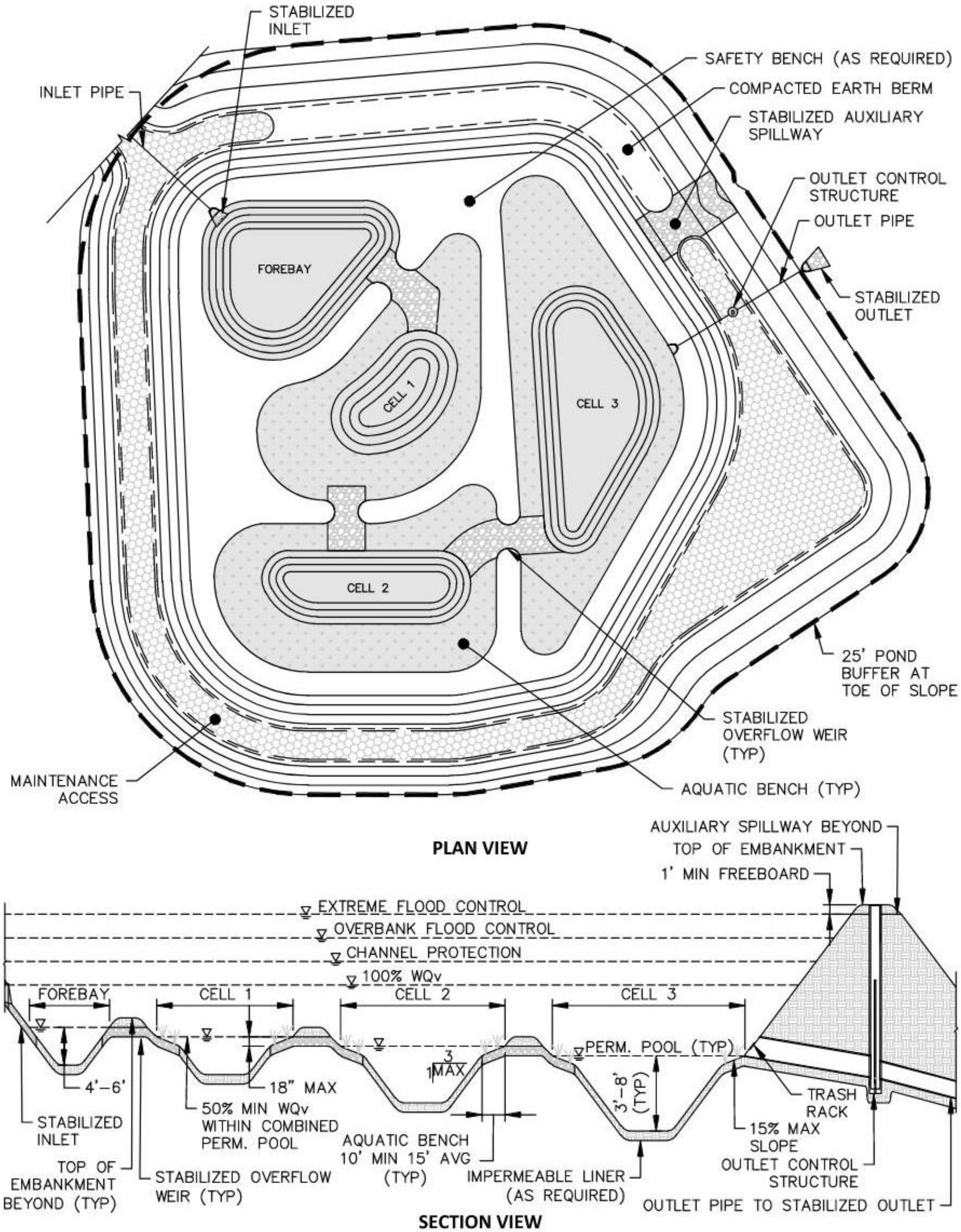


Figure 6.4 Multiple Pond System (P-4)

6.1.1 Feasibility

- Stormwater ponds shall not be located within jurisdictional waters, including wetlands.
- Evaluate the site to determine the Hazard Class, and to determine what design elements are required to ensure dam safety (see **Appendix A**). For the most recent copy of this document, contact the New York State Department of Environmental Conservation, Dam Safety Division, at: 518-402-8151.
- Stormwater ponds shall not be located in areas with natural slopes greater than 15%, unless a slope stability analysis is performed by a qualified geotechnical engineer.
- Stormwater ponds shall be located in areas with underlying soils that have an infiltration rate less than or equal to 0.014 inch/hr, unless an impermeable liner is provided in accordance with **Section 6.1.4.1**.
- Stormwater ponds shall meet the minimum separation requirements listed in **Table 6.2** below. Vertical separations shall be taken from the bottom of pond. Horizontal separations shall be taken from the maximum water surface elevation (Extreme Flood peak water surface elevation) of the pond.

Table 6.2 Stormwater Pond Practice Minimum Separation Requirements

	Vertical Separation		Horizontal Separation				
Design Variant	**Seasonal High Water Table[1,2]**	**Sound Bedrock[1]**	**Structures Without Foundation Waterproofing[4]**	**Structures With Foundation Waterproofing[4]**	**Water Supply Well/ Reservoir**	**Septic System[3,4]**	**Sanitary Sewer Main**
Micropool Extended Detention Pond (P-1)	0 ft	0 ft	25 ft	25 ft	25 ft	50 ft	25 ft
Wet Pond (P-2)							
Wet Extended Detention Pond (P-3)							
Multiple Pond System (P-4)							

[1] As documented by on-site geotechnical testing.
[2] Separation shall be increased to 2 ft in sole source aquifers or when treating stormwater hotspots.
[3] Septic systems are inclusive of septic tanks, distribution boxes, and absorption fields.
[4] Ponds shall be located downgradient of structures and septic systems.

- Design P-1 shall have a minimum contributing area of 10 acres. The minimum contributing area can be reduced to 5 acres, if a water balance calculation is performed in accordance with **Section 6.1.4.2**.
- Designs P-2, P-3, and P-4 shall have a minimum contributing area of 25 acres. The minimum contributing area can be reduced to 10 acres, if a water balance calculation is performed in accordance with **Section 6.1.4.2**.
- The use of stormwater ponds (with the exception of design P-1) on trout waters is strongly discouraged, as available evidence suggests that these practices can increase stream temperatures. However, designs P-2, P-3, and P-4 can be used on trout waters if designed off-line and under shade to minimize thermal impacts.
- For design P-1 the outlet structure is sized to detain the water quality volume for 24-hrs, or 12-hrs when discharging to trout waters.

6.1.2 Conveyance

Inlet Protection

- Inlet points must be stabilized to ensure non-erosive conditions. If riprap or other channel liner is used, it shall extend 1 ft below the permanent pool elevation.
- Inlet pipe(s) shall have a slope no flatter than 0.5% (1% for pipes smaller than 12 inches diameter) and inverts shall be located at or above the permanent pool elevation.

Outlet Structure/Outfall Protection

- A controlled outlet shall be provided for each pond, using one of the following methods:
  - An outlet structure located within the embankment, with a pipe invert set at the permanent pool elevation that extends downward to the structure;
  - An outlet structure located within the embankment, with a submerged reverse-slope pipe that extends downward from the structure to an inflow invert set 1 ft minimum below the permanent pool elevation and 1 ft minimum above the bottom of the pond;
  - An outlet structure located within the embankment, with an adequately sized downward elbow with an extension that extends 1 ft below the permanent pool elevation;
  - An outlet structure located partially within the embankment, with outlet openings in the face of the structure; or
- Where a CPv control orifice is provided (See **Section 4.6** for CPv requirements and waivers), one of the following methods shall be applied:
  - Minimum 3 inch low flow orifice installed in an internal weir plate within the outlet structure with acceptable external trash rack or orifice protection (See **Appendix C** for details of a low flow orifice and trash rack options).
  - Minimum 3 inch low flow external orifice installed in the face of the outlet structure (See **Appendix C** for details of a low flow orifice and trash rack options). Orifice protection shall be provided.
- An auxiliary spillway shall be provided to safely convey stormwater exceeding the Extreme Flood.
- The auxiliary spillway shall not be located in fill, where possible.
- A stilling basin, outlet protection, level spreader, or other energy dissipator shall be used to reduce flow velocities from the principal spillway to non-erosive velocities at the discharge. (See **Appendix G** for a table of erosive velocities for grass and soil).
- If a pond daylights to a channel or stream, care shall be taken to minimize tree clearing along the downstream flow path. Prior to tree clearing next to a stream or wetland, all necessary permits shall be obtained. Excessive use of riprap shall be avoided to reduce channel or stream warming. The channel immediately below a pond outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance.

Non-clogging Low Flow Orifice

- A 3 inch minimum low flow orifice shall be provided, with acceptable external trash rack or internal orifice protection (See **Appendix C** for details of a low flow orifice and trash rack options). Trash racks shall be installed at a shallow angle to prevent ice formation.
- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the permanent pool (See **Appendix C** for details). When a standard weir is used, the minimum slot width shall be 3 inches.

6.1.3 Pretreatment

- For each stormwater pond, pretreatment equaling a minimum of 10% of the WQv shall be provided at each pond inflow point, unless an inflow point provides less than 10% of the total design storm flow to the pond. The forebay storage volume counts toward the total WQ_v requirement.
- In sole source aquifers, 100% of the WQv for stormwater runoff from designated hotspots shall be provided in pretreatment.
- Pretreatment shall be achieved with a sediment forebay, or an equivalent upstream pretreatment device. When a sediment forebay is applied, it shall meet the following design criteria:
  - Shall consist of a separate cell, formed by an acceptable earthen or structural barrier. Berms and weirs separating the forebay and treatment cells shall be constructed with native or imported clay or very low hydraulic conductivity soils.

- Depth: 4 to 6 ft.
- Outlet designed to ensure non-erosive flows into the pond.
- Optional: a fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.
- Optional: the bottom of the forebay may be hardened using concrete, asphalt, paver blocks, or grouted riprap, to ease sediment removal.

6.1.4 Treatment

6.1.4.1 Design Criteria

Table 6.3 Stormwater Ponds Design Specifications					
		P-1	**P-2**	**P-3**	**P-4**
Freeboard[1]	**Depth**	1 ft min. measured from Extreme Flood elevation to top of embankment			
Perimeter Fencing	**Applicability**	As required, when pond slope requirements or any other required safety feature cannot be met			
	Location	Installed at or above the maximum water surface level and must consider access for required maintenance to be performed			
Safety Bench	**Applicability**	As required, for ≥ 3:1 (h:v) side slopes above permanent pool			
	Slope	6% max.			
	Width	10 ft min., 15 ft average			
Aquatic Bench[1]	**Slope**	15% max.			
	Slope to Pond Floor	≤ 3:1 (h:v) from inner bench edge to pond basin floor			
	Width	10 ft min., 15 ft average			
	Depth	18 inch max. from permanent pool elevation to inner bench edge			
Impermeable Liner	**Applicability**	As required, see **Section 6.1.4.1**			
	Material	12 - 24 inch of clay soil (min. 50% passing #200 sieve and max. permeability 1 x 10^{-5} cm/sec) or 40 mil HDPE geomembrane			
Maintenance Access[1]	**Slope**	15% max.			
	Width	12 ft min.			
	Material	Able to withstand loading of maintenance equipment and vehicles			

Footnotes:
[1]Required for all Design Variants

Impermeable Liner

- When a pond is located in areas listed below, an impermeable liner shall be required.
  - Underlying soils have an infiltration rate greater than 0.014 inch/hr, (Appendix D); or
  - Geotechnical testing is not performed; or
  - Underlying soils consist of gravel or fractured bedrock.
- When required, the impermeable liner shall be installed for the entire wetted perimeter and extend a minimum of 12 inches above the permanent pool elevation.

Maintenance Access

- A maintenance access easement shall extend to the practices from a public or private road.
- Adequate maintenance access must extend to the forebay, safety bench, outlet structure/overflow, auxiliary spillway and must have sufficient area to allow vehicles to turn around.
- Where applicable, access to the outlet structure shall be provided by lockable manhole cover or grate to allow operation of valves and other controls.

Pond Drain

- All ponds shall be equipped with a mechanism that can completely drain the pond within 24-hrs, as follows:
    - A portable trash pump with suction hose, filter sock, and discharge hose; or
    - A drain pipe, sized as noted in DEC Dam Design Guidelines (**Appendix A**), with an elbow or protected intake within the pond to prevent sediment deposition. In this case, the drain pipe shall be equipped with an adjustable gate valve that is designed to prevent rapid draw down, is located at a point where it will not be normally inundated, is located to allow for safe operation, and is protected from vandalism or improper use (i.e. lockable cover, or within the outlet structure).
- The approving jurisdiction or MS4 shall be notified before draining a stormwater pond. Ponds shall not be drained during the spring season.

Safety Features

- Both the safety bench and the aquatic bench must be landscaped to discourage access to the deep pool. The vegetation must be established before pond is rendered in-service.
- The principal spillway opening shall not permit access by small children and shall be protected with some form of grating (pipe, rebar, etc.) having a maximum opening of 8 inches on center.
- End walls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent fall hazard.

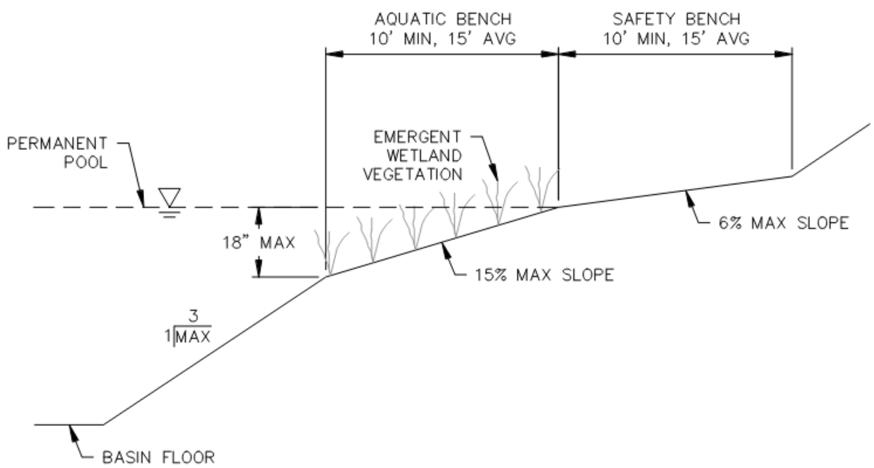


Figure 6.5 Slope Diagram for Pond Benches

Pond Buffer

- A vegetated buffer shall extend 25 ft outward from the maximum water surface elevation (Extreme Flood peak water surface elevation) of the pond or to the toe of the embankment, whichever is greater. The vegetated buffer shall be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers).

6.1.4.2 Sizing Criteria

- Provide water quality treatment storage to capture the computed WQ_v from the contributing area, through a combination of forebay (if applicable), permanent pool and extended detention (WQ_v-ED), as outlined in **Table 6.4**.

- The volume of the permanent pool cannot be applied as available detention (dry storage). CP_v storage must be provided above the permanent pool. WQ_v cannot be met by simply providing CP_v storage, as a percentage of the WQ_v must always be provided within the permanent pool.

Table 6.4 Water Quality Volume Distribution in Pond Design

Design Variation	%WQ_v	
	Permanent Pool	Extended Detention
P-1	20% min.	80% max.
P-2	100%	0%
P-3	50% min.	50% max.
P-4	50% min.	50% max.

- A minimum flow path of 1.5:1 (i.e. length to relative width) shall be provided from the inflow points to the outflow points across the stormwater pond. If a forebay is used for pretreatment, the forebay shall be included in this ratio.
- Provide a minimum pond surface area to contributing area ratio of 1:100.
- Design P-1 micropool shall be 4 to 6 ft depth.
- Designs P-2, P-3, and P-4 shall have a permanent pool with a minimum depth of 3 ft and a maximum depth of 8 ft. A preferred depth of 4 to 6 ft is optimal for pond function.
- Multiple Pond Systems (P-4) shall be separated by constructed berms with overflow weirs between the cells. Equalizer pipes between the cells are not allowed.

Water Balance Analysis

If the minimum contributing area to a pond cannot be achieved, then a water balance analysis shall be performed, using the following equation, to calculate the required minimum depth of the permanent pool to prevent a nuisance condition. The water balance ensures that there is sufficient inflow to the pond to compensate for infiltration and evapotranspiration losses during a 30-day summer drought, without causing unacceptable drawdown in the permanent pool depth.

$$DP \geq ET + INF + RES$$

Where:

DP = minimum depth of permanent pool (inches)

ET = summer evapotranspiration rate (5 inches)

INF = monthly infiltration loss (10.1 inches per Impermeable Liner Design Specifications)

RES = water reservoir for factor of safety (P-1=48 inches min; P-2, P-3 and P-4=36 inches min)

6.1.5 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.
- A landscaping plan for a stormwater pond and its buffer shall be prepared to indicate how the hydrologic zones will be stabilized and established with vegetation and show the selection and layout of corresponding plant species.
- Safety benches and slopes of the pond must be established with vegetation before the pond is rendered in-service.
- It is required to excavate large and deep holes around the proposed planting sites and backfill these with uncompacted topsoil. Planting holes shall be three times deeper and wider than the diameter of the rootball (of balled and burlap stock), and five times deeper and wider for container grown stock.
- Woody vegetation shall not be planted or allowed to grow within 15 ft of the toe of any berm or slope and 25 ft from the principal spillway structure.

Fact Sheet: Micropool Extended Detention Pond (P-1)

Description: A variation of a wet extended detention pond, where only a small micropool is maintained at the outlet of the pond. The micropool prevents resuspension of previously settled sediments and prevents clogging of the low flow orifice.

(Photo Source: Ohio EPA)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional waters, including wetlands
- Unless a slope stability analysis is performed, shall not be located in areas with natural slopes greater than 15%
- Underlying soils shall have an infiltration rate less than or equal to 0.014 inch/hr, unless an impermeable liner is provided
- Minimum contributing area is 10 acres. Minimum contributing area can be reduced to 5 acres if a water balance calculation is performed
- Size outlet structure to detain WQv for 24 hrs (12 hrs to trout waters)

CONVEYANCE

- Inlet points shall be stabilized to ensure non-erosive conditions
- Inlet pipe slope ≥ 0.5% (1% for pipes smaller than 12 inches diameter)
- A controlled outlet structure shall be provided
- An auxiliary spillway shall be provided

PRETREATMENT

- Minimum 10% WQv shall be provided at each inlet point
- 100% of WQv for stormwater runoff from designated hotspots shall be provided in pretreatment in sole source aquifers

TREATMENT

- 1 ft min. freeboard
- 3:1 max. side slope in safety (where required) and aquatic bench
- Min. 12 ft wide maintenance access is required at a max. 15% slope
- Provide a mechanism that can completely drain the pond in 24 hrs
- Min. flow path of 1.5:1 (length to relative width) from all inlet points to the outflow points across the pond
- Min. pond surface area to contributing area ratio of 1:100
- Micropool shall be 4 ft min. to 6 ft max. depth
- Permanent pool shall be sized for 20% min. WQv
- Extended detention shall be sized for 80% max. WQv

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Wet Pond (P-2)

Description: A stormwater basin constructed of a permanent pool of water having a storage volume equal to the water quality volume. Stormwater runoff displaces the water already present in the pool.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional waters, including wetlands
- Unless a slope stability analysis is performed, shall not be located in areas with natural slopes greater than 15%
- Underlying soils shall have an infiltration rate less than or equal to 0.014 inch/hr, unless an impermeable liner is provided
- Minimum contributing area is 25 acres. Minimum contributing area can be reduced to 10 acres if a water balance calculation is performed
- Size outlet structure to detain WQv for 24 hrs (12 hrs to trout waters)

CONVEYANCE

- Inlet points shall be stabilized to ensure non-erosive conditions
- Inlet pipe slope ≥ 0.5% (1% for pipes smaller than 12 inches diameter)
- A controlled outlet structure shall be provided
- An auxiliary spillway shall be provided

PRETREATMENT

- Minimum 10% WQv shall be provided at each inlet point
- 100% of WQv for stormwater runoff from designated hotspots shall be provided in pretreatment in sole source aquifers

TREATMENT

- 1 ft min. freeboard
- 3:1 max. side slope in safety (where required) and aquatic bench
- Min. 12 ft wide maintenance access is required at a max. 15% slope
- Provide a mechanism that can completely drain the pond in 24 hrs
- Min. flow path of 1.5:1 (length to relative width) from all inlet points to the outflow points across the pond
- Min. pond surface area to contributing area ratio of 1:100
- Micropool shall be 3 ft min. to 8 ft max. depth
- Permanent pool shall be sized for 100% WQv
- Extended detention shall be sized for 0% WQv

STORMWATER MANAGEMENT SUITABILITY

✓	Water Quality
✓	Channel Protection
✓	Overbank Flood Protection
✓	Extreme Flood Protection
	Runoff Reduction
✓	Treatment of Hotspots
✓	Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

M	Capital Cost
M	Maintenance Burden
H	Safety Risk
H	Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

G	Phosphorus
G	Nitrogen
F	Metals
F	Pathogens
G	Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Wet Extended Detention Pond (P-3)

Description: A wet pond where the water quality volume is split evenly between the permanent pool and extended detention storage above the permanent pool.

(Photo Source: Blaine, Minnesota Water Resources Division)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional waters, including wetlands
- Unless a slope stability analysis is performed, shall not be located in areas with natural slopes greater than 15%
- Underlying soils shall have an infiltration rate less than or equal to 0.014 inch/hr, unless an impermeable liner is provided
- Minimum contributing area is 25 acres. Minimum contributing area can be reduced to 10 acres if a water balance calculation is performed
- Size outlet structure to detain WQv for 24 hrs (12 hrs to trout waters)

CONVEYANCE

- Inlet points shall be stabilized to ensure non-erosive conditions
- Inlet pipe slope ≥ 0.5% (1% for pipes smaller than 12 inches diameter)
- A controlled outlet structure shall be provided
- An auxiliary spillway shall be provided

PRETREATMENT

- Minimum 10% WQv shall be provided at each inlet point
- 100% of WQv for stormwater runoff from designated hotspots shall be provided in pretreatment in sole source aquifers

TREATMENT

- 1 ft min. freeboard
- 3:1 max. side slope in safety (where required) and aquatic bench
- Min. 12 ft wide maintenance access is required at a max. 15% slope
- Provide a mechanism that can completely drain the pond in 24 hrs
- Min. flow path of 1.5:1 (length to relative width) from all inlet points to the outflow points across the pond
- Min. pond surface area to contributing area ratio of 1:100
- Micropool shall be 3 ft min. to 8 ft max. depth
- Permanent pool shall be sized for 50% min. WQv
  Extended detention shall be sized for 50% max. WQv

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Multiple Pond System (P-4)

Description: Consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The multiple cells create high surface area to volume ratios, complex microtopography, longer pollutant removal pathways, and improved downstream protection.

(Photo Source: Monroe County, New York)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional waters, including wetlands
- Unless a slope stability analysis is performed, shall not be located in areas with natural slopes greater than 15%
- Underlying soils shall have an infiltration rate less than or equal to 0.014 inch/hr, unless an impermeable liner is provided
- Minimum contributing area is 25 acres. Minimum contributing area can be reduced to 10 acres if a water balance calculation is performed
- Size outlet structure to detain WQv for 24 hrs (12 hrs to trout waters)

CONVEYANCE

- Inlet points shall be stabilized to ensure non-erosive conditions
- Inlet pipe slope ≥ 0.5% (1% for pipes smaller than 12 inches diameter)
- A controlled outlet structure shall be provided
- An auxiliary spillway shall be provided

PRETREATMENT

- Minimum 10% WQv shall be provided at each inlet point
- 100% of WQv for stormwater runoff from designated hotspots shall be provided in pretreatment in sole source aquifers

TREATMENT

- 1 ft min. freeboard
- 3:1 max. side slope in safety (where required) and aquatic bench
- Min. 12 ft wide maintenance access is required at a max. 15% slope
- Provide a mechanism that can completely drain the pond in 24 hrs
- Min. flow path of 1.5:1 (length to relative width) from all inlet points to the outflow points across the pond
- Min. pond surface area to contributing area ratio of 1:100
- Micropool shall be 3 ft min. to 8 ft max. depth
- Permanent pool shall be sized for 50% min. WQv
- Extended detention shall be sized for 50% max. WQv

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Section 6.2 Stormwater Wetlands

Stormwater wetlands are practices that create shallow marsh areas to treat urban stormwater and often incorporate small permanent pools and/or extended detention storage to achieve the full WQ_v. Design variants include:

W-1	Shallow Wetland	(**Figure 6.6**)
W-2	ED Shallow Wetland	(**Figure 6.7**)
W-3	Pond/Wetland System	(**Figure 6.8**)
W-4	Pocket Wetland	(**Figure 6.9**)
W-5	Gravel Wetland	(**Figure 6.10**)

Refer to the **Fact Sheets** at the end of this section for key considerations of each wetland design variant, including performance criteria, practice suitability, implementation considerations, pollutant removal capability, and runoff reduction credit.

IMPORTANT NOTES:

1. ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE GUIDELINES FOR DESIGN OF DAMS (**APPENDIX A**) AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY SECTION. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER WETLANDS CREATED BY A DAM.
2. STORMWATER WETLANDS DESIGNED ACCORDING TO THIS MANUAL MAY ACT AS A COMMUNITY AMMENITY, AND MAY PROVIDE SOME LEVEL OF HABITAT VALUE. HOWEVER, THEY CANNOT BE ANTICIPATED TO FUNCTION AS NATURAL WETLANDS. TO ENSURE LONG-TERM FUNCTION AS INTENDED, THEY MUST BE PROPERLY MAINTAINED.

Shallow Wetland (W-1)

A shallow wetland is intended for water quality treatment only, and provides the majority of the treatment volume within a combination of high and low marsh areas. The only deep portions of the design are the forebay at the inlet and a small micropool at the outlet. Shallow wetlands cannot be used for extended detention, so the outlet structure should be simplified. To meet quantity control requirements, this design variant can be installed parallel to a dry detention basin or another detention practice.

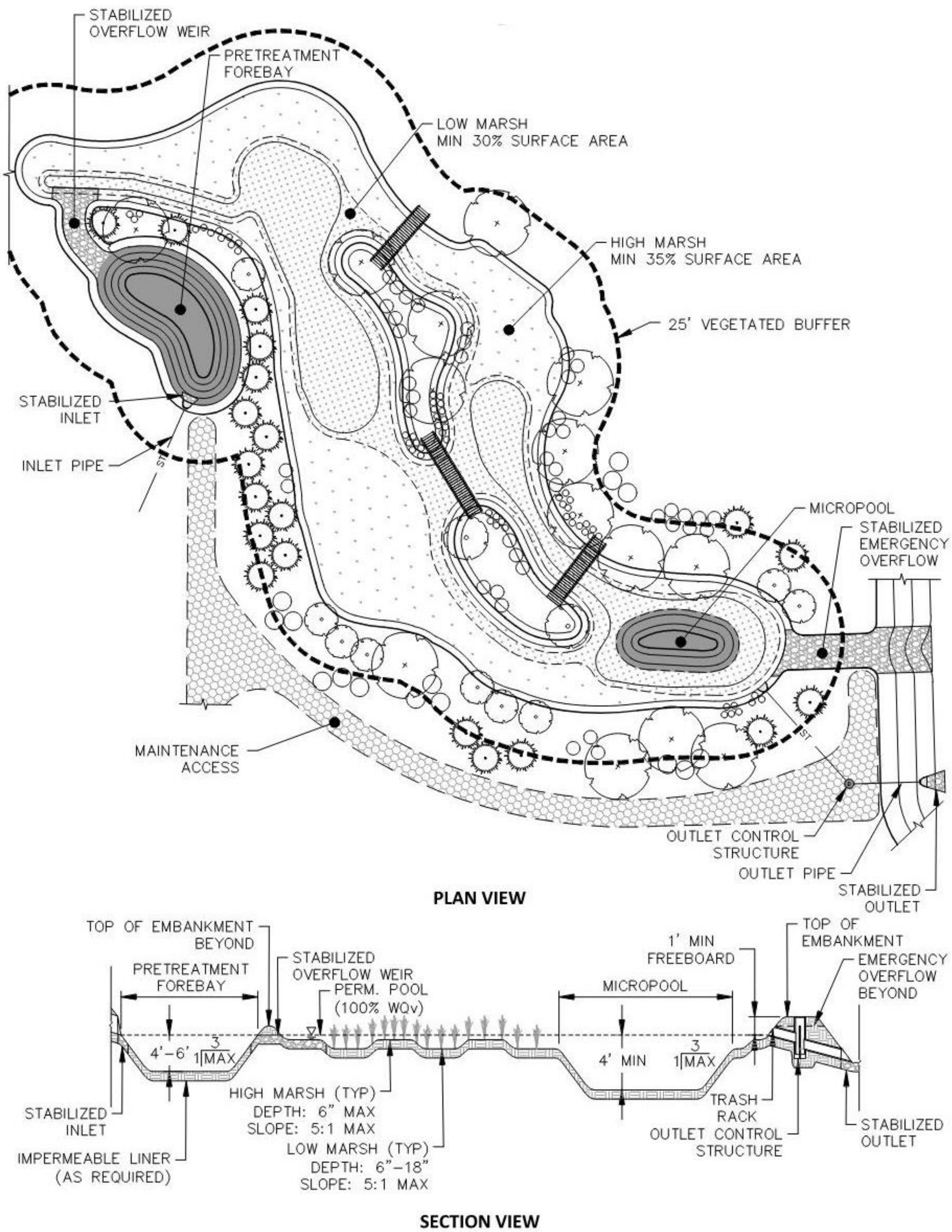


Figure 6.6 Shallow Wetland (W-1)

Extended Detention Shallow Wetland (W-2)

The extended detention shallow wetland design is similar to the shallow wetland, except that part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24-hrs. An outlet structure is used to create the pool and a small orifice is placed in the outlet structure above the bottom of the wetland to create a shallow permanent pool. Storm events that are greater than the design volume can be released through the top of the outlet structure and/or through an emergency spillway channel.

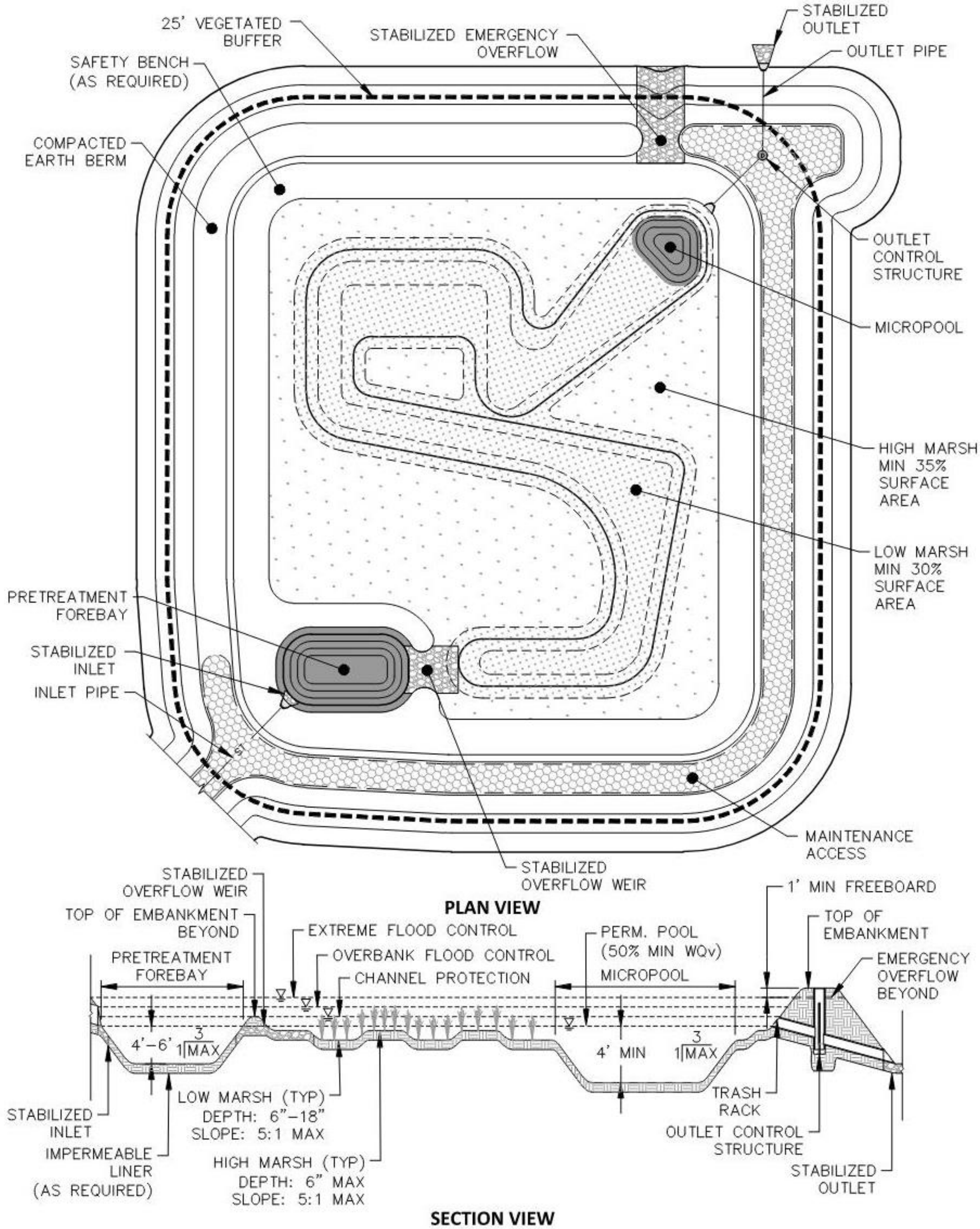


Figure 6.7 Extended Detention Shallow Wetland (W-2)

Pond/Wetland System (W-3)

The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediment and reduces runoff velocities prior to entering the wetland. An outlet structure is used to create the pool and a small orifice is placed in the outlet structure above the bottom of the wetland to create a shallow permanent pool. Storm events that are greater than the design volume can be released through the top of the outlet structure and/or through an emergency spillway channel.

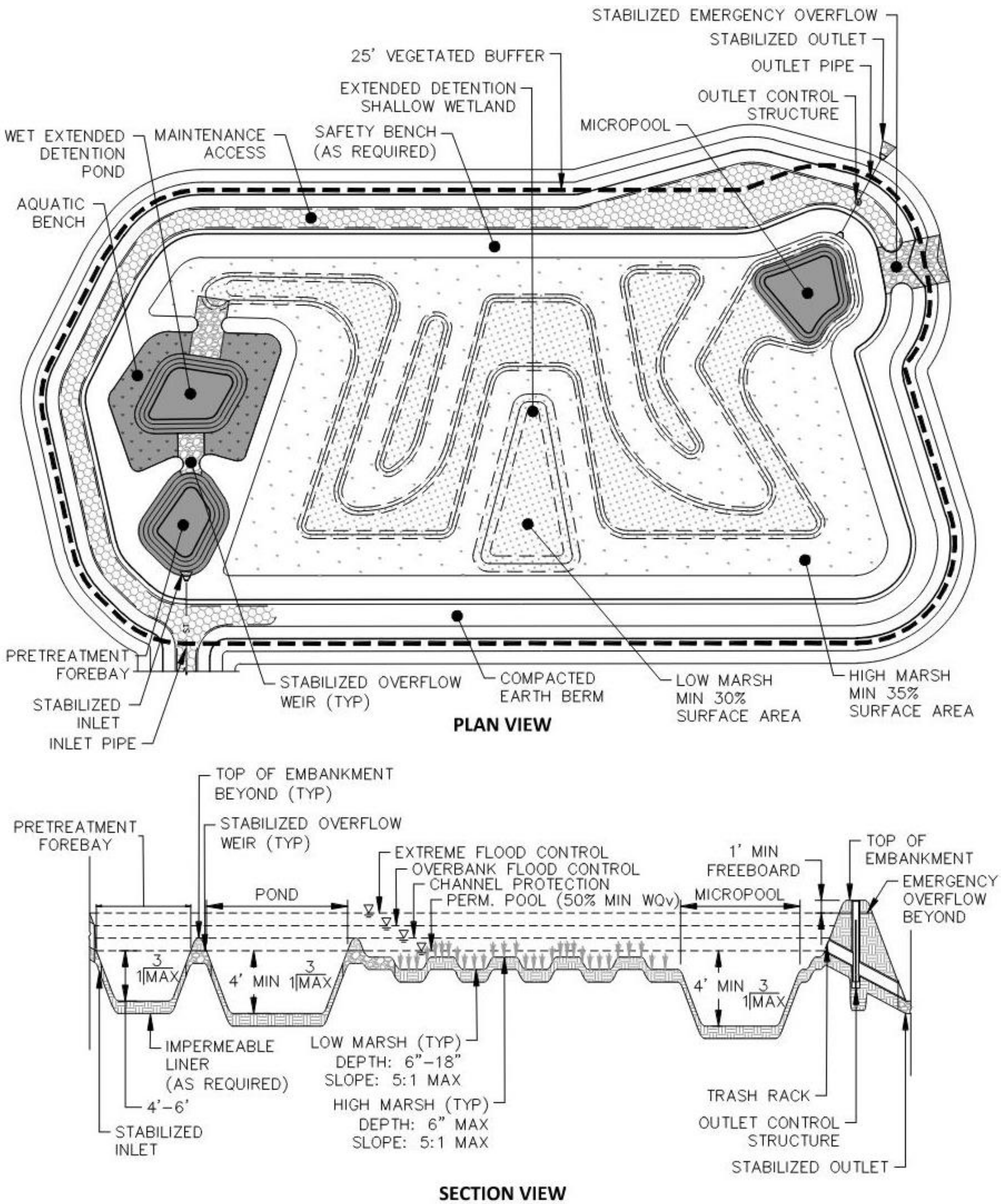


Figure 6.8 Pond/Wetland System (W-3)

Pocket Wetland (W-4)

The pocket wetland requires excavation down to the water table for a reliable water source to support the wetland system. They cannot be used for extended detention, so the outlet structure should be simplified to meet water quality objectives. To meet quantity control requirements, they can be installed parallel to dry detention basins or another detention practice.

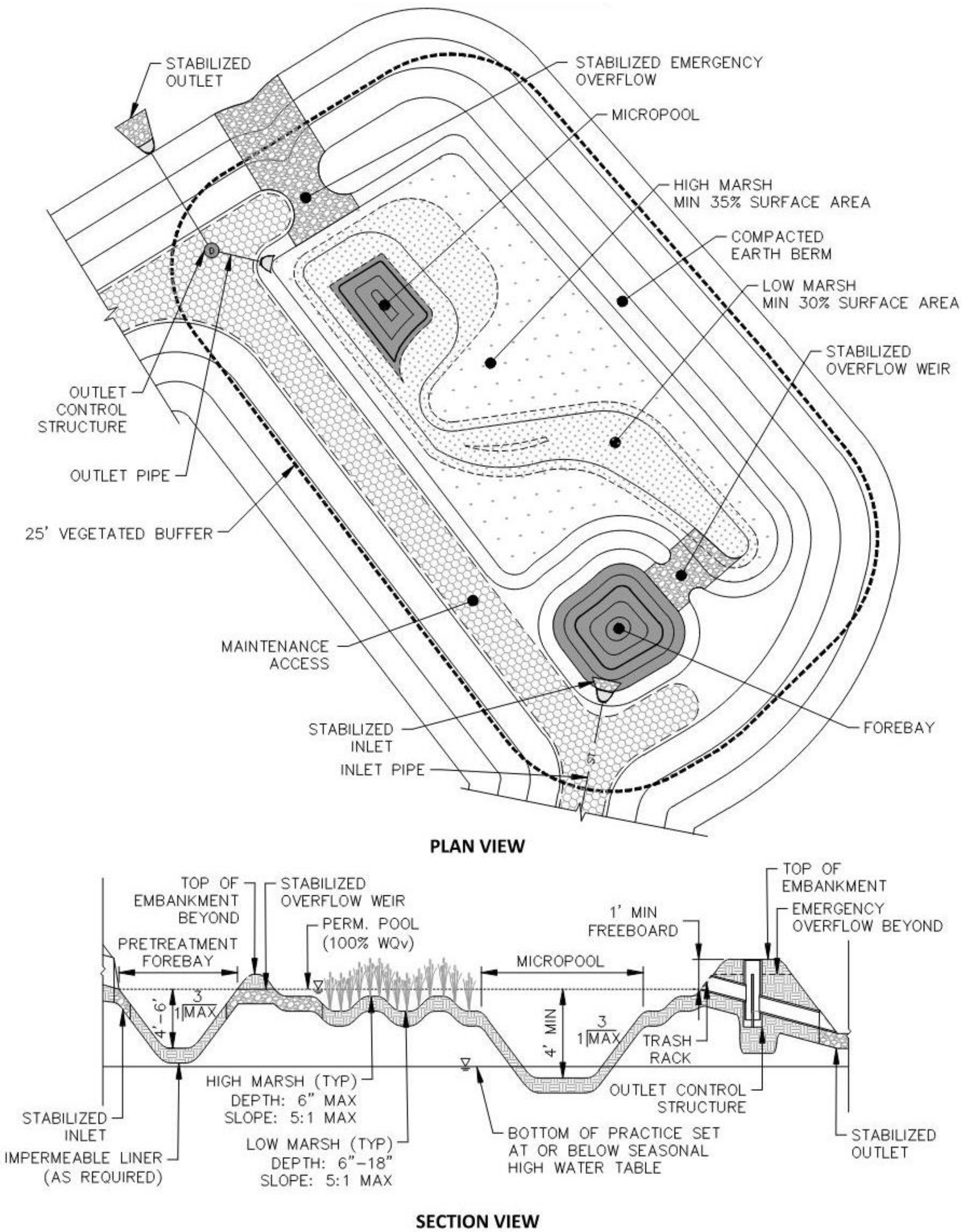


Figure 6.9 Pocket Wetland (W-4)

Gravel Wetland (W-5)

The gravel wetland system consists of one or more treatment cells that are filled with crushed rock or gravel and designed to allow stormwater to flow subsurface through the root zone of the constructed wetland, where pollutant removal takes place. This practice provides both aerobic and anaerobic treatment zones for enhanced pollutant removal.

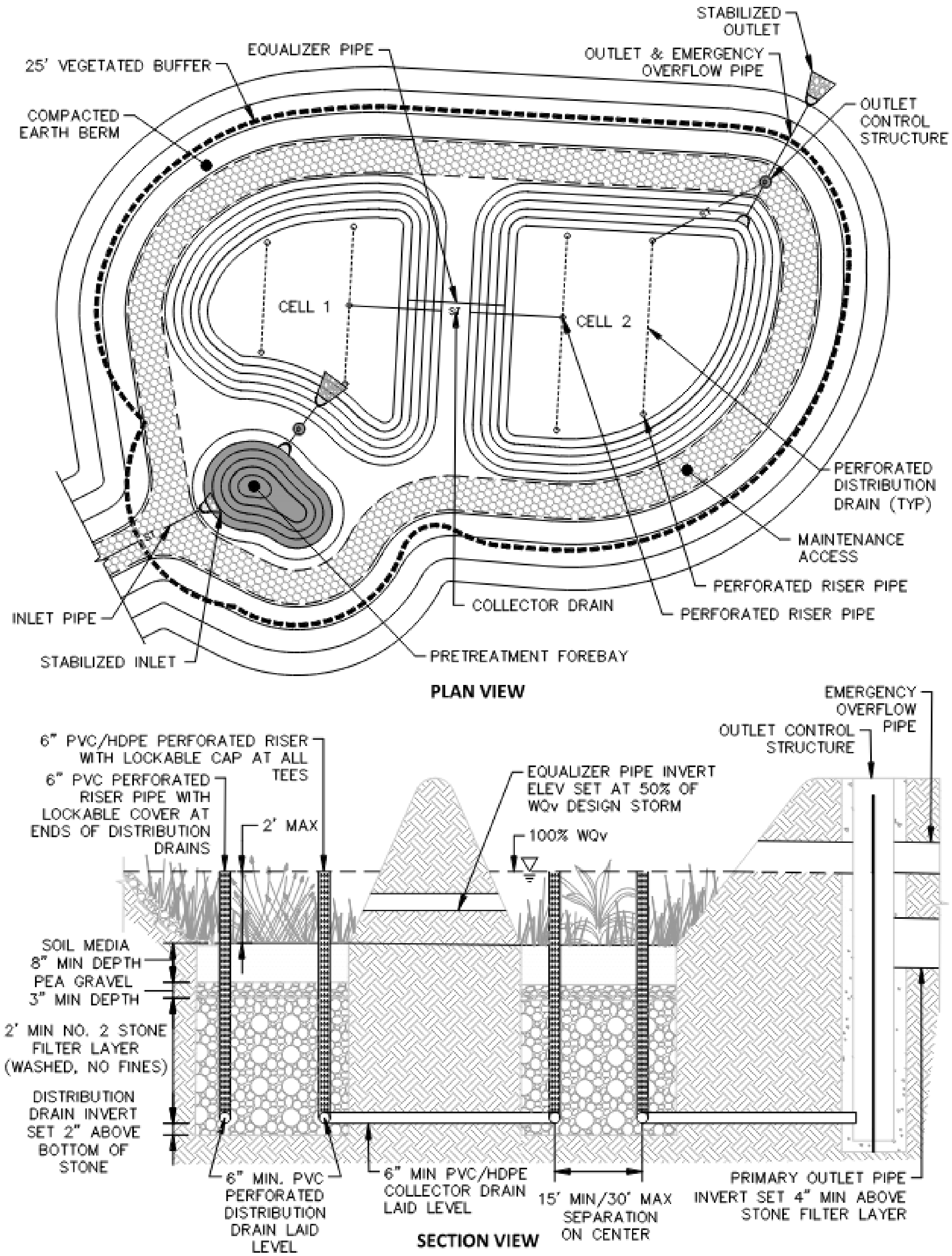


Figure 6.10 Gravel Wetland (W-5)

6.2.1 Feasibility

- Stormwater wetlands shall not be located within existing jurisdictional wetlands. In some limited cases, a permit may be granted to convert an existing degraded wetland, in the context of local watershed restoration efforts. The designer shall contact the authority having jurisdiction for permitting requirements
- Stormwater wetlands shall not be located on areas with natural slopes greater than 15%, unless a slope stability analysis is performed by a qualified geotechnical engineer.
- Stormwater wetlands (with the exception of W-5) shall not be used when discharging to trout waters.
- Designs W-1 and W-4 shall be designed for water quality only. All other storm events shall be diverted.
- Wetlands (with the exception of W-4) can be applied on sites with an underlying water supply aquifer or when treating a stormwater hotspot, if a minimum separation distance of 2 ft is provided between the bottom of the wetland and the elevation of the seasonal high water table. In addition, for design (W-5), an impermeable liner shall be provided between the bottom of gravel and seasonal high water table.
- The contributing area to stormwater wetlands shall meet the requirements listed in **Table 6.5**.

Table 6.5 Stormwater Wetland Contributing Area Requirements

Design Variant	Contributing Area
Shallow Wetland (W-1)	25 acres minimum
Extended Detention Shallow Wetland (W-2)	25 acres minimum
Pond/Wetland System (W-3)	25 acres minimum
Pocket Wetland (W-4)	5 acres minimum
Gravel Wetland (W-5)	5 acres maximum

- Stormwater wetlands shall meet the minimum separation requirements listed in **Table 6.6**. Vertical separations shall be taken from the bottom of wetland. Horizontal separations shall be taken from the maximum water surface elevation (Extreme Flood peak water surface elevation) of the wetland.

Table 6.6 Stormwater Wetland Practice Minimum Separation Requirements

	Vertical Separation		Horizontal Separation				
Design Variant	**Seasonal High Water Table[1,2]**	**Sound Bedrock[1]**	**Structures Without Foundation Waterproofing[4]**	**Structures With Foundation Waterproofing[4]**	**Water Supply Well/ Reservoir**	**Septic System[3,4]**	**Sanitary Sewer Main**
Shallow Wetland (W-1)	0 ft	0 ft	25 ft	25 ft	25 ft	50 ft	25 ft
Extended Detention Shallow Wetland (W-2)							
Pond/Wetland System (W-3)							
Pocket Wetland (W-4)							
Gravel Wetland (W-5)							

[1] As documented by on-site geotechnical testing.
[2] With the exception of W-4, separation shall be increased to 2 ft in sole source aquifers or when treating stormwater hotspots.
[3] Septic systems are inclusive of septic tanks, distribution boxes, and absorption fields.
[4] Wetlands shall be located downgradient of structures and septic systems.

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6.2.2 Conveyance

Inlet Protection

- Inlets shall be designed to ensure non-erosive conditions.

Outlet Structure/Outfall Protection

- For Designs W-1, W-2, W-3, & W-4, a controlled outlet shall be provided for each wetland, using one of the following methods:
  - An outlet structure located within the embankment, with a pipe invert set at the permanent pool elevation that extends downward to the structure;
  - An outlet structure located within the embankment, with a submerged reverse-slope pipe that extends downward from the structure to an inflow invert set 1 ft minimum below the permanent pool elevation and 1 ft minimum above the bottom of the pond;
  - An outlet structure located within the embankment, with an adequately sized downward elbow with an extension that extends 1 ft below the permanent pool elevation;
  - An outlet structure located partially within the embankment, with outlet openings in the face of the structure; or
- Where a CPv control orifice is provided (See **Section 4.6** for CPv requirements and waivers), one of the following methods shall be applied:
  - Minimum 3 inch low flow orifice installed in an internal weir plate within the outlet structure with acceptable external trash rack or orifice protection (See **Appendix C** for details of a low flow orifice and trash rack options).
  - Minimum 3 inch low flow external orifice installed in the face of the outlet structure (See **Appendix C** for details of a low flow orifice and trash rack options). Orifice protection shall be provided.
- An emergency spillway shall be provided to safely convey stormwater exceeding the Extreme Flood. A stilling basin, outlet protection, level spreader, or other energy dissipator shall be installed to reduce flow velocities from the spillway to non-erosive velocities. (See **Appendix G** for a table of erosive velocities for grass and soil).
- For Design W-5, the following outlet design criteria shall apply:
  - The primary outlet invert shall be located 4 inches below the elevation of the wetland soil surface to maintain a subsurface water level. The primary outlet shall be open or vented to prevent siphoning.
  - An outlet control structure shall be designed with a 3 inch minimum orifice (with acceptable internal orifice protection) to drain the WQv in a minimum of 24 hrs and a maximum of 48 hrs.
  - A maintenance outlet shall be installed at the bottom of stone elevation to completely drain the wetland within 48 hours. This outlet shall remain plugged during regular operation.

6.2.3 Pretreatment

- For each stormwater wetland, pretreatment equaling a minimum of 10% of the WQv shall be provided at each wetland inflow point, unless an inflow point provides less than 10% of the total design storm flow to the wetland. The forebay storage volume counts toward the total WQ_v requirement.
- In sole source aquifers, pretreatment equivalent to 100% of the WQ_v shall be provided for runoff from designated stormwater hotspots. The forebay storage volume does not count toward the total WQ_v requirement.
- Pretreatment shall be achieved with a sediment forebay, or an equivalent upstream pretreatment device. When a sediment forebay is applied, it shall meet the following design criteria:
  - Shall consist of a separate cell, formed by an acceptable earthen or structural barrier. Berms and weirs separating the forebay and treatment cells shall be constructed with native or imported clay or very low hydraulic conductivity soils.
  - Depth: 4 to 6 ft.
  - Outlet designed to ensure non-erosive flows into the pond.

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- Optional: a fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.
- Optional: the bottom of the forebay may be hardened using concrete, asphalt, paver blocks, or grouted riprap, to ease sediment removal.

6.2.4 Treatment

6.2.4.1 Design Criteria

Table 6.7 Stormwater Wetland Design Specifications						
		W-1	W-2	W-3	W-4	W-5
Freeboard[1]	Depth	1 ft min. measured from design storm elevation to top of embankment				
	Design Storm	WQv	Extreme Flood		WQv	Extreme Flood
Filter Media	Applicability	N/A	N/A	N/A	N/A	Required
	Depth	8 inch min.				
	Material	NYSDOT Standard Specification 713-01 Topsoil-Wetland				
Pea Gravel	Applicability	N/A	N/A	N/A	N/A	Required
	Depth	3 inch min.				
	Material	ASTM D448 No. 6 Stone, Porosity = 32%				
Filter Course	Applicability	N/A	N/A	N/A	N/A	Required
	Depth	24 inch min.				
	Material	No. 2 stone, washed, no fines				
Drainage Course	Applicability	N/A	N/A	N/A	N/A	Required
	Depth	3 inch min. below distribution drain				
	Material	AASHTO No. 57 stone, washed, no fines				
Safety Bench	Applicability	As required, for ≥ 3:1 (h:v) side slopes above permanent pool				N/A
	Width	10 ft min., 15 ft average measured outward from the normal water edge				
	Slope	6% max.				
Equalizer Pipe	Applicability	N/A	N/A	N/A	N/A	Required
	Material	12" min. solid PVC/HDPE laid level				
	Depth	Inlet set at 50% of WQv Storage				
Distribution Drain	Applicability	N/A	N/A	N/A	N/A	Required
	Material	6 inch perforated PVC/HDPE laid level				
	Spacing	15 – 30 ft				
	Depth	2 inch above bottom of stone layer				
Riser	Applicability	N/A	N/A	N/A	N/A	Required
	Material	6 inch perforated PVC/HDPE with inlet grate at the end of each distribution drain				
	Spacing	15 ft min.				
	Depth	6 inch - 24 inch above soil surface				
Impermeable Liner	Applicability	As Required, see **Section 6.2.4.1**				
	Material	12 - 24 inch of clay soil (min. 50% passing #200 sieve and max. permeability 1 x 10^{-5} cm/sec) or 40 mil HDPE geomembrane				
Maintenance Access[1]	Slope	15% max.				
	Width	12 ft min.				
	Material	Able to withstand loading of maintenance equipment and vehicles				

Footnotes:
[1]Required for all Design Variants.

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Impermeable Liner

- When a stormwater wetland is located in areas listed below, an impermeable liner shall be required.
  - Underlying soils have an infiltration rate greater than 0.014 inch/hr, (**Appendix D**); or
  - Geotechnical testing is not performed; or
  - Underlying soils consist of gravel or fractured bedrock.
- When required, the impermeable liner shall be installed for the entire wetted perimeter and extend a minimum of 12 inches above the permanent pool elevation. This shall apply to all treatment cells and include the berms and weirs.

Maintenance Access

- A maintenance access easement shall extend to the practices from a public or private road.
- Adequate maintenance access must extend to the forebay, safety bench (where required), outlet structure/overflow, emergency spillway and must have sufficient area to allow vehicles to turn around.
- Where applicable, access to the outlet structure shall be provided by lockable manhole cover or grate.

Pond Buffer

- A vegetated buffer shall extend 25 ft outward from the maximum water surface elevation (Extreme Flood peak water surface elevation) of the wetland. The vegetated buffer shall be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers).

6.2.4.2 Sizing Criteria

Design Variants W-1, W-2, W-3, and W-4

- The surface area of the entire stormwater wetland shall be at least 1% of the contributing area (1.5% for design W-1).
- A minimum flow path ratio of 2:1 (length to relative width) shall be provided from the inflow point(s) to the outflow point(s) across the stormwater wetland. This path may be achieved by constructing microtopography using internal berms (e.g., high marsh wedges or rock filter cells). If a forebay is used for pretreatment, the forebay shall be included in this ratio.
- Stormwater wetlands shall meet the geometric requirements listed in **Table 6.8**:

Table 6.8 Stormwater Wetland Geometry Requirements

Wetland Zone	Depth	Side Slope	% Surface Area	% WQ_v Storage
Forebay[1]	4 ft - 6 ft	3:1 max.	-	10% min.
High Marsh	6 inches max. below permanent pool	5:1 max.	35% min.	-
Low Marsh	6-18 inches below permanent pool	5:1 max.	30% min.	-
Micropool[1]	4 ft min.	3:1 max.	-	10% min.
Pond (Design W-3)	4 ft min.	3:1 max.	-	25% min.
Extended Detention (W-2 & W-3, if required)	3 ft max. above permanent pool	3:1 max.	-	50% max. (not including permanent pool)

[1]For design W-1, W-2 & W-4, the cumulative WQv storage within the forebay and micropool shall be at least 25%.

- The micropool shall be provided and located at the practice outlet to protect the low flow pipe from clogging and prevent sediment resuspension.

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- To promote greater nitrogen removal, rock beds may be used as a medium for growth of wetland plants. The rock shall be 1 to 3 inches in diameter, placed up to the permanent pool elevation, and open to flow-through from either direction.

Design Variant W-5

- A minimum of one treatment cell shall be provided. The practice shall provide WQv storage, with 10% in the forebay and 90% above the treatment cell.
- When discharging to trout waters, a minimum of two treatment cells shall be provided. The practice shall provide WQv storage, with 10% in the forebay, and the remaining WQv equally divided above each treatment cell.
- Where multiple treatment cells are provided, they shall be separated by an acceptable earthen or structural barrier connected with an equalizer pipe or a stabilized overflow weir. Berms and weirs separating the treatment cells shall be constructed with native or imported clay or very low hydraulic conductivity soils.
- A minimum flow path ratio of 2:1 (length to relative width) shall be provided from the inflow point(s) to the outflow point within each treatment cell and the minimum flow path length shall be 15 ft.

6.2.5 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.
- A landscaping plan for a stormwater wetland and its buffer shall be prepared to indicate how the hydrologic zones will be stabilized and established with vegetation, and show the selection and layout of corresponding plant species.

Fact Sheet: Shallow Wetland (W-1)

Description: A shallow wetland is intended for water quality treatment only, and provides the majority of the treatment volume within a combination of high and low marsh areas. The only deep portions of the design are the forebay at the inlet and a small micropool at the outlet. Shallow wetlands cannot be used for extended detention, so the outlet structure should be simplified. To meet quantity control requirements, this design variant can be installed parallel to a dry detention basin or another detention practice.

(Photo Source: City of Redmond, Washington)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional wetlands
- Unless a slope stability analysis is performed, wetlands shall not be located on areas with natural slopes greater than 15%
- Shall not be used when discharging to trout waters
- In hotspots or an underlying water supply aquifer, a min separation of 2 ft shall be provided between the bottom of the wetlands and the seasonal high water table
- Min contributing area is 25 acres

CONVEYANCE

- Inlets shall have non-erosive conditions
- A controlled outlet shall be provided
- The outlet structure shall be located within the embankment
- An emergency spillway shall be provided with an energy dissipator installed to reduce flow velocities

PRETREATMENT

- 10% WQv pretreatment shall be provided for each wetland inflow point
- In sole source aquifers, 100% WQv pretreatment shall be provided for runoff from hotspots
- Pretreatment shall be achieved with a sediment forebay, or equivalent upstream pretreatment device

TREATMENT

- Surface area of the entire wetland shall be at least 1.5% of the contributing area
- Min flow path ratio of 2:1 (length to relative width) from inflow point(s) to the outflow point(s)
- Micropool shall be provided and located at the practice outlet
- Min 12 inches of freeboard shall be provided, measured from the WQv elevation to the top of embankment

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

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Fact Sheet: Extended Detention Shallow Wetland (W-2)

Description: Similar to the shallow wetland in design however, part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24-hrs. An outlet structure is used to create the pool and a small orifice is placed in the outlet structure above the bottom of the wetland to create a shallow permanent pool.

(Photo Source: Minnesota Pollution Control Agency)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional wetlands
- Unless a slope stability analysis is performed, wetlands shall not be located on areas with natural slopes greater than 15%
- Shall not be used when discharging to trout waters
- In hotspots or an underlying water supply aquifer, a min separation of 2 ft shall be provided between the bottom of the wetlands and the seasonal high water table
- Min contributing area is 25 acres

CONVEYANCE

- Inlets shall have non-erosive conditions
- A controlled outlet shall be provided
- The outlet structure shall be located within the embankment
- An emergency spillway shall be provided with an energy dissipator installed to reduce flow velocities

PRETREATMENT

- 10% WQv pretreatment shall be provided for each wetland inflow point
- In sole source aquifers, 100% WQv pretreatment shall be provided for runoff from hotspots
- Pretreatment shall be achieved with a sediment forebay, or equivalent upstream pretreatment device

TREATMENT

- Surface area of the entire wetland shall be at least 1% of the contributing area
- Min flow path ratio of 2:1 (length to relative width) from inflow point(s) to the outflow point(s)
- Micropool shall be provided and located at the practice outlet

  Min 12 inches of freeboard shall be provided, measured from the Extreme Flood elevation to the top of embankment

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Pond/Wetland System (W-3)

Description: Practice with two separate cells: a wet pond and a shallow marsh. The wet pond traps sediment and reduces runoff velocities prior to entering the wetland. An outlet structure is used to create the pool and a small orifice is placed in the outlet structure above the bottom of the wetland to create a shallow permanent pool.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional wetlands
- Unless a slope stability analysis is performed, wetlands shall not be located on areas with natural slopes greater than 15%
- Shall not be used when discharging to trout waters
- In hotspots or an underlying water supply aquifer, a min separation of 2 ft shall be provided between the bottom of the wetlands and the seasonal high water table
- Min contributing area is 5 acres

CONVEYANCE

- Inlets shall have non-erosive conditions
- A controlled outlet shall be provided
- The outlet structure shall be located within the embankment
- An emergency spillway shall be provided with an energy dissipator installed to reduce flow velocities

PRETREATMENT

- 10% WQv pretreatment shall be provided for each wetland inflow point
- In sole source aquifers, 100% WQv pretreatment shall be provided for runoff from hotspots
- Pretreatment shall be achieved with a sediment forebay, or equivalent upstream pretreatment device

TREATMENT

- Surface area of the entire wetland shall be at least 1% of the contributing area
- Min flow path ratio of 2:1 (length to relative width) from inflow point(s) to the outflow point(s)
- Micropool shall be provided and located at the practice outlet

  Min 12 inches of freeboard shall be provided, measured from the Extreme Flood elevation to the top of embankment

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

.

Fact Sheet: Pocket Wetland (W-4)

Description: Requires excavation down to the water table for a reliable water source to support the wetland system.

(Photo Source: British Columbia Wildlife Federation)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional wetlands
- Unless a slope stability analysis is performed, wetlands shall not be located on areas with natural slopes greater than 15%
- Shall not be used when discharging to trout waters
- Min contributing area = 25 acre

CONVEYANCE

- Inlets shall have non-erosive conditions
- A controlled outlet shall be provided
- The outlet structure shall be located within the embankment
- An emergency spillway shall be provided with an energy dissipator installed to reduce flow velocities

PRETREATMENT

- 10% WQv pretreatment shall be provided for each wetland inflow point
- In sole source aquifers, 100% WQv pretreatment shall be provided for runoff from hotspots
- Pretreatment shall be achieved with a sediment forebay, or equivalent upstream pretreatment device

TREATMENT

- Surface area of the entire wetland shall be at least 1% of the contributing area
- Min flow path ratio of 2:1 (length to relative width) from inflow point(s) to the outflow point(s)
- Micropool shall be provided and located at the practice outlet

  Min 12 inches of freeboard shall be provided, measured from the WQv elevation to the top of embankment

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection
- Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- H Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

.

Fact Sheet: Gravel Wetland (W-5)

Description: Consists of one or more treatment cells that are filled with crushed rock or gravel and designed to allow stormwater to flow subsurface through the root zone of the constructed wetland, where pollutant removal takes place. This practice provides both aerobic and anaerobic treatment zones for enhanced pollutant removal.

(Photo Source: University of New Hampshire Stormwater Center)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be located within jurisdictional wetlands
- Unless a slope stability analysis is performed, wetlands shall not be located on areas with natural slopes greater than 15%
- In hotspots or an underlying water supply aquifer, an impermeable liner shall be provided in addition to min 2 ft separation between the bottom of gravel and seasonal high water table
- Max contributing area is 5 acres

CONVEYANCE

- Inlets shall have non-erosive conditions
- The outlet structure shall be located within the embankment
- An emergency spillway shall be provided with an energy dissipator installed to reduce flow velocities
- The primary outlet invert shall be located 4 inches below the elevation of the wetland soil service and be open or vented
- The outlet control structure shall be designed with a 3 inch min orifice to drain the WQv in a min of 24 hrs and a max of 48 hrs

PRETREATMENT

- 10% WQv pretreatment shall be provided for each wetland inflow point
- In sole source aquifers, 100% WQv pretreatment shall be provided for runoff from hotspots
- Pretreatment shall be achieved with a sediment forebay, or equivalent upstream pretreatment device

TREATMENT

- Surface area of the entire wetland shall be at least 1% of the contributing area
- Min flow path ratio of 2:1 (length to relative width) from inflow point(s) to the outflow point(s)
- Micropool shall be provided and located at the practice outlet
- Min 12 inches of freeboard shall be provided, measured from the Extreme Flood elevation to the top of embankment

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- H Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- F Nitrogen
- F Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

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Section 6.3 Stormwater Infiltration Practices

Stormwater infiltration practices capture and temporarily store the WQ_v allowing it to infiltrate into the soil over a maximum two-day period. Design variants include the following:

- I-1 Infiltration Trench (**Figure 6.11**)
- I-2 Infiltration Basin (**Figure 6.12**)
- I-3 Dry Well (**Figure 6.13**)
- I-4 Underground Infiltration (**Figure 6.14**)

Refer to the **Fact Sheets** at the end of this section for key considerations of each infiltration practice design variant, including performance criteria, practice suitability, implementation considerations, pollutant removal capability, and runoff reduction credit.

IMPORTANT NOTES:

1. PROVIDING ADEQUATE PRETREATMENT IS CRITICAL TO LONG-TERM PERFORMANCE OF INFILTRATION PRACTICES.
2. TO ASSUE THAT INFILTRATION RATES ARE PRESERVED LONG-TERM, POST-CONSTRUCTION INSPECTION AND MAINTENANCE ACTIVITIES MUST BE CLEARLY DEFINED IN ACCORDANCE WITH **CHAPTER 12**.

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Infiltration Trench (I-1)

Infiltration trenches are excavated trenches filled with stone, designed to capture and temporarily store runoff in the stone reservoir, where it exfiltrates into the surrounding native soils.

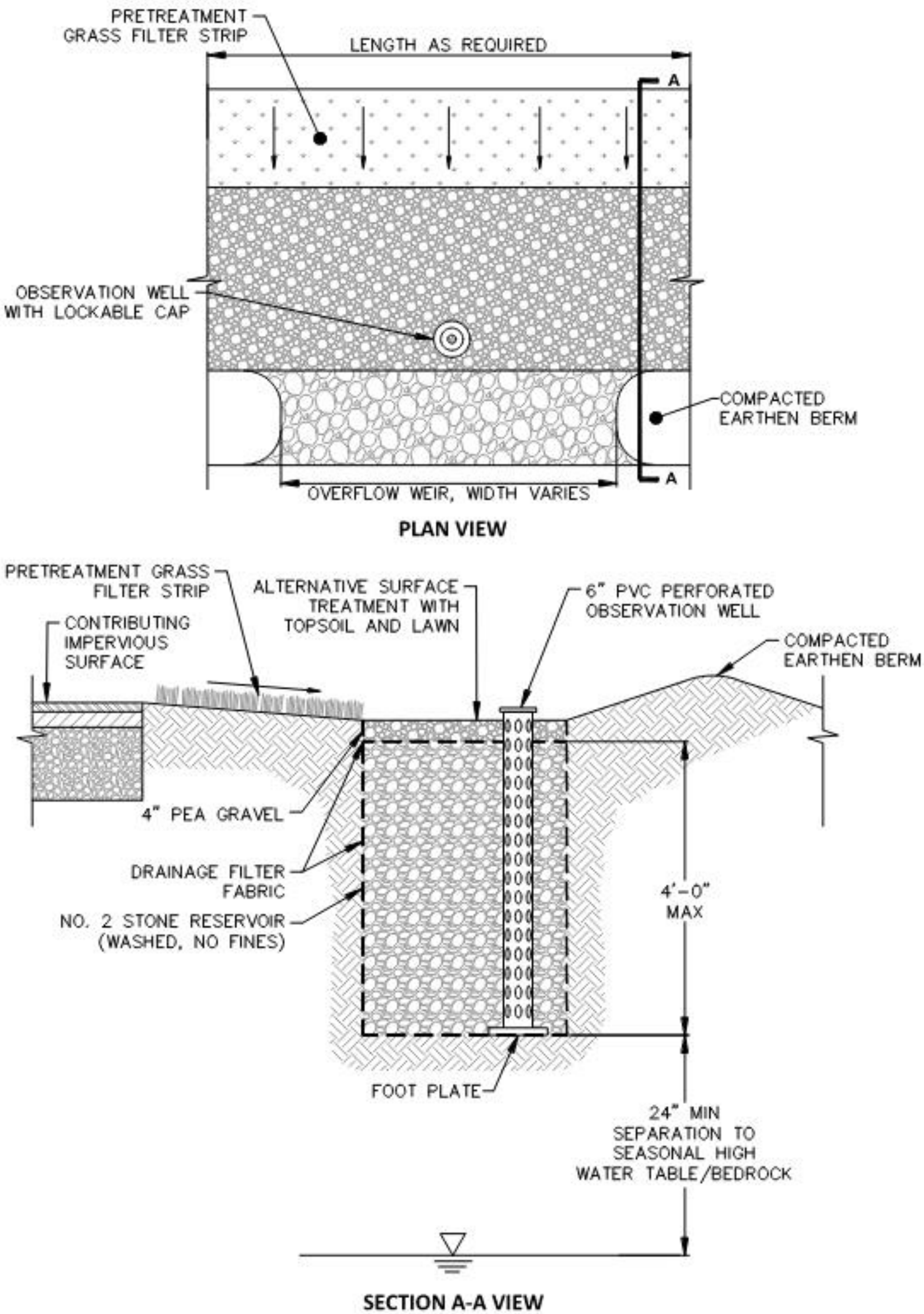

Figure 6.11 Infiltration Trench (I-1)

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Infiltration Basin (I-2)

Infiltration basins are vegetated excavations designed to capture and temporarily store stormwater runoff to promote infiltration into the surrounding native soils.

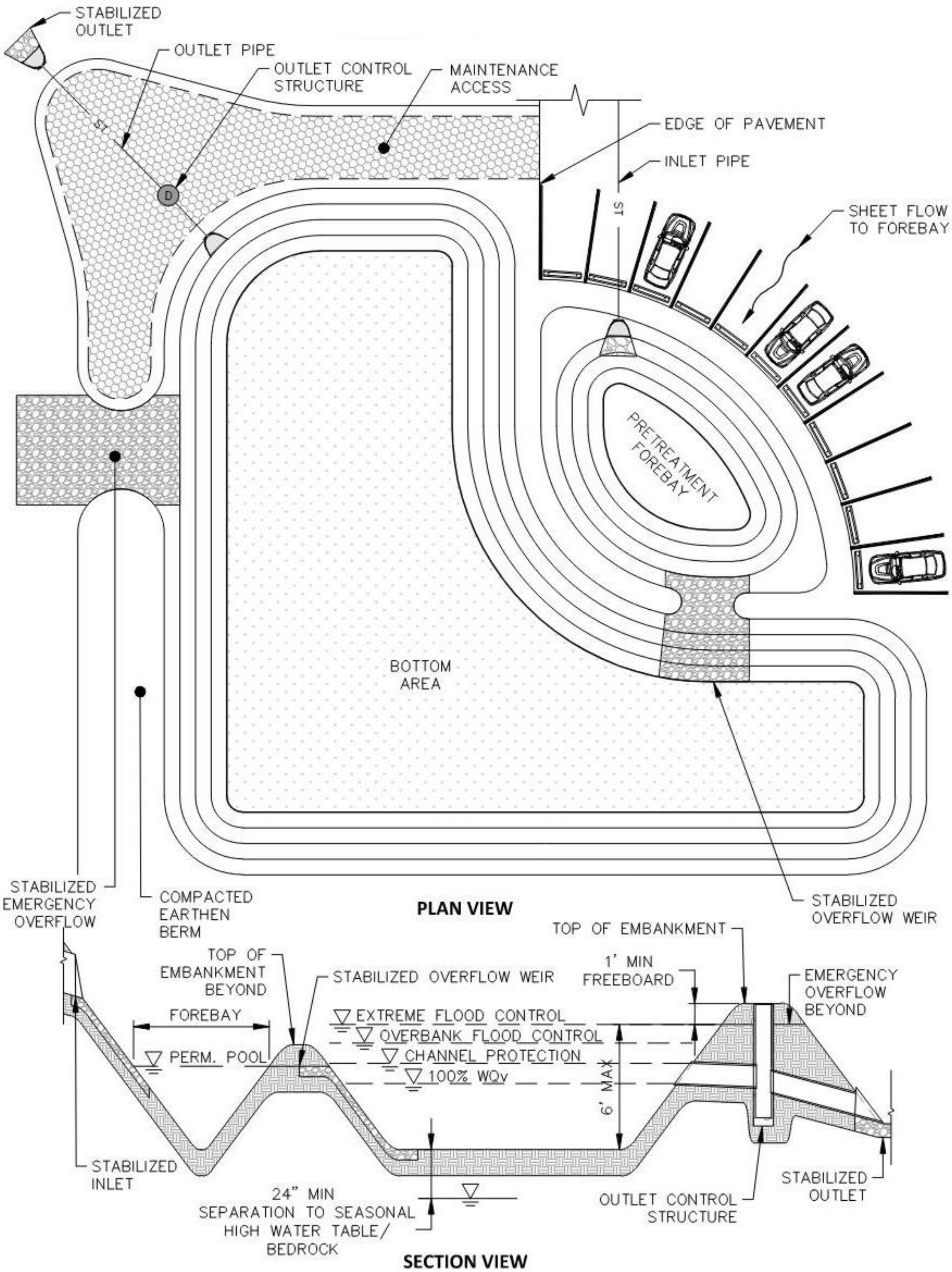

Figure 6.12 Infiltration Basin (I-2)

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Dry Well (I-3)

Dry wells consist of shallow excavations filled with stone or underground perforated structures surrounded by stone, that are designed to intercept and temporarily store runoff to promote infiltration into the surrounding native soils.

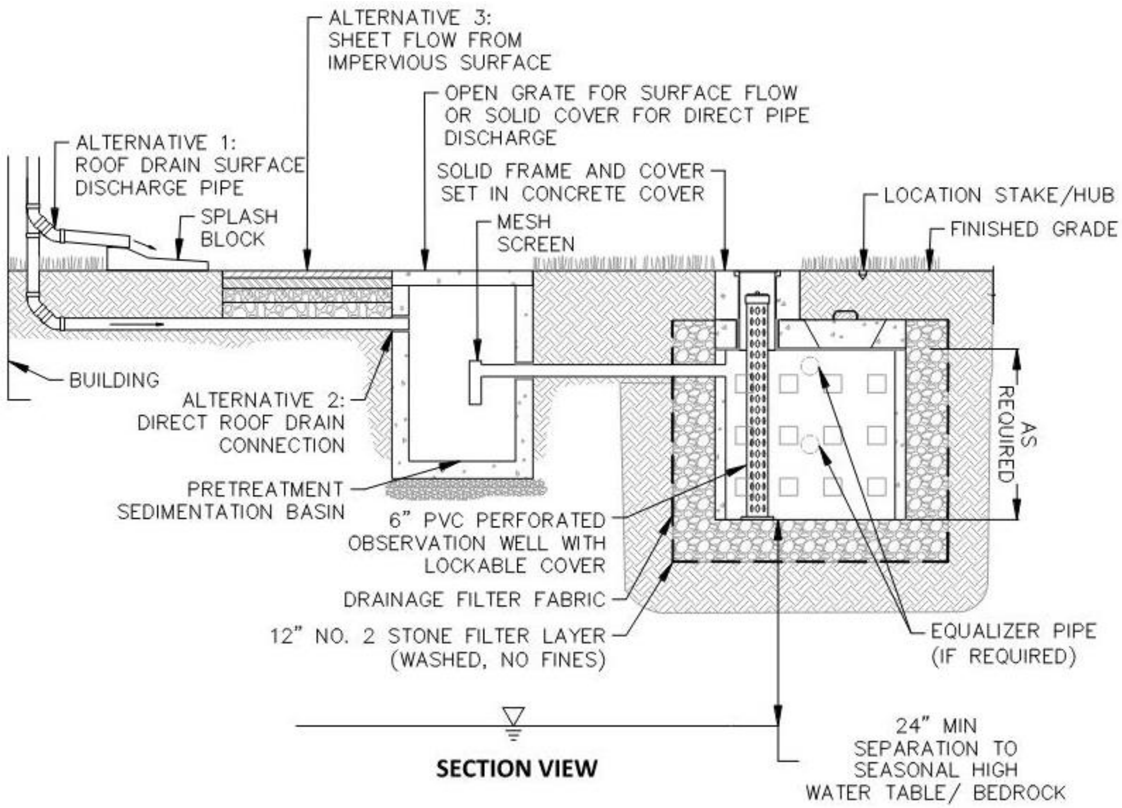


Figure 6.13 Dry Well (I-3)

Underground Infiltration (I-4)

Underground infiltration systems are practices, typically installed below parking lots and other impervious surfaces, designed to capture and temporarily store stormwater runoff in pre-manufactured pipes, vaults or other modular structures, while infiltrating into the surrounding soils.

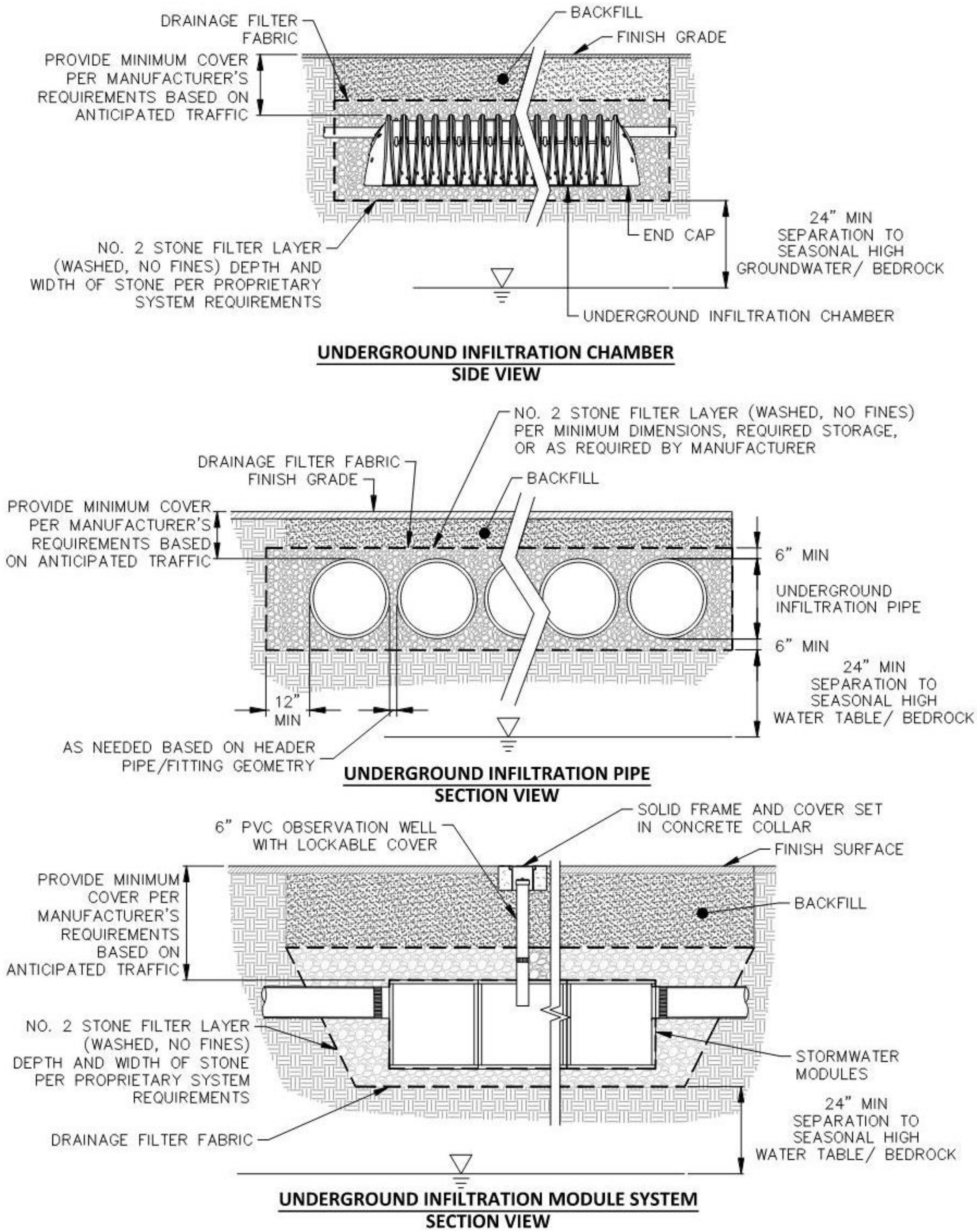


Figure 6.14 Underground Infiltration (I-4)

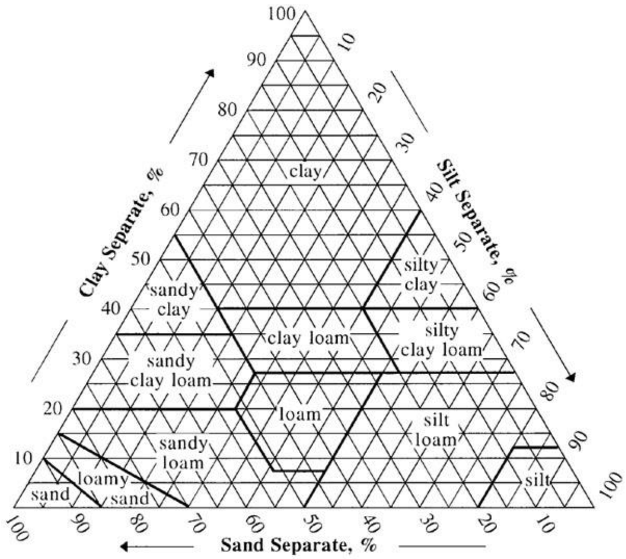
6.3.1 Feasibility

- To be suitable for infiltration, underlying soils shall have an infiltration rate (f_c) of at least 0.5 in/hr, as confirmed by field geotechnical tests. The minimum geotechnical testing shall be consistent with **Appendix D**.
- Underground infiltration systems likely qualify as a Class V injection well based upon the definition of a subsurface fluid distribution system (i.e. "an assemblage of perforated pipes, drain tiles, or other similar mechanisms intended to distribute fluids below the surface of the ground"). Refer to the EPA UIC Program for system registration requirements.
- Designers must be selective with the design of infiltration on sites with karst geology, shallow bedrock and soils, and hotspot land uses. Projects located over karst geology must provide runoff reduction by techniques that do not involve large infiltration basins and deep, concentrated recharge to the ground. A geotechnical assessment is recommended for infiltration and recharge at small scales.
- Infiltration practices shall not be located on areas with natural slopes greater than 15%, unless a slope stability analysis is performed by a qualified geotechnical engineer.
- Underground infiltration systems may be applied as a practice for urban stormwater management (**Chapter 8**).
- Urban fill soils shall not be used for infiltration practices. Urban fill in considered soil that includes unsuitable materials such as brick, cement, asphalt, demolition debris, etc.
- If infiltration practices are constructed in engineered fill soils, then the following criteria shall be met:
  - In-situ/natural soil layer below the infiltration system shall have an infiltration rate greater or equal to the engineered fill soils, as determined by geotechnical testing (**Appendix D**);
  - Soils proposed for engineered fill shall be classified as suitable using **Table 6.9** and **Figure 6.15**;
  - Soils proposed for engineered fill shall have a minimum infiltration rate of 0.50 inch/hr and a material gradation similar to the in-situ/natural soils, as determined by geotechnical testing;
  - After placement of engineered fill, permeability testing (**Appendix D**) shall be performed to confirm the infiltration rate. If engineered fill material requirements are not met, the material shall be removed;
  - The required vertical separation shall be measured from the existing grade of in-situ/natural soil. Engineered fill soils shall not be used to meet separation requirements; and
  - Construction of infiltration practices on slopes, through cut and fill operations, shall utilize the existing cut material to the greatest extent possible. The downhill berm shall be designed to prevent seeps, breakouts and slippage through the berm and at the interface of the in-situ/natural and fill material. A slope stability analysis shall be performed by a qualified geotechnical engineer.

Table 6.9 Hydrologic Soil Properties Classified by Soil Texture

Soil Texture Class	Hydrologic Soil Group	Minimum Infiltration Rate (inch/hr)	Suitability
Sand	A	8.27	Suitable for engineered fill for infiltration practice design
Loamy sand	A	2.41	
Sandy loam	B	1.02	
Loam	B	0.52	
Silt loam	C	0.27	Not suitable for engineered fill for infiltration practice design
Sandy clay loam	C	0.17	
Clay loam	D	0.09	
Silt clay loam	D	0.06	
Sandy clay	D	0.05	
Silty clay	D	0.04	
Clay	D	0.02	

Figure 6.15 USDA Soil Textural Classification



- Runoff from designated stormwater hotspots shall not be directed to an infiltration practice, unless two treatment practices are provided in series (i.e. non-infiltration standard SMP followed by an infiltration practice), both of which shall be sized to treat the entire WQ_v.
- In areas of known contamination, or if contamination is discovered during excavation, contamination levels must be evaluated by a qualified professional and the state remediation program to determine if infiltration is permitted.
- Infiltration practices shall meet the minimum separation requirements listed in **Table 6.10**. Vertical separation shall be taken from the bottom of practice, or stone reservoir where applicable. Horizontal separations shall be taken from the maximum water surface elevation (Extreme Flood peak water surface elevation) of the practice.

<table>
<tr><th colspan="9">Table 6.10 Infiltration Practice Minimum Separation Requirements</th></tr>
<tr><th></th><th colspan="2">Vertical Separation</th><th colspan="6">Horizontal Separation</th></tr>
<tr><th>Design Variant</th><th>Seasonal High Water Table[1,2]</th><th>Sound Bedrock[1]</th><th>Structures Without Foundation Waterproofing[4]</th><th>Structures With Foundation Waterproofing[4]</th><th>Water Supply Well/ Reservoir</th><th>Septic System[3,4]</th><th>Sanitary Sewer Main</th></tr>
<tr><td>Infiltration Trench (I-1)</td><td rowspan="5">2 ft</td><td rowspan="5">2 ft</td><td>25 ft</td><td>0 ft</td><td rowspan="5">100 ft</td><td rowspan="5">50 ft</td><td rowspan="5">25 ft</td></tr>
<tr><td>Infiltration Basin (I-2)</td><td colspan="2">25 ft</td></tr>
<tr><td>Dry Well (I-3)</td><td colspan="2">10 ft (single dry well)
25 ft (multiple dry wells in series)</td></tr>
<tr><td>Underground Infiltration System (I-4)</td><td colspan="2">25 ft</td></tr>
<tr><td>Infiltration Bioretention (F-4)</td><td>25 ft</td><td>10 ft</td></tr>
</table>

[1] Sound bedrock, fractured bedrock or karst geology as documented by on-site geotechnical testing
[2] Separation shall be increased to 4 ft in sole source aquifer
[3] Septic systems are inclusive of septic tanks, distribution boxes, absorption fields
[4] Infiltration practices shall be located downgradient of structures and septic systems

.

- The maximum contributing area shall meet the requirements listed in **Table 6.11**.

Table 6.11 Infiltration Practice Maximum Contributing Area Requirements

Design Variant	Maximum Contributing Area
Infiltration Trench (I-1)	5 ac
Infiltration Basin (I-2)	10 ac (where f_c of underlying soils 0.50 to 5.0 in/hr OR Contributing Impervious Area ≤ 10 acres) 25 ac (where f_c of underlying soils > 5.0 to 10.0 in/hr AND Contributing Impervious Area ≤ 15 acres) 50 ac (where f_c of underlying soils > 10 in/hr AND Contributing Impervious Area ≤ 20 acres)
Dry Well (I-3)	0.50 ac (for larger contributing areas, use multiple dry wells in series)
Underground Infiltration (I-4)	10 ac

Infiltration Basin Example 1:

Contributing Area = 13 acres
Contributing Impervious Area = 13 acres
Infiltration Rate = 6 in/hr

Under these design criteria, the maximum contributing area is 25 acres, and the designer can convey the entire contributing area to one infiltration basin.

Infiltration Basin Example 2:

Contributing Area = 23 acres
Contributing Impervious Area = 17 acres
Infiltration Rate = 4 in/hr

Under these design criteria, the maximum contributing area is 10 acres to one basin, since the infiltration rate and contributing impervious area do not meet the criteria for a maximum contributing area of 25 acres. Therefore, designer must convey the contributing area to at least three separate infiltration basins.

Construction Requirements

- Practice areas shall be clearly marked before any site work begins and heavy equipment traffic shall be restricted to avoid soil disturbance and compaction. The Erosion and Sediment Control plan shall clearly indicate how sediment will be prevented from entering the practice areas.
- For Design I-1, large tree roots shall be trimmed flush with the trench sides to prevent puncturing or tearing of the filter fabric. The side walls shall be roughened where sheared and sealed by heavy equipment.
- Permanent vegetative cover with 80% uniform density shall be established over the entire contributing pervious drainage area before runoff is directed into the facility.
- Infiltration practices shall never serve as a sediment control device during site construction phase and shall be installed at the end of the construction sequence, to the greatest extent practical.

6.3.2 Conveyance

- Infiltration practices shall be sized to store and infiltrate the required WQ_v. If inflow exceeds the storage capacity under larger storm events, then an adequate outlet pipe or overflow shall be designed to provide safe conveyance. If computed flow velocities exceed erosive velocities, the overflow shall be properly stabilized.
- Runoff conveyed to an infiltration practice by pipe or concentrated flow, under all storm events, shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the practice. If flow velocity cannot be reduced to non-erosive conditions, then the practice shall be designed off-line (refer to **Appendix C**) by use of a flow regulator or flow splitter diversion structure to divert the WQ_v to the practice and allow larger flows to bypass the practice.
- An emergency spillway shall be provided to safely convey stormwater exceeding the Extreme Flood.

6.3.3 Pretreatment

- Prior to entering an infiltration practice, the following pretreatment volume shall be provided:
  - 25% of the WQv for $f_c \leq 10.00$ in/hr.
  - 50% of the WQv for $f_c > 10.00$ in/hr.
- Adequate pretreatment for Designs I-1, I-2, I-3, and I-4 shall include one of the following:
  - Sedimentation chamber, plunge pool, or forebay, sized in accordance with **Section 6.4.3**; or
  - Vegetated swale with check dams (Maximum velocity of 1 fps for water quality flow).
  - Approved proprietary pretreatment device (Refer to **Chapter 9**).
- For Design I-1: when runoff is conveyed to the practice via sheet flow, adequate pretreatment also includes a grass filter strip sized in accordance with **Table 6.13**.
- Exit velocities from pretreatment devices shall be designed to ensure non-erosive outlet conditions.

6.3.4 Treatment

6.3.4.1 Design Criteria

Table 6.12 Infiltration Practice Design Specifications

		I-1	I-2	I-3	I-4
Freeboard	**Applicability**	N/A	Required	N/A	N/A
	Depth	1 ft. min. measured from top of Extreme Flood elevation to top of embankment			
Pea Gravel	**Applicability**	Required	N/A	N/A	N/A
	Depth	4 inch			
	Material	ASTM D448 No. 6 stone, Porosity = 32%			
Stone Reservoir	**Applicability**	Required	N/A	Required	As Required
	Depth	4 ft. max.	N/A	1 ft. min. on all sides & bottom	Per proprietary requirements
	Material	No. 2 stone, washed, no fines; Porosity=40%			
Storage[1]	**Depth**	Within reservoir	6 ft. max.	As Required[2]	As Required
	Side Slope	N/A	3:1 (h:v) max.	N/A	N/A
Observation Well	**Applicability**	Required	N/A	Required	N/A
	Material	6 inch min. perforated PVC or HDPE pipe with lockable cap			
Drainage Filter Fabric	**Applicability**	Required	N/A	Required	Required
	Material[3]	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)			
Maintenance Access[1]	**Applicability**	As Required	Required	As Required	As Required
	Slope	15% max.			
	Width	12 ft. min.			
	Material	Able to withstand loading of maintenance equipment and vehicles			

Footnotes:

[1]Required for all Design Variants

[2] An Underground Injection Control Permit may be required when certain conditions are met. Designer must Consult EPA's Underground Injection Control Program Fact Sheet for further information.

[3]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel

.

General

- All infiltration practices shall be designed to fully drain within 48-hrs of the maximum storm event for which it was designed.
- Designs I-1 and I-2 shall account for reduced infiltration rates under frozen conditions.
- All infiltration practices shall be designed such that the length, width, or diameter is greater than the depth in order to satisfy the UIC criteria. Refer to **Section 6.3.1**.

Maintenance Access

- A maintenance access easement shall extend to the practices from a public or private road.
- Adequate maintenance access must extend to the pretreatment device, outlet structure/overflow, emergency spillway, and must have sufficient area to allow vehicles to turn around.
- Where applicable, access to the outlet structure shall be provided by lockable manhole cover or grate.

6.3.4.2 Sizing Criteria

- Infiltration practices shall be designed to exfiltrate the entire WQ_v through the bottom surface area of the practice (vertical sides are not considered in sizing).
- Design I-1: calculate the minimum surface area of an infiltration trench using the following equation:

$$A_T = \frac{WQ_V}{\Phi \ x \ d_t}$$

  Where:

  A_T = Surface area of the infiltration trench (sf)

  WQ_V = Water Quality Volume (cf)

  Φ = Porosity (assume 0.4)

  d_t = Depth of trench (ft)

- Design I-2: calculate the minimum bottom area of an infiltration basin using the following equation:

$$A_b = \frac{WQ_V}{d_b}$$

  Where:

  A_b = Bottom area of the infiltration basin (sf)

  WQ_V = Water Quality Volume (cf)

  d_b = Depth of basin (ft) (measured from bottom to first outlet)

- Design I-3: calculate the Water Quality Volume provided by dry wells using the following equation:

$$WQ_V = N \ x \ V_W$$
$$V_W = V_i + V_s$$
$$V_i = \pi \ x \ ID \ x \ H$$
$$V_s = \big(\pi \ x \ (ID + 2t + 2t_s) \ x \ (H + 2t_s)\big) x \ 0.40$$

  Where:

  WQ_V = Water Quality Volume (cf)

  N = Number of dry wells

  V_w = Volume provided per dry well (cf)

  V_i = Inside volume of dry well (cf)

  V_s = Volume of stone reservoir (cf)

  ID = Inside diameter of dry well (ft)

  H = Inside height of dry well (ft)

  t = Thickness of dry well wall (ft)

  t_s = Thickness of stone reservoir (ft)

.

- Design I-4: calculate the minimum stone area of underground infiltration systems using the following equation:

$$A_b = \frac{WQ_V}{d_p}$$

  Where:

  A_b = Bottom area of the infiltration basin (sf)

  WQ_V = Water Quality Volume (cf)

  d_p = Depth of bottom stone (ft) (measured from bottom of stone to bottom of chambers)

- Design I-4: calculate the Water Quality Volume provided by underground infiltration systems using the following equation:

$$WQ_V = V_{st} + V_{sys}$$

  Where:

  WQ_V =Water Quality Volume (cf)

  V_{st} = Volume of stone reservoir (cf) (assume 40% voids)

  V_{sys} = Volume of system (cf) (excluding volume of stone)

- For Design I-4, the system shall be sized using hydrologic modeling, hydrologic calculations or calculations provided by the manufacturer, to demonstrate that the water quality and quantity control objectives have been met.

- For Designs I-1, I-3, and I-4, the bottom of the stone reservoir shall be laid level, so that runoff will infiltrate through the entire bottom surface area.

6.3.5 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.

- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Infiltration Trench (I-1)

Description: Excavated trenches filled with stone, designed to capture and temporarily store runoff in the stone reservoir, where it exfiltrates into the surrounding native soils.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Underlying soils shall have an min. infiltration rate of 0.50 inch/hr
- Practices shall not be located on areas with natural slopes > 15%
- Urban fill soils shall not be used for infiltration practices
- Max contributing area is 5 acres
- Min 2 ft separation to seasonal high-water table or bedrock
- Two treatment practices in series both sized to treat the entire WQv (non-infiltration standard SMP followed by an infiltration practice) shall be provided for hotspot treatment

CONVEYANCE

- Practice shall be size to store and infiltrate the WQv
- An outlet pipe or overflow for safe conveyance shall be provided in the event inflow exceeds the storage capacity under larger storm events
- An emergency spillway shall be provided
- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce velocity prior to entering the practice

PRETREATMENT

- Pretreatment volume shall be 25% WQv for fc ≤ 10.00 inch/hr or 50% WQv for fc > 10.00 inch/hr

TREATMENT

- Stone reservoir max. depth is 4 ft
- Stone reservoir shall have a 40% porosity
- An observation well with lockable cap shall be provided
- A min. 12 ft wide maintenance access, max. 15% slope, may be required
- Design to fully drain within 48 hrs of max. storm event for which it was designed
- Design shall account for reduced infiltration rates under frozen conditions
- Length or width of the practice shall be greater than the depth

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✱ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice
✱ suitable with exceptions

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- L Maintenance Burden
- L Safety Risk
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

Fact Sheet: Infiltration Basin (I-2)

Description: Vegetated excavations designed to capture and temporarily store stormwater runoff to promote infiltration into the surrounding native soils.

(Photo Source: Clark County, Washington)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Underlying soils shall have an min. infiltration rate of 0.50 inch/hr
- Practices shall not be located on areas with natural slopes > 15%
- Urban fill soils shall not be used for infiltration practices
- Max contributing area is 10 acres, 25 acres or 50 acres depending on underlying soil infiltration rates and contributing impervious area
- Min 2 ft separation to seasonal high-water table or bedrock
- Two treatment practices in series both sized to treat the entire WQv (non-infiltration standard SMP followed by an infiltration practice) shall be provided for hotspot treatment

CONVEYANCE

- Practice shall be size to store and infiltrate the WQv
- An outlet pipe or overflow for safe conveyance shall be provided in the event inflow exceeds the storage capacity under larger storm events
- An emergency spillway shall be provided
- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce velocity prior to entering the practice

PRETREATMENT

- Pretreatment volume shall be 25% WQv for fc ≤ 10.00 inch/hr or 50% WQv for fc > 10.00 inch/hr

TREATMENT

- 1 ft min. freeboard shall be provided
- 6 ft max. basin depth
- Provide a min. 12 ft wide maintenance access at a max. 15% slope
- Design to fully drain within 48 hrs of max. storm event for which it was designed
- Design shall account for reduced infiltration rates under frozen conditions
- Length or width of the practice shall be greater than the depth

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✱ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice
✱ suitable with exceptions

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- M Safety Risk
- M Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

Fact Sheet: Dry Well (I-3)

Description: Shallow excavations filled with stone or underground perforated structures surrounded by stone, that are designed to intercept and temporarily store runoff to promote infiltration into the surrounding native soils.

(Photo Source: Alpha Environmental)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Underlying soils shall have an min. infiltration rate of 0.50 inch/hr
- Practices shall not be located on areas with natural slopes > 15%
- Urban fill soils shall not be used for infiltration practices
- Max contributing area per drywell is 0.50 acre (for larger contributing areas, use multiple dry wells in series)
- Min 2 ft separation to seasonal high-water table or bedrock
- Two treatment practices in series both sized to treat the entire WQv (non-infiltration standard SMP followed by an infiltration practice) shall be provided for hotspot treatment

CONVEYANCE

- Practice shall be size to store and infiltrate the WQv
- An outlet pipe or overflow for safe conveyance shall be provided in the event inflow exceeds the storage capacity under larger storm events
- An emergency spillway shall be provided
- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce velocity prior to entering the practice

PRETREATMENT

- Pretreatment volume shall be 25% WQv for fc ≤ 10.00 inch/hr or 50% WQv for fc > 10.00 inch/hr

TREATMENT

- A stone reservoir shall be provided around the dry well, extending 1 ft min. on all sides and bottom of the dry well
- A min. 12 ft wide maintenance access, max. 15% slope, may be required
- Design to fully drain within 48 hrs of max. storm event for which it was designed
- Length, width or diameter of the practice shall be greater than the depth

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✱ Treatment of Hotspots
- Linear Applications

✓ suitable for this practice
✱ suitable with exceptions

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- L Safety Risk
- NA Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

Fact Sheet: Underground Infiltration (I-4)

Description: Practices that are typically installed below parking lots and other impervious surfaces, designed to capture and temporarily store stormwater runoff in pre-manufactured pipes, vaults or other modular structures, while infiltrating into the surrounding soils.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Underlying soils shall have an min. infiltration rate of 0.50 inch/hr
- Practices shall not be located on areas with natural slopes > 15%
- Urban fill soils shall not be used for infiltration practices
- Max contributing area per underground infiltration system is 10 acres
- Min 2 ft separation to seasonal high-water table or bedrock
- Two treatment practices in series both sized to treat the entire WQv (non-infiltration standard SMP followed by an infiltration practice) shall be provided for hotspot treatment

CONVEYANCE

- Practice shall be size to store and infiltrate the WQv
- An outlet pipe or overflow for safe conveyance shall be provided in the event inflow exceeds the storage capacity under larger storm events
- An emergency spillway shall be provided
- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce velocity prior to entering the practice

PRETREATMENT

- Pretreatment volume shall be 25% WQv for fc ≤ 10.00 inch/hr or 50% WQv for fc > 10.00 inch/hr

TREATMENT

- Designers shall provide stone reservoir per proprietary requirements
- A min. 12 ft wide maintenance access, max. 15% slope, may be required
- Design to fully drain within 48 hrs of max. storm event for which it was designed
- Length or width of the practice shall be greater than the depth

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✱ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice
✱ suitable with exceptions

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- M Maintenance Burden
- L Safety Risk
- NA Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

Section 6.4 Stormwater Filtering Practices

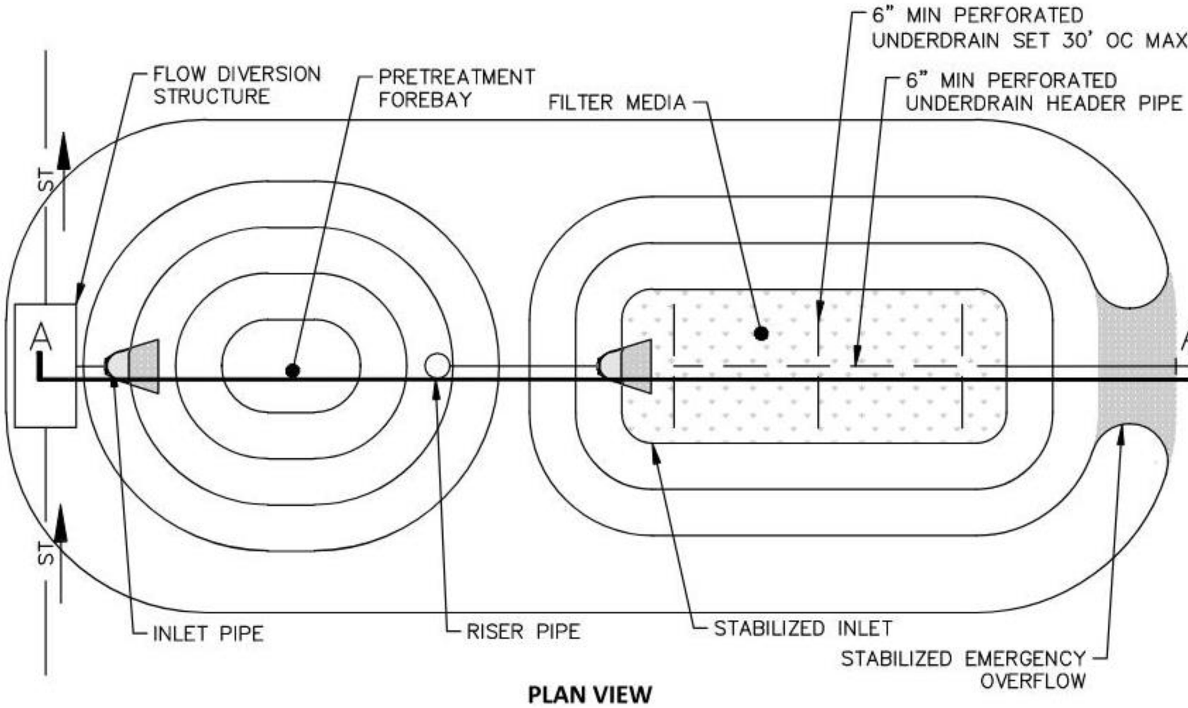
Stormwater filtering practices capture and temporarily store the WQ_v and pass it through a filter of sand, or soil. Filtered runoff may be collected and returned to the conveyance system or allowed to partially exfiltrate into the soil. Design variants include:

F-1 Surface Sand Filter	(**Figure 6.16**)
F-2 Underground Sand Filter	(**Figure 6.17**)
F-3 Perimeter Sand Filter	(**Figure 6.18**)
F-4 Infiltration Bioretention	(**Figure 6.19**)
F-5 Filtration Bioretention	(**Figure 6.20**)
F-6 Bioslopes	(**Figure 6.21**)

Refer to the **Fact Sheets** at the end of this section for key considerations of each filtering practice design variant, including performance criteria, practice suitability, implementation considerations, pollutant removal capability, and runoff reduction credit.

Surface Sand Filter (F-1)

A surface sand filter consists of a pretreatment sedimentation chamber or other pretreatment that discharges to an open sand filter bed designed to treat stormwater runoff, then return it to the conveyance system through a perforated underdrain system.



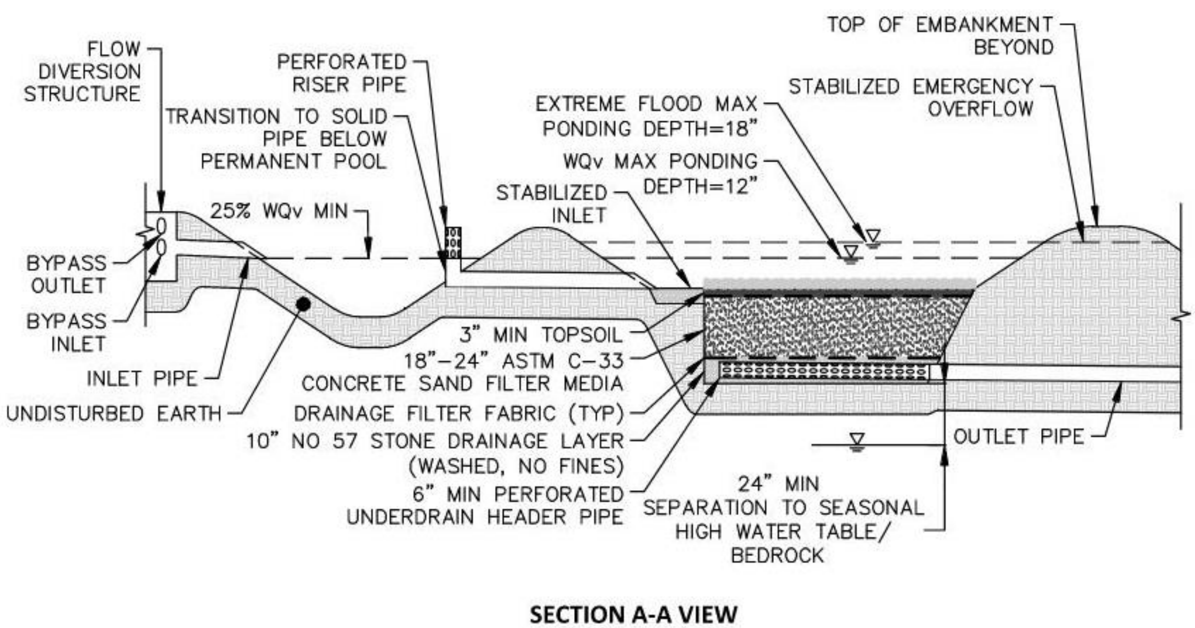
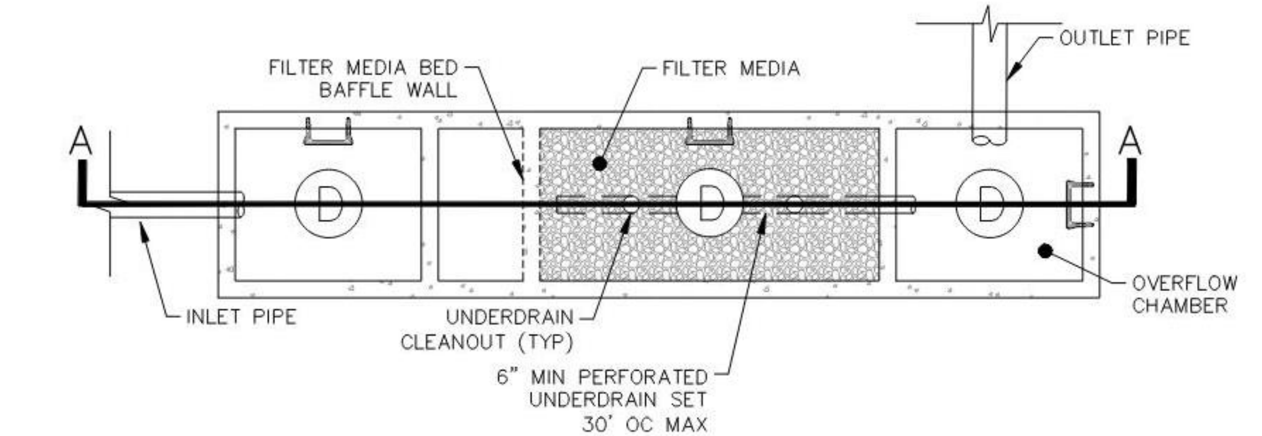


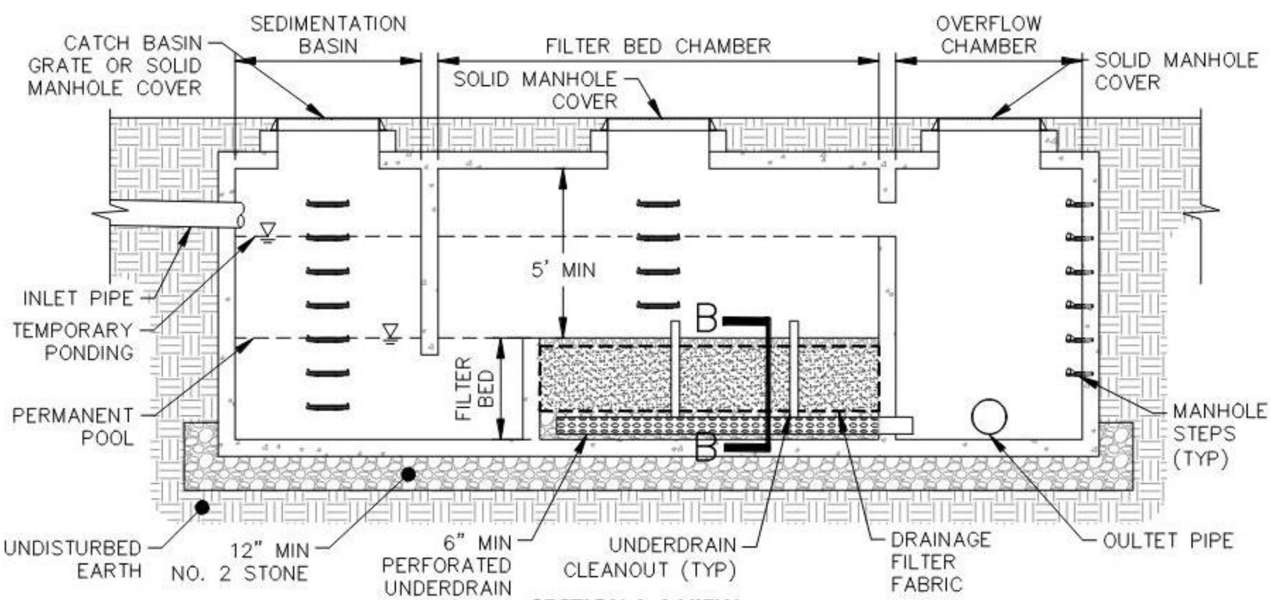
Figure 6.16 Surface Sand Filter (F-1)

Underground Sand Filter (F-2)

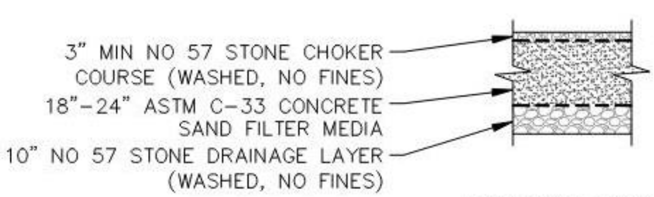
An underground sand filter is a practice where piped stormwater runoff is conveyed to an underground vault, consisting of a pretreatment sedimentation chamber that overflows to a sand filter bed designed to treat stormwater runoff, then return it to the conveyance system through an outlet pipe.



PLAN VIEW



SECTION A-A VIEW



SECTION B-B VIEW

Figure 6.17 Underground Sand Filter (F-2)

Perimeter Sand Filter (F-3)

A perimeter sand filter is a practice where stormwater runoff is conveyed via sheet flow to an underground vault with open grates that consists of a pretreatment sedimentation chamber that overflows to a sand filter bed designed to treat stormwater runoff, then return it to the conveyance system through an outlet pipe.

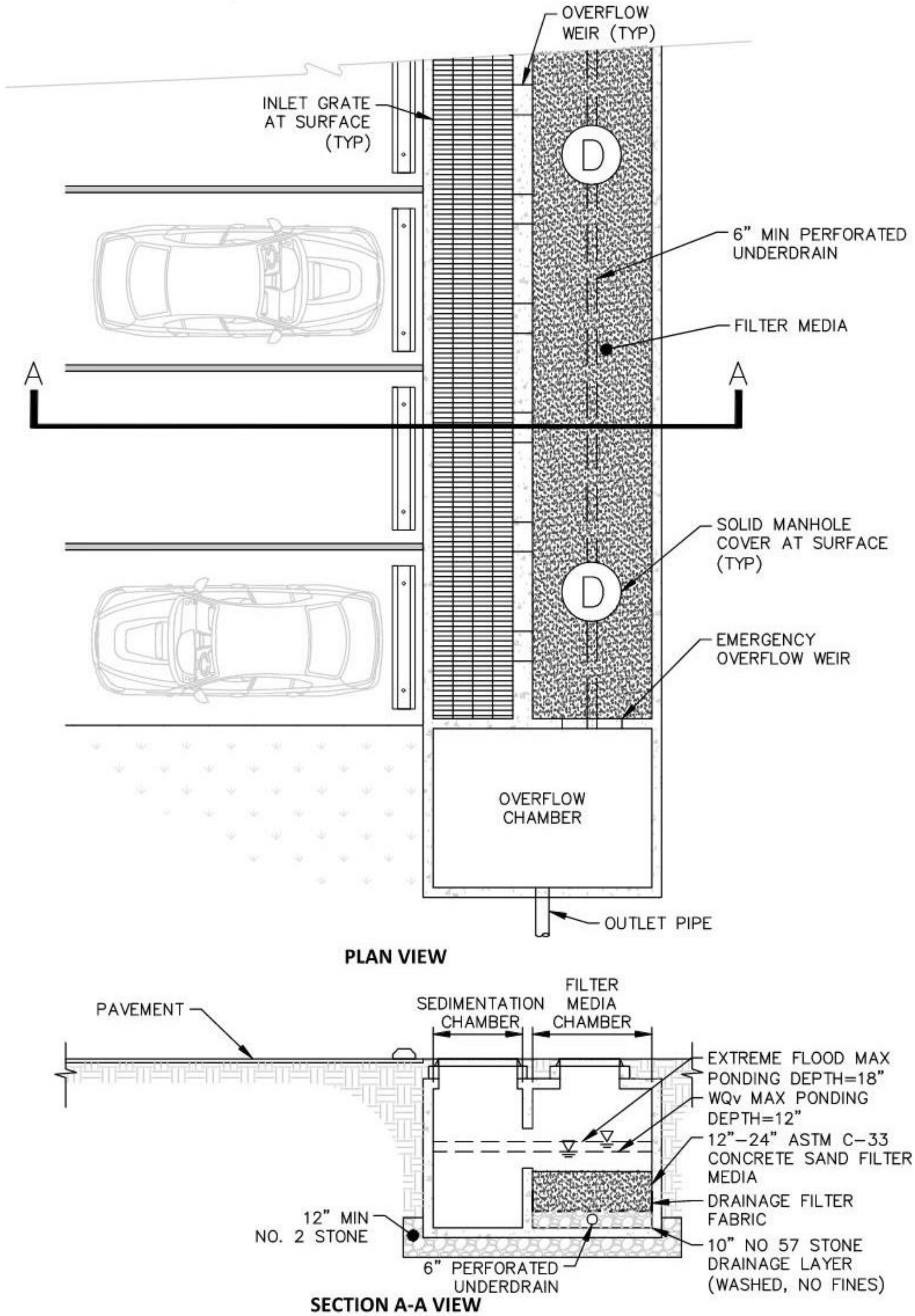


Figure 6.18 Perimeter Sand Filter (F-3)

Infiltration Bioretention (F-4)

Infiltration bioretention areas are shallow stormwater controls that utilize vegetation and engineered filter media to capture, treat, and infiltrate stormwater runoff into the underlying soils.

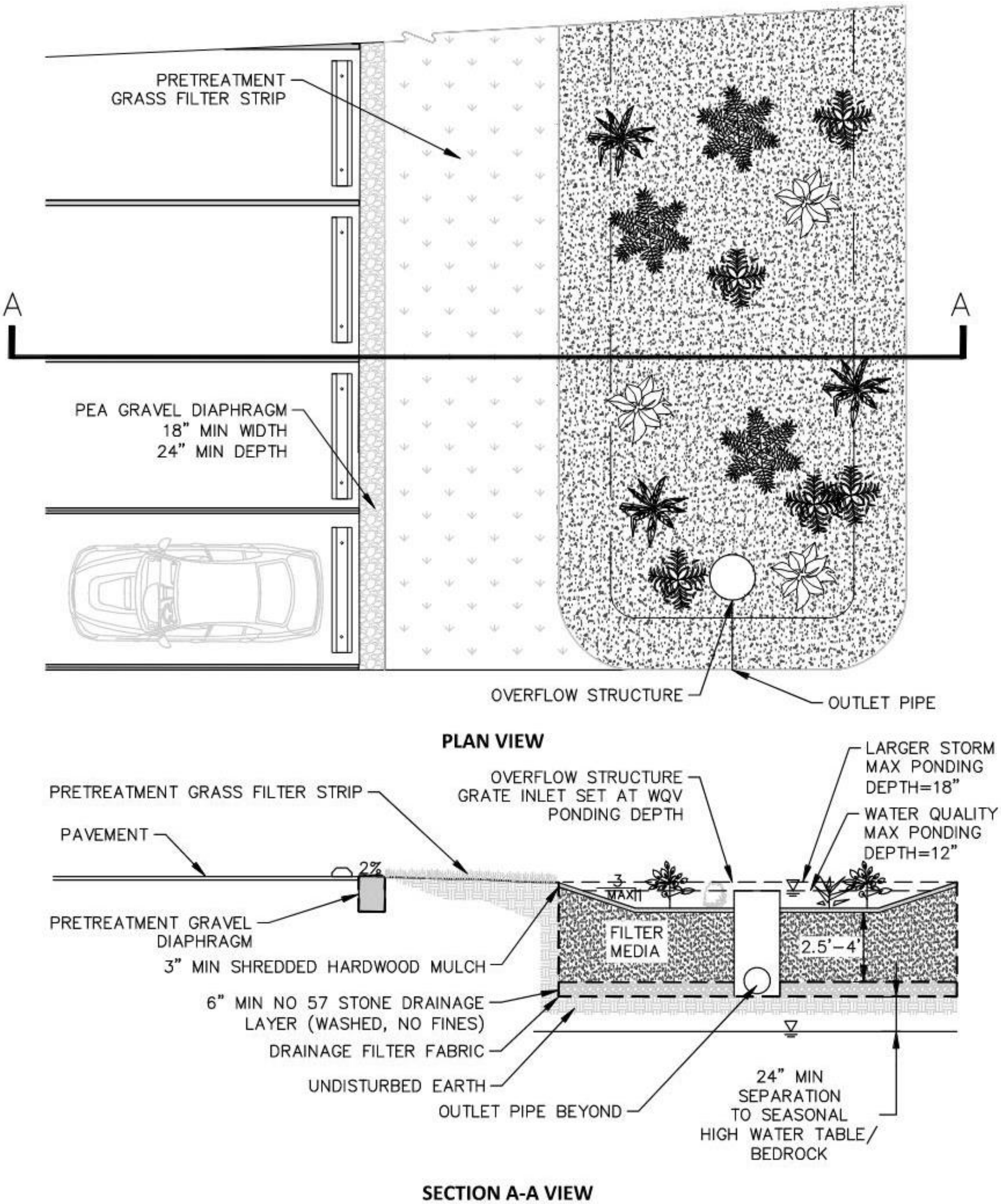


Figure 6.19 Infiltration Bioretention (F-4)

Filtration Bioretention (F-5)

Filtration bioretention areas are shallow stormwater control that utilize vegetation and engineered filter media to capture and treat stormwater runoff, then return it to the conveyance system through a perforated underdrain system.

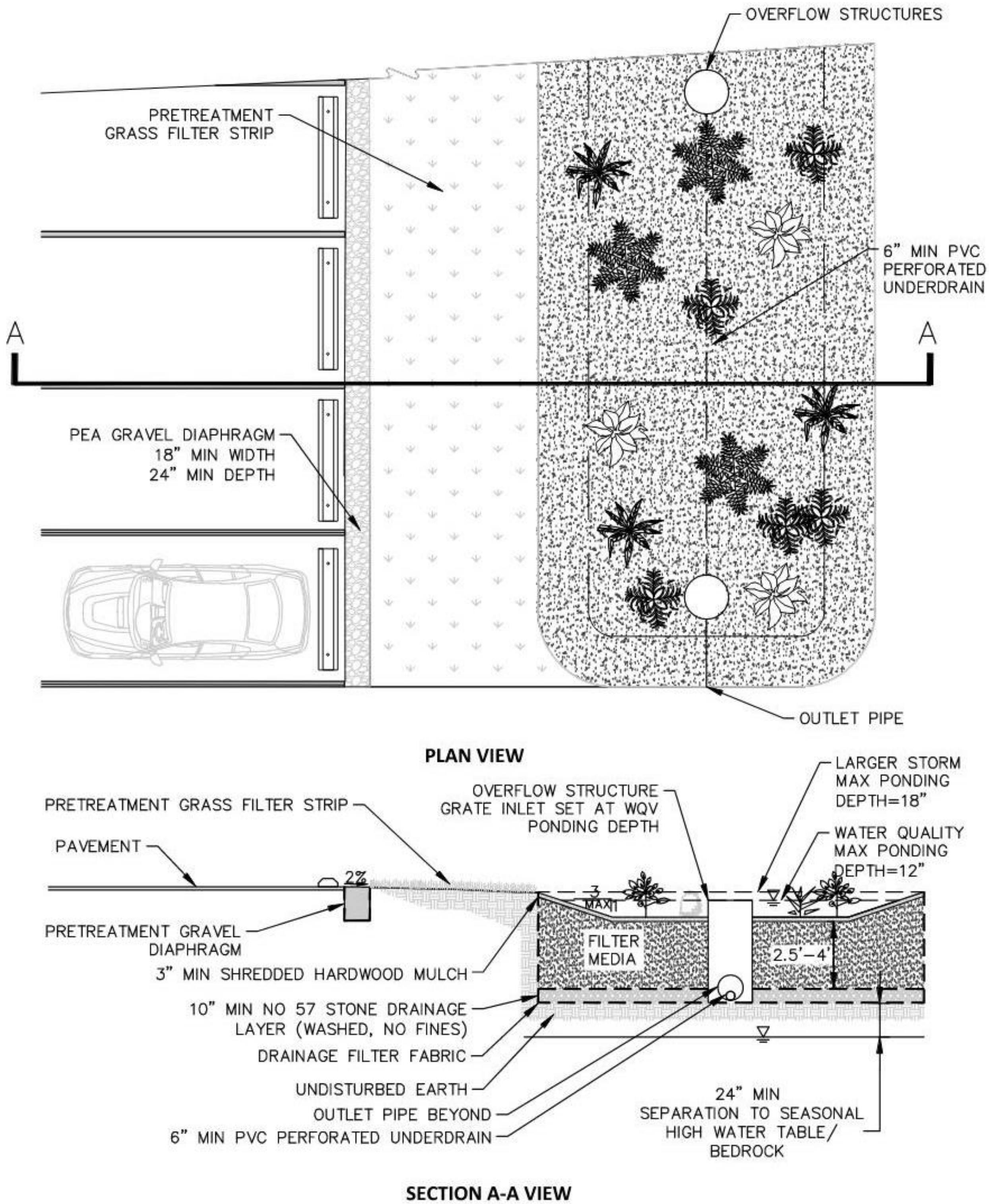


Figure 6.20 Filtration Bioretention (F-5)

Bioslope (F-6)

Bioslopes are installed adjacent to impervious surfaces, along embankments or slopes, and use a permeable engineered soil media to treat sheet flow stormwater runoff. These are designed with limited longitudinal slopes to force flow down through the engineered soil media and into an underdrain for conveyance.

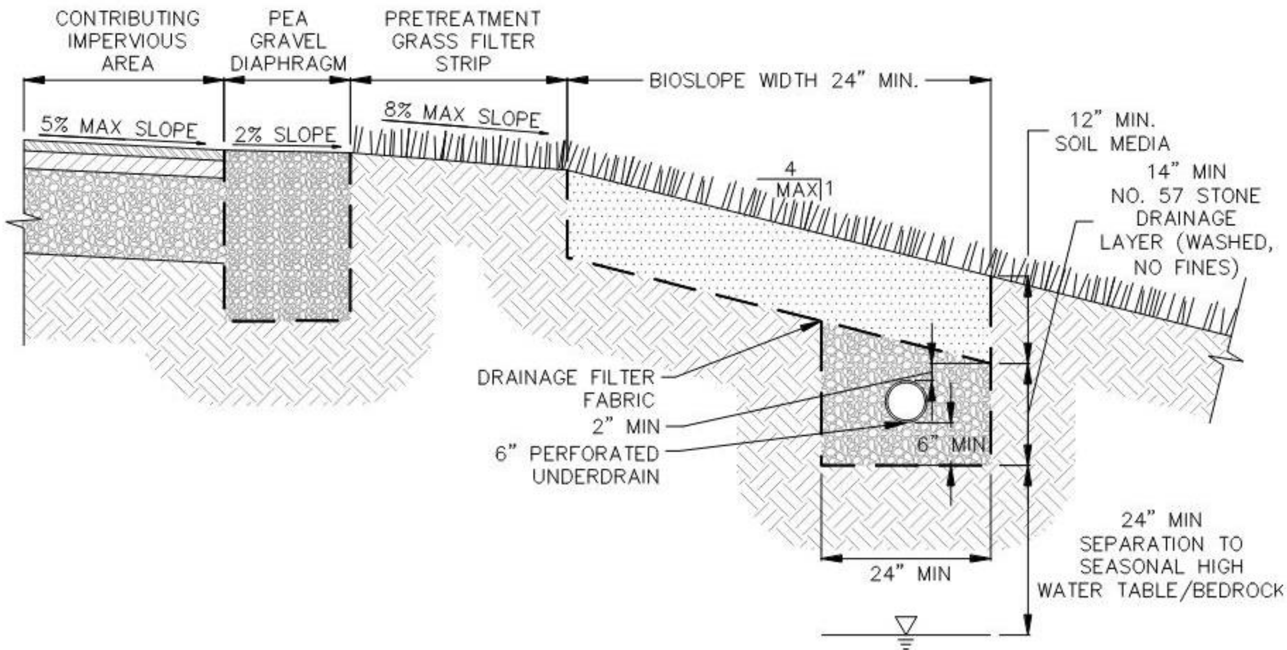


Figure 6.21 Bioslope (F-6)

6.4.1 Feasibility

- The maximum contributing area shall be:
  - Designs F-1: 10 acres
  - Designs F-2 and F-3: 2 acres
  - Designs F-4 and F-5: 5 acres
- The maximum contributing flow path length shall be:
  - Design F-6: 100 ft from impervious surfaces and 150 ft total.
- Designs F-1, F-2, F-3, and F-5, and F-6 shall have a minimum 2 ft separation between the bottom of the stone drainage layer and seasonal high water table or bedrock. For Designs F-1, F-5, and F-6, where 2 ft separation cannot be met, an impermeable liner shall be provided at bottom of drainage layer and all sides.
- Designs F-1, F-2, F-3, F-4 and F-5 shall be designed and constructed level, with no longitudinal or lateral slope.
- Design F-6 shall have a maximum 5% slope along the contributing impervious flow path.
- Design F-4 shall meet the minimum separation requirements outlined in **Table 6.10.**
- Design F-4 shall have underlying soils with an infiltration rate greater than or equal to 0.50 inch/hr. The minimum geotechnical testing shall be consistent with **Appendix D**. If underdrains are provided or the infiltration rate is less than 0.50 inch/hr, then the practice shall meet the criteria of Design F-5.
- Designs F-4, F-5 and F-6 may be applied as practices for urban stormwater management (see **Chapter 8**).
- Design F-6 may only be applied for access road; sidewalk, bike path or walking path projects, surfaced with an impervious cover; highway; and linear utility projects.
- Filtering practices can be used to treat stormwater runoff from a designated hotspot, when meeting the following design criteria:
  - Designs F-1, F-5, and F-6: an impermeable liner shall be provided at bottom of drainage layer and all sides.
  - Design F-4: runoff shall be directed to two practices in series (i.e. non-infiltration standard SMP followed by an infiltration practice), both of which are sized to treat the entire WQ_v.
- In areas of known contamination, or if contamination is discovered during excavation, the following design criteria shall be met:
  - Design F-1, F-5, and F-6: an impermeable liner shall be provided at bottom of drainage layer and all sides.
  - Design F-4: contamination levels must be evaluated by a qualified professional and the state remediation program to determine if infiltration is permitted.

Construction Requirements

- Practice areas shall be clearly marked before any site work begins and heavy equipment traffic shall be restricted to avoid soil disturbance and compaction. The Erosion and Sediment Control plan shall clearly indicate how sediment will be prevented from entering the practice areas.
- Permanent vegetative cover with 80% uniform density shall be established over the entire contributing pervious drainage area before runoff is directed into the facility.
- Filtration practices shall never serve as a sediment control device during site construction phase. Ideally, the practices shall be installed at the end of the construction sequence.

6.4.2 Conveyance

- Runoff that is conveyed to Designs F-1, F-2, F-3, F-4, and F-5 by pipe or concentrated flow, shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the filter media. If flow velocity cannot be reduced to non-erosive conditions, then the practice shall be designed off-line (refer to **Appendix C**) by use of a flow regulator or flow splitter diversion structure to divert the WQ_v to the practice and allow larger flows to bypass the practice.
- For Design F-6, the distance between the impervious surface and the practice shall be no more than 30 ft to avoid re-concentration of stormwater runoff and/or erosion of the engineered media. Runoff shall be conveyed by overland sheet flow only.
- Designs F-1, F-2, F-3, F-5 and F-6 shall be equipped with a perforated pipe underdrain in a washed stone drainage layer.
- For Design F-5, except where a liner is provided, underdrain systems shall be designed to create an internal water storage using one of the following methods:
  - Provide an upturned elbow, set 10 inches above the bottom of practice (See **Appendix C**)
  - Set the outlet pipe invert, at the outlet control structure, 10 inches above the bottom of practice; or
  - Increase the drainage layer depth to provide 8 inches of stone below the underdrain.
- Filtering practice outlet(s) shall be designed to ensure non-erosive outlet conditions.
- Designs F-1, F-2, F-3, F-4 and F-5 shall include an emergency spillway or overflow chamber with outlet pipe to safely convey stormwater exceeding the Extreme Flood.
- Designs F-4 and F-5 shall be equipped with an outlet mechanism designed to meet the maximum ponding depths, defined in **Table 6.14**. This can be accomplished with an overflow weir, an overflow structure or a combination of the two. Multiple outlet mechanisms may be necessary.

6.4.3 Pretreatment

6.4.3.1 Design Criteria

- Adequate pretreatment for Designs F-1, F-2, and F-3 shall incorporate a pretreatment volume equivalent to at least 25% of the required WQ_v, within one of the following pretreatment devices:
  - A sedimentation chamber, plunge pool or forebay with a length to width ratio of 1.5:1; or
  - Approved proprietary pretreatment device (Refer to **Chapter 9**).
- Adequate pretreatment for Designs F-4, and F-5 shall incorporate one of the following:
  - Sheet flow to minimum 24 inch wide by 12 inch deep pea gravel diaphragm and grass filter strip; or
  - Concentrated flow through a vegetated swale into a flow spreader; or
  - Concentrated flow into a flow spreader that discharges into a minimum 24 inch wide by 12 inch deep pea gravel diaphragm to a grass filter strip; or
  - Concentrated flow into a sedimentation chamber, plunge pool or forebay with a length to width ratio of 1.5:1 that is sized to hold a pretreatment volume equivalent to 25% of the required WQv; or
  - Concentrated flow into an approved proprietary pretreatment device (Refer to **Chapter 9**) that discharges into a flow spreader.
  - Sheet flow into gabion baskets or stone and curb check dams, when located within parking lot or roadway islands, medians or bumpouts (Refer to **Chapter 8**).
- Adequate pretreatment for Design F-6 shall incorporate the following:
  - Sheet flow to a minimum 24 inch wide by 12 inch deep pea gravel diaphragm and grass filter strip.

Sizing of Grass Filter Strip

- The grass filter strip shall be sized using the guidelines in **Table 6.13.**

Table 6.13 Guidelines for Grass Filter Strip Pretreatment Sizing

Parameter	Impervious Parking Lots/Roads				Residential Lots			
Max. Inflow Approach Length (ft)	35		75		75		150	
Grass Filter Strip Slope	≤ 2%	2-8%	≤ 2%	2-8%	≤ 2%	2-8%	≤ 2%	2-8%
Min. Grass Filter Strip Length (ft)	10	15	20	25	10	12	15	18

Sizing of Sedimentation Chamber

- Calculate the minimum surface area of the sedimentation using the Camp-Hazen equation:

$$A_s = -1 * \left(\frac{Q_0}{W_s}\right) \ln(1 - E)$$

Where:

A_s = Sedimentation chamber surface area (sf)
E = Sediment basin efficiency (use 0.90)
W_s = Particle settling velocity (ft/sec)
use 0.0004 ft/sec for imperviousness (I) ≤ 75%
use 0.0033 ft/sec for I > 75%
Q_0 = Discharge rate from basin = (WQ_v/24-hr/3600s)
WQ_v = Water Quality Volume (cf)

This equation reduces to:

A_s = (0.066) (WQ_v) sf for I ≤ 75%
A_s = (0.0081) (WQ_v) sf for I > 75%

- Calculate the maximum depth of the sedimentation chamber:

$$d_s = \frac{(\%PT * WQv)}{A_s}$$

Where:

A_s = Sedimentation chamber surface area (sf)
d_s = Depth of sedimentation chamber (ft)
%PT = Percent WQv pretreatment required
WQ_v = Water Quality Volume (cf)

- If proposed depth of sedimentation chamber is less than the maximum depth of sedimentation chamber, calculate the new minimum surface area of sedimentation chamber:

$$A_s = \frac{WQ_V}{d_s\ proposed}$$

- If multiple sedimentation chambers are provided to meet the minimum surface area, then the surface area shall be distributed across the structures. The percentage of the surface area provided by each structure shall correlate to the percentage of contributing impervious area to each structure.

6.4.4 Treatment

6.4.4.1 Design Criteria

General

- For Designs F-1, F-2, F-3, F-4, F-5, the surface of the filter media shall be completely level.
- For Design F-2, the minimum internal structure height shall be 5 ft.
- For Design F-5, the ends of underdrains, not terminating in an observation well, shall be capped.
- Designs F-4 and F-5 shall use the standard material for the filter media, as listed in **Table 6.14**. However, is the practice is being constructed in a phosphorus impaired watershed Designs F-4 and F-5 shall use the enhanced material for the filter media, as listed in **Table 6.14**.
- For Design F-6, the following criteria shall apply:
    - The underdrain system shall discharge to a storm drainage structure or a stable outfall. The underdrain shall be capped at the beginning of run.
    - Must be adequately designed to safely pass flows that exceed the design storm flows.
    - Embankment slopes shall be 4:1 or flatter.
    - Longitudinal slopes (parallel with the embankment) shall be no more than 5%.
    - Minimum width of soil media shall be 2 feet.
    - Ponded water shall not be permitted above the soil media.
    - The soil media shall have an initial infiltration rate of 50 inch/hr and an infiltration rate of 28 inch/hr. For sizing, an infiltration rate of 10 inch/hr shall be used in calculations as a factor of safety.

Table 6.14 Stormwater Filtering Design Specifications

<table>
<tr><th></th><th></th><th>F-1</th><th>F-2</th><th>F-3</th><th>F-4</th><th>F-5</th><th>F-6</th></tr>
<tr><td rowspan="3">Pea Gravel Diaphragm</td><td>Applicability</td><td>N/A</td><td>N/A</td><td>N/A</td><td>As Required</td><td>As Required</td><td>Required</td></tr>
<tr><td>Depth</td><td colspan="6">24 inch min.</td></tr>
<tr><td>Material</td><td colspan="6">ASTM D448 No. 6 Stone, Porosity = 32%</td></tr>
<tr><td rowspan="2">Ponding</td><td>Applicability</td><td>Required</td><td>Required</td><td>Required</td><td>Required</td><td>Required</td><td>N/A</td></tr>
<tr><td>Depth</td><td colspan="6">12 inch max. (WQv)
18 inch max. (Extreme Flood)</td></tr>
<tr><td rowspan="3">Surface Layer</td><td>Applicability</td><td>Required</td><td>Required</td><td>N/A</td><td>Required</td><td>Required</td><td>N/A</td></tr>
<tr><td>Depth</td><td colspan="6">3 inch min.</td></tr>
<tr><td>Material</td><td>Topsoil</td><td>Choker Course: AASHTO No. 57 stone, washed, no fines</td><td>N/A</td><td colspan="2">Shredded Hardwood Mulch</td><td>N/A</td></tr>
<tr><td rowspan="3">Filter Media[1,2]</td><td>Depth</td><td colspan="2">18-24 inch</td><td>12-24 inch</td><td colspan="2">30-48 inch</td><td>12 inch min.</td></tr>
<tr><td>Standard Material</td><td colspan="3" rowspan="2">Sand: ASTM C-33 concrete sand</td><td colspan="2">ASTM C-33 Sand: 60%-75%
Topsoil[4]: 25%-40%</td><td rowspan="2">Blend of Stone, Perlite, Dolomite, Gypsum</td></tr>
<tr><td>Enhanced Material[3]</td><td colspan="2">ASTM C-33 Sand:85%-95%
Topsoil/ Organic[5]: 5%-15%
P-Index: 12 to 30</td></tr>
<tr><td rowspan="2">Drainage Layer[1]</td><td>Depth</td><td colspan="3">10 inch</td><td>6 inch</td><td>10 inch</td><td>≥14 inch</td></tr>
<tr><td>Material</td><td colspan="6">AASHTO No. 57 stone, washed, no fines</td></tr>
<tr><td rowspan="2">Underdrain</td><td>Applicability</td><td>Required</td><td>Required</td><td>Required</td><td>N/A</td><td>Required</td><td>Required</td></tr>
<tr><td>Material</td><td colspan="6">6” perforated PVC or HDPE laid at 0.5% slope min. at 30 ft max. O.C.</td></tr>
<tr><td rowspan="2">Drainage Filter Fabric</td><td>Applicability</td><td>Required</td><td>Required</td><td>Required</td><td>Required</td><td>Required</td><td>Required</td></tr>
<tr><td>Material[6]</td><td colspan="6">Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)</td></tr>
<tr><td rowspan="2">Impermeable Liner</td><td>Applicability</td><td>As Required</td><td>N/A</td><td>N/A</td><td>N/A</td><td>As Required</td><td>As Required</td></tr>
<tr><td>Material</td><td colspan="6">12 - 24 inch of clay soil (min. 50% passing #200 sieve and max. permeability 1 x 10^{-5} cm/sec)
or 40 mil HDPE geomembrane</td></tr>
<tr><td rowspan="3">Maintenance Access[1]</td><td>Slope</td><td colspan="6">15% max.</td></tr>
<tr><td>Width</td><td colspan="6">12 ft. min.</td></tr>
<tr><td>Material</td><td colspan="6">Able to withstand loading from maintenance equipment and vehicles</td></tr>
</table>

Footnotes:

[1]Required for all Design Variants

[2]Design Variant F-6:

- Stone: No. 89, no recycled material, non-limestone material mineral aggregate
- Perlite: Agricultural grade, free of toxic materials (0-30% passing No.18 Sieve, 0-10% passing No.30 Sieve) 1 cy/3 cy of stone
- Dolomite: CaMg(CO3)2 (calcium magnesium carbonate) Agricultural grade, free of toxic materials (100% passing No.8 Sieve, 0% passing No.16 Sieve) 10 lbs/cy perlite
- Gypsum: CaSO4●2H2O (hydrated calcium sulfate). Non-calcined, agricultural grade, free of toxic materials (100% passing No.8 Sieve, 0% passing No.16 Sieve) 1.5 lb/cy perlite

[3]Enhanced Filter Media shall be used within watersheds requiring enhanced phosphorus removal. Refer to **Chapter 4** for impaired watershed information.

[4]Topsoil shall conform to NYSDOT Standard Specification 713-01 for Roadside Mix or Specialty Planting Mix.

[5]For Designs F-4 and F-5, the organic component shall not consist of compost.

[6]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel

Maintenance Access

- A maintenance access easement shall extend to the practices from a public or private road.
- Adequate maintenance access must extend to the pretreatment device, outlet structure/overflow, emergency spillway, and must have sufficient area to allow vehicles to turn around.
- For Designs F-2, F-3, F-4 and F-5, access shall be provided by lockable manhole cover or grate to the practice/outlet structure.
- For Design F-6 access shall be provided from the adjacent impervious surface.

6.4.4.2 Sizing Criteria

Design Variants (F-1 through F-5)

- The practice shall have a minimum of 50% WQv provided in ponding above the filter media. In addition, the practice shall be sized to capture, retain and filter the entire WQv event without overflow or bypass.
- A permeability flow rate (k) for filter media shall be as follows:
  - Sand: 3.5 ft/day (City of Austin 1988)
  - Bioretention: 1 ft/day
- The filter area shall be sized based on the principles of Darcy's Law. Calculate the minimum bottom area:

$$A_f = \frac{WQ_v d_f}{k\left(h_f + d_f\right)t_f}$$

Where:

A_f = Filter area (sf)
WQ_v = Water Quality Volume (cf)
d_f = Depth of filter (ft)
k = Permeability flow rate of filter media (ft/day)
h_f = Average height of ponding (ft) (0.5 ft max.)
t_f = Maximum filter bed drain time (days) (use 1.67 days for sand filters, 2 days for bioretention)

Design Variants (F-6)

- The width of soil media shall be sized, to treat the WQv for the surface discharge tributary to the bioslope. The length of the bioslope is equal to the length of the contributing area. Calculate the minimum soil media width required, using the calculations below. The minimum soil media width shall be no less than 24 inches.
  - First, calculate the required WQv, per **Chapter 4**.
  - Then, calculate the Water Quality Peak Flow Rate (**Appendix B**).
  - Calculate the required soil media width:

$$W = \frac{43{,}200 * WQ_F}{kL}$$

Where:

W = Bioslope width (ft)
WQ_F = Water Quality Peak Flow Rate (cfs)
k = Permeability flow rate of filter media (10 in/hr)
L = Bioslope length (ft)

6.4.5 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.
- A landscaping plan for Designs F-4 and F-5 shall be prepared to indicate how the practice bottom surface area and side slopes will be stabilized and established with vegetation and show the selection and layout of corresponding plant species.

Fact Sheet: Surface Sand Filter (F-1)

Description: Consists of a pretreatment sedimentation chamber or other pretreatment that discharges to an open sand filter bed designed to treat stormwater runoff, then return it to the conveyance system through a perforated underdrain system.

(Photo Source: Chesapeake Stormwater Network)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Max. contributing area is 10 acres
- Minimum 2 ft separation to seasonal high-water table or bedrock, unless an impermeable liner is provided
- Design and construct level, with no longitudinal or lateral slope
- Impermeable liner shall be provided at the bottom of the drainage layer and all sides when accepting hotspot runoff

CONVEYANCE

- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the filter media
- If flow velocity cannot be reduced to non-erosive conditions, the practice shall be designed off-line
- Equip practice with a perforated pipe underdrain in a washed stone drainage layer
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow chamber with outlet pipe to safely convey stormwater exceeding the Extreme Flood shall be included

PRETREATMENT

- Pretreatment shall provide min 25% WQv using a sedimentation chamber, plunge pool or forebay with a length to width ratio of 1.5:1, or an approved proprietary pretreatment device

TREATMENT

- Practice shall be sized (including pretreatment) to temporarily hold the WQv prior to filtration
- Max ponding is 12 inches (WQv) and 18 inches (Extreme Flood)
- Depth of filter media shall be 18 inches min and 24 inches max
- Depth of drainage layer shall be 10 inches
- Min 12 ft wide maintenance access shall be provided 15% max slope

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- H Maintenance Burden
- L Safety Risk
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See* ***Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Underground Sand Filter (F-2)

Description: A practice where piped stormwater runoff is conveyed to an underground vault, consisting of a pretreatment sedimentation chamber that overflows to a sand filter bed designed to treat stormwater runoff, then return it to the conveyance system through an outlet pipe

(Photo Source: Water Online)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Max contributing area is 2 acres
- Minimum 2 ft separation to seasonal high-water table or bedrock
- Design and construct level, with no longitudinal or lateral slope

CONVEYANCE

- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the filter media
- If flow velocity cannot be reduced to non-erosive conditions, the practice shall be designed off-line
- Equip practice with a perforated pipe underdrain in a washed stone drainage layer
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow chamber with outlet pipe to safely convey stormwater exceeding the Extreme Flood shall be included

PRETREATMENT

- Pretreatment shall provide min 25% WQv using a sedimentation chamber, plunge pool or forebay with a length to width ratio of 1.5:1, or an approved proprietary pretreatment device

TREATMENT

- Practice shall be sized (including pretreatment) to temporarily hold the WQv prior to filtration
- Min internal structure height is 5 ft
- Max ponding is 12 inches (WQv) and 18 inches (Extreme Flood)
- Depth of filter media shall be 18 inches min and 24 inches max
- Depth of drainage layer shall be 10 inches
- Min 12 ft wide maintenance access shall be provided 15% max slope

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- H Maintenance Burden
- L Safety Risk
- NA Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Perimeter Sand Filter (F-3)

Description: A practice where stormwater runoff is conveyed via sheet flow to an underground vault with open grates that consists of a pretreatment sedimentation chamber that overflows to a sand filter bed designed to treat stormwater runoff, then return it to the conveyance system through an outlet pipe.

(Photo Source: Greensboro, North Carolina, Department of Water Resources)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Max contributing area is 2 acres
- Minimum 2 ft separation to seasonal high-water table or bedrock
- Design and construct level, with no longitudinal or lateral slope

CONVEYANCE

- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the filter media
- If flow velocity cannot be reduced to non-erosive conditions, the practice shall be designed off-line
- Equip practice with a perforated pipe underdrain in a washed stone drainage layer
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow chamber with outlet pipe to safely convey stormwater exceeding the Extreme Flood shall be included

PRETREATMENT

- Pretreatment shall provide min 25% WQv using a sedimentation chamber, plunge pool or forebay with a length to width ratio of 1.5:1, or an approved proprietary pretreatment device

TREATMENT

- Practice shall be sized (including pretreatment) to temporarily hold the WQv prior to filtration
- Max ponding is 12 inches (WQv) and 18 inches (Extreme Flood)
- Depth of filter media shall be 12 inches min and 24 inches max
- Depth of drainage layer shall be 10 inches
- Min 12 ft wide maintenance access shall be provided 15% max slope

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- H Maintenance Burden
- L Safety Risk
- NA Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% RRv provided

Fact Sheet: Infiltration Bioretention (F-4)

Description: Shallow stormwater controls that utilize vegetation and engineered filter media to capture, treat, and infiltrate stormwater runoff into the underlying soils.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Underlying soils shall have an min. infiltration rate of 0.50 inch/hr
- Design and construct level, with no longitudinal or lateral slope
- Max contributing area is 5 acres
- Min 2 ft separation to seasonal high-water table or bedrock
- Two treatment practices in series both sized to treat the entire WQv (non-infiltration standard SMP followed by an infiltration practice) shall be provided for hotspot treatment

CONVEYANCE

- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the filter media
- If flow velocity cannot be reduced to non-erosive conditions, the practice shall be designed off-line
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow chamber with outlet pipe to safely convey stormwater exceeding the Extreme Flood shall be included

PRETREATMENT

- Pretreatment shall provide min 25% WQv

TREATMENT

- Practice shall be sized (including pretreatment) to temporarily hold the WQv prior to filtration
- Max ponding is 12 inches (WQv) and 18 inches (Extreme Flood)
- Depth of filter media shall be 30 inches min and 48 inches max
- Depth of drainage layer shall be 6 inches
- Min 12 ft wide maintenance access shall be provided 15% max slope

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- H Maintenance Burden
- M Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- G Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 100% RRv provided

Fact Sheet: Filtration Bioretention (F-5)

Description: Shallow stormwater controls that utilize vegetation and engineered filter media to capture and treat stormwater runoff, then return it to the conveyance system through a perforated underdrain system.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Max contributing area is 5 acres
- Minimum 2 ft separation to seasonal high-water table or bedrock, unless an impermeable liner is provided
- Design and construct level, with no longitudinal or lateral slope
- Impermeable liner shall be provided at the bottom of the drainage layer and all sides when accepting hotspot runoff

CONVEYANCE

- Runoff conveyed by pipe or concentrated flow shall utilize a pretreatment device or flow dissipator to reduce flow velocity prior to entering the filter media
- If flow velocity cannot be reduced to non-erosive conditions, the practice shall be designed off-line
- Equip practice with a perforated pipe underdrain in a washed stone drainage layer
- Underdrain systems shall include an upturned elbow, set 10 inches above the bottom of practice
- Outlet(s) shall be designed to ensure non-erosive outlet conditions
- An emergency spillway or overflow chamber with outlet pipe to safely convey stormwater exceeding the Extreme Flood shall be included

PRETREATMENT

- Pretreatment shall provide min 25% WQv

TREATMENT

- Practice shall be sized (including pretreatment) to temporarily hold the WQv prior to filtration
- Max ponding is 12 inches (WQv) and 18 inches (Extreme Flood)
- Depth of filter media shall be 30 inches min and 48 inches max
- Depth of drainage layer shall be 10 inches
- Min 12 ft wide maintenance access shall be provided 15% max slope

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- H Maintenance Burden
- M Safety Risk
- H Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- F Nitrogen
- G Metals
- G Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 40% RRv provided

Fact Sheet: Bioslope (F-6)

Description: Installed along embankments or other slopes and use a permeable engineered soil media to treat sheet flow stormwater runoff. They are designed with limited longitudinal slopes to force flow through an engineered soil media and to an underdrain for conveyance.

(Photo Source: Atlanta Regional Commission)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Max contributing flow path shall be 100 ft from impervious surfaces and 150 ft total
- Minimum 2 ft separation to seasonal high-water table or bedrock, unless an impermeable liner is provided
- Max slope along the contributing impervious flow path is 5%
- Impermeable liner shall be provided at the bottom of the drainage layer and all sides when accepting hotspot runoff

CONVEYANCE

- The distance between the impervious surface and the practice shall be no more than 30 ft
- Runoff shall be conveyed by overland sheet flow only
- Equip practice with a perforated pipe underdrain in a washed stone drainage layer
- Outlet(s) shall be designed to ensure non-erosive outlet conditions

PRETREATMENT

- Pretreatment shall provide min 25% WQv with a pea gravel diaphragm and grass filter strip

TREATMENT

- Depth of filter media shall be 14 inches min
- Depth of drainage layer shall be 14 inches min
- Min 12 ft wide maintenance access shall be provided 15% max slope
- Maintenance access shall be provided from the adjacent impervious surface

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection
- ✓ Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- H Maintenance Burden
- M Safety Risk
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See Table 10.3*)

- G Phosphorus
- F Nitrogen
- G Metals
- F Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 40% RRv provided for HSG A or B
  20% RRv provided for HSG C or D

Section 6.5 Open Channel Systems

Open channel systems are vegetated open channels that are explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means. Design variants include:

O-1	Dry Swale	(**Figure 6.22**)
O-2	Wet Swale	(**Figure 6.23**)

Dry Swale (O-1)

Dry swales are a vegetated conveyance channel designed to include a filter bed of prepared soil that may overlay an underdrain system. Dry swales are sized to allow the entire WQv to be filtered or infiltrated through the bottom of the swale.

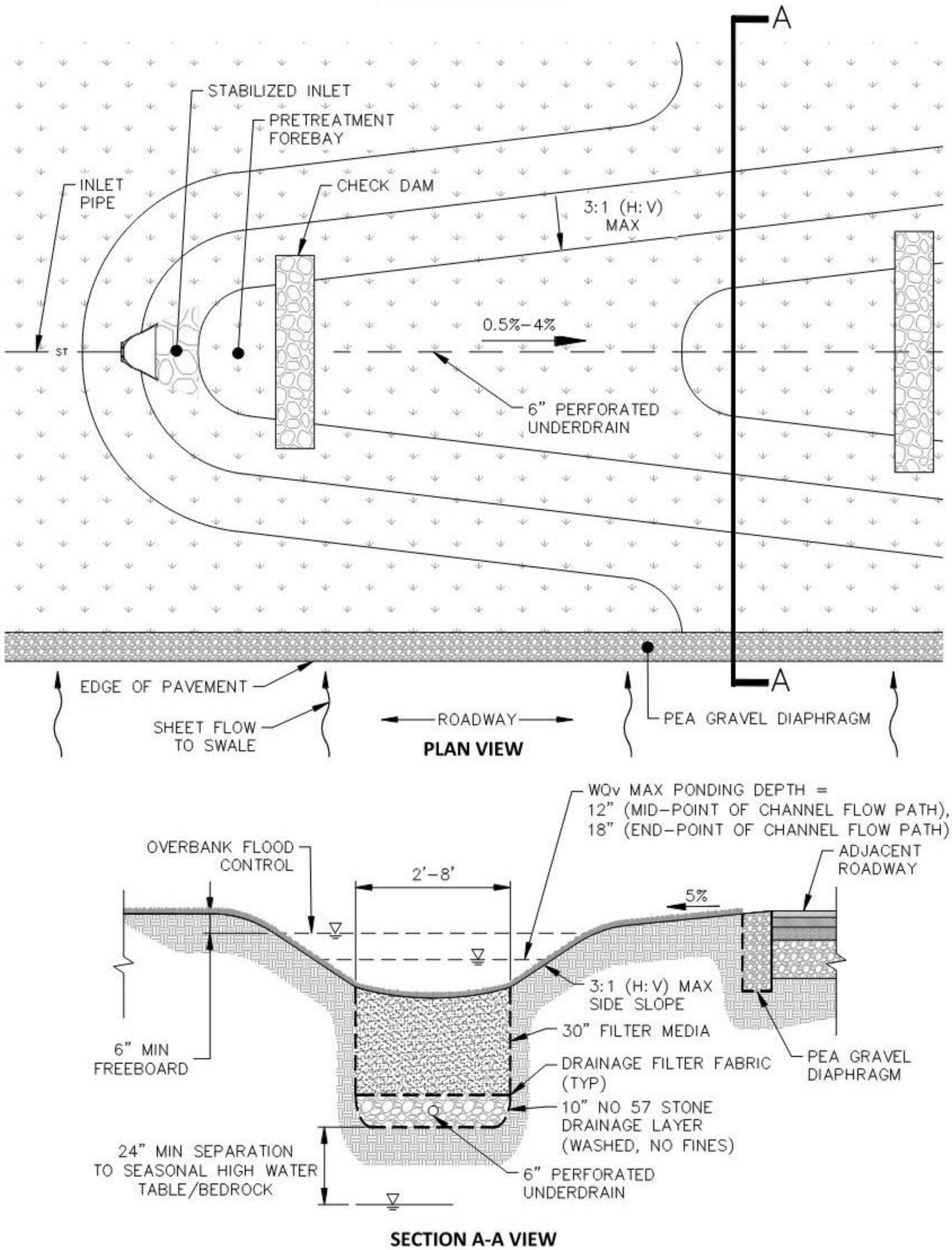


Figure 6.22 Dry Swale (O-1)

Wet Swale (O-2)

Wet swales are a vegetated conveyance channel designed to retain water/create marshy conditions that support wetland vegetation. A seasonal high water table or poorly drained soils are necessary to retain water. The wet swale essentially acts as a linear shallow wetland treatment system, where the WQ_v is retained.

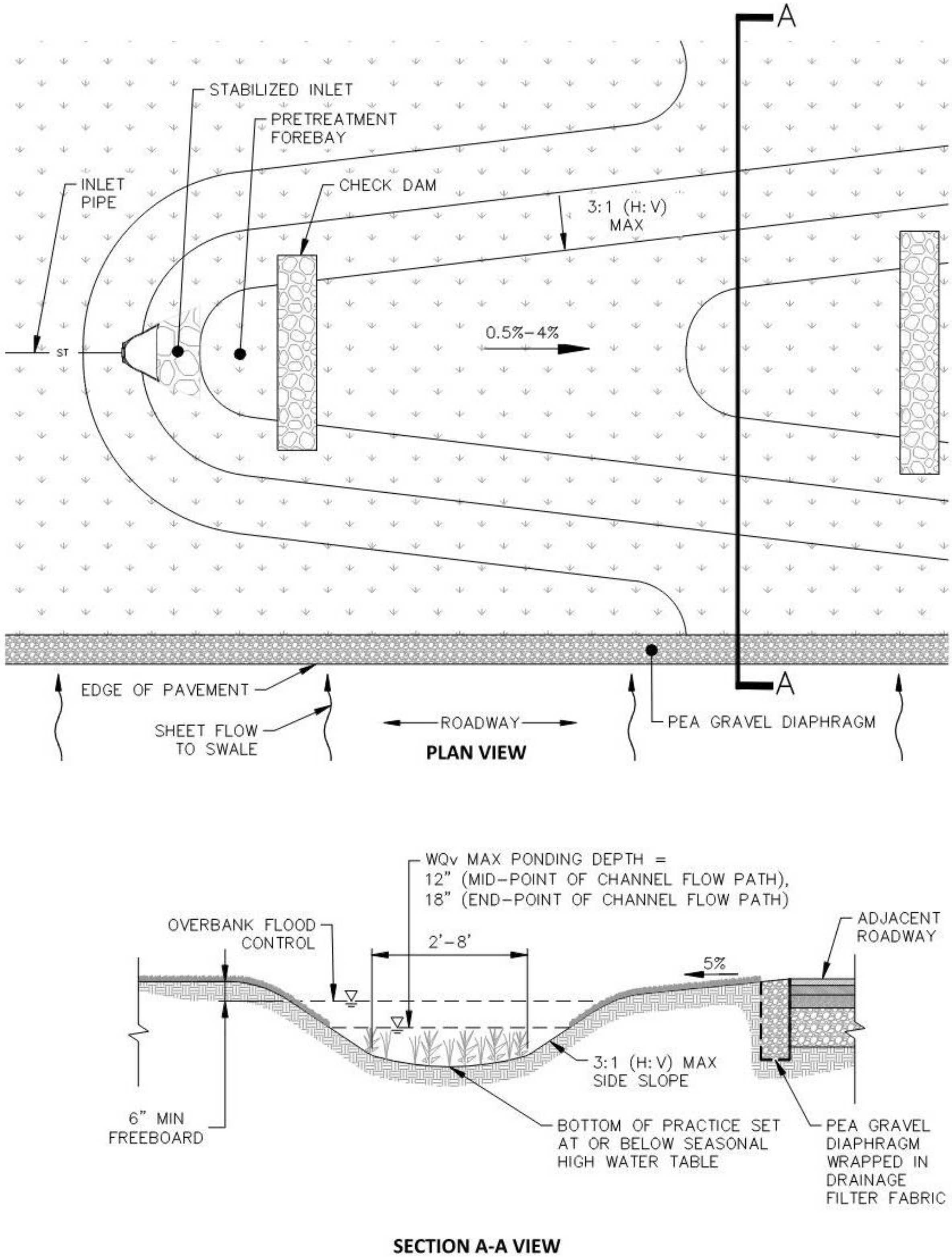


Figure 6.23 Wet Swale (O-2)

6.5.1 Feasibility

- O-1 shall be applied for land uses such as roads, highways, residential development, and pervious areas.
- O-2 shall not be applied in residential areas because of the potential for stagnant water and ponding.
- O-1 shall have a minimum 2 ft separation between the bottom of the stone drainage layer and seasonal high water table or bedrock. Where separation cannot be met, an impermeable liner shall be provided at bottom of drainage layer and all sides.
- O-1 can be used to treat stormwater runoff from a designated hotspot. However, an impermeable liner shall be provided at bottom of drainage layer and all sides. Design O-2 shall not be used to treat stormwater runoff from a designated hotspot.
- The maximum contributing area shall be 5 acres.

6.5.2 Conveyance

- Swales shall be designed to ensure non-erosive outlet conditions.
- Channels shall be designed to drain the entire WQ_v within 48-hrs after the storm event.
- When runoff sheet flows from an impervious surface to an open channel system, a maximum 6 inch drop to a minimum 24 inch wide by 12 inch deep pea gravel diaphragm shall be provided.
- Where culvert pipes are proposed, the pipe shall have a minimum diameter of 12 inches and minimum slope of 0.50%, designed to convey the Overbank Flood event while safely conveying the Extreme Flood event.

6.5.3 Pretreatment

- Prior to entering the open channel system, 10% of the WQ_v shall be provided as pretreatment.
- The following pretreatment devices are appropriate for use with open channel systems.
    - Pretreatment sedimentation chamber sized in accordance with Section 6.4.3.
    - Plunge pool or forebay.
    - Provide check dams, or other low flow control structure capable of draining the channel within 48 hours, at inlet pipes and/or driveway crossings.
    - For runoff conveyed via sheet flow, provide a 24 inch wide by 12 inch deep pea gravel diaphragm at the downgradient edge of the impervious surface. In this case, the maximum contributing surface slope shall be 5%.
    - Approved proprietary pretreatment device (Refer to **Chapter 9**).

6.5.4 Treatment

6.5.4.1 Design Criteria

- Open channel practices shall meet the design criteria outlined in the table below:

Table 6.15 Open Channel Design Specifications

		O-1	O-2
Freeboard[1]	**Depth**	6 inch min. measured from Overbank Flood elevation to top of swale	
Ponding	**Depth**	12 inch max. at mid-point of channel flow path during WQv Storm 18 inch max. at end point of channel flow path during WQv Storm	
Channel	**Width**	2 ft min. 8 ft max.	
	Longitudinal Slope	0.5% min. 4% max.	
	Side Slope	3:1 (h:v) max.	
Filter Media	**Applicability**	Required	N/A
	Depth	30 inches	
	Standard Material	ASTM C-33 Sand: 75%-85% Topsoil[4]: 15%-25%	
Drainage Layer	**Applicability**	Required	N/A
	Depth	10 inches min.	
	Material	AASHTO No. 57 stone, washed, no fines	
Drainage Filter Fabric	**Applicability**	Required	N/A
	Material[5]	Non-woven, polypropylene geotextile with flow rate greater than 125 gpm/sf (ASTM D4491) and Apparent Opening Size US #70 sieve (ASTM D4751)	
Impermeable Liner	**Applicability**	As Required	N/A
	Material	12 - 24 inch of clay soil (min. 50% passing #200 sieve and max. permeability 1×10^{-5} cm/sec) or 40 mil HDPE geomembrane	
Underdrain	**Applicability**	Required	N/A
	Material	6" min. perforated PVC or HDPE	
Check Dams[1]	**Depth**	1 ft max.	
	Side Slopes	2:1 max.	
	Spacing	Refer to Section 6.5.4.2	
	Material	Well graded stone matrix 2 to 9 inches	

Footnotes:
[1]Required for all Design Variants
[2]Enhanced Filter Media shall be used within watersheds requiring enhanced phosphorus removal.
[3]Topsoil shall conform to NYSDOT Standard Specification 713-01 for Roadside Mix or Specialty Planting Mix.
[4]The organic component shall not consist of compost.
[5]Or acceptable alternatives, such as a 3 inch minimum layer of pea gravel

6.5.4.2 Sizing Criteria

- First, compute the required WQ_v, per **Chapter 4**:
- Next, select proposed dimensions of the open channel for the bottom width, side slopes, channel length and channel height, and longitudinal slope.
- Then calculate the swale top width and area:

$$W_{Top} = b + (2\ x\ Side\ Slope)\ x\ C_H$$

$$A = \frac{C_H\ x\ (b + W_{Top})}{2}$$

Where:

W_{Top} = Channel top width (ft)

A = Area of swale (sf)

b = Bottom width (ft)

C_H = Check dam height (ft)

- Calculate the required swale length. The proposed channel length shall be greater than or equal to the required swale length.

$$L_r = \frac{WQ_V}{A_{Trap}}$$

$$L_p \geq L_r$$

Where:

L_r = Required channel length (ft)

L_p = Proposed channel length (ft)

- Calculate the channel volume provided. The volume of the channel shall be greater or equal to the required WQ_v.

$$V_C = L_p\ x\ A$$

$$V_C \geq WQ_V$$

- Select a check dam height and calculate the required check dam spacing and number of check dams required, based on the NYSDEC Standard and Specifications for Check Dam.

$$C_S = \frac{C_H}{S_L}$$

$$C = \frac{L_p}{C_S}$$

Where:

C_S = Check dam spacing (ft)

C_H = Check dam height (ft)

C = Number of check dams

- Select Manning's coefficient for flow through the channel and determine the 2-year average flow depth. Calculate the 2-yr velocity within the channel using Manning's equation.

$$V = \frac{1.49}{n}\ x\ D_2{}^{2/3}\ x\ S_L{}^{1/2}$$

Where:

V = 2-yr velocity (fps)

n = Manning's coefficient

D_2 = 2-yr average flow depth (ft)

S_L = longitudinal slope (ft/ft)

- Confirm that a minimum of 6 inches of freeboard is provided during the Overbank Flood event.

6.5.5 Landscaping

- For planting guidance for stormwater management facilities, refer to **Chapter 11**.
- Permanent vegetative cover shall achieve 80% uniform density established over the entire contributing pervious area, before runoff is directed into the facility.

Fact Sheet: Dry Swale (O-1)

Description: Vegetated channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry cells. Dry swales include a filter bed of prepared soil and are sized to filter or infiltrate the entire WQ_v.

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall be applied for land uses such as roads, highways, residential development, and pervious areas
- Min 2 ft separation to seasonal high water table or bedrock, unless impermeable liner is provided
- Impermeable liner shall be provided for hotspots
- Max contributing area is 5 acres

CONVEYANCE

- An underdrain shall be provided
- Shall have non-erosive outlet conditions
- Design to drain the entire WQv within 48 hrs after the storm event
- For sheetflow from impervious surfaces, a max 6 inch drop to a pea gravel diaphragm shall be provided
- Where culvert pipes are proposed, the pipe shall have a min 12 inch diameter and a min slope of 0.50%, designed to convey the Overbank Flood event and safely convey the Extreme Flood event

PRETREATMENT

- 10% WQv shall be provided as pretreatment

TREATMENT

- Min 6 inch freeboard shall be provided from the Overbank Flood elevation to the top of swale
- Max ponding depth during WQv event is 12 inch at the mid-point of the channel flow path and 18 inch at the end point of the channel flow path
- Filter media depth shall be 30 inches
- Min drainage layer depth shall be 10 inches
- Bottom width shall be a min of 2 ft and a max of 8 ft
- Channel slope shall be 0.50% min and 4.0% max
- Max 3:1 side slope
- Check dams shall be provided

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- Extreme Flood Protection
- ✓ Runoff Reduction
- ✓ Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- M Capital Cost
- M Maintenance Burden
- L Safety Risk
- L Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- F Nitrogen
- G Metals
- P Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 40% RRv provided for HSG A or B
  20% RRv provided for HSG C or D

Fact Sheet: Wet Swale (O-2)

Description: Vegetated channels that are explicitly designed and constructed to capture and treat stormwater runoff. Wet swales retain water to support wetland vegetation and essentially act as a linear shallow wetland treatment system, where the WQ_v is retained.

(Photo Source: Maryland State Highway Administration)

Key Considerations

PERFORMANCE CRITERIA

FEASIBILITY

- Shall not be applied in residential areas
- Max contributing area is 5 acres

CONVEYANCE

- Shall have non-erosive outlet conditions
- Design to drain the entire WQv within 48 hrs after the storm event
- For sheet flow from impervious surfaces, a max 6 inch drop to a pea gravel diaphragm shall be provided
- Where culvert pipes are proposed, the pipe shall have a min 12 inch diameter and a min slope of 0.50%, designed to convey the Overbank Flood event and safely convey the Extreme Flood event

PRETREATMENT

- 10% WQv shall be provided as pretreatment

TREATMENT

- Min 6 inch freeboard shall be provided from the Overbank Flood elevation to the top of swale
- Max ponding depth during WQv event is 12 inch at the mid-point of the channel flow path and 18 inch at the end point of the channel flow path
- Bottom width shall be a min of 2 ft and a max of 8 ft
- Channel slope shall be 0.50% min and 4.0% max
- Max 3:1 side slope
  Check dams shall be provided

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- Extreme Flood Protection
- Runoff Reduction
- Treatment of Hotspots
- ✓ Linear Applications

✓ suitable for this practice

IMPLEMENTATION CONSIDERATIONS

- L Capital Cost
- M Maintenance Burden
- L Safety Risk
- M Landscaping

L = Low **M** = Moderate **H** = High
NA = Not Applicable

POLLUTANT REMOVAL (*See **Table 10.3***)

- G Phosphorus
- F Nitrogen
- G Metals
- P Pathogens
- G Total Suspended Solids

G = Good **F** = Fair **P** = Poor

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided by this practice

Chapter 7: Stormwater Management Design Examples

This Chapter presents design examples for a hypothetical development in the State of New York. The proposed project is a residential development on a vacant undeveloped parcel. The Chapter is divided into four sections, each providing an example of the most commonly used standard stormwater management practices.

- **Section 7.1** Using data from the example project, this section walks through watershed/subcatchment delineation, times of concentration, the six-step process based on **Chapter 4,** and design and sizing for conservation of natural areas, filtration bioretention and wet pond in accordance with **Chapter 6.**
- **Section 7.2** Uses modified data from the example project to design and size a filtration bioretention and infiltration basin in a designated hotspot that meets the requirements of **Chapter 4** and **Chapter 6**.
- **Section 7.3** Uses modified data from the example project to design and size a dry swale that meets the requirements of **Chapter 4** and **Chapter 6**.
- **Section 7.4** Uses modified data from the example project to design and size multiple dry wells in series that meet the requirements of **Chapter 4** and **Chapter 6**.

Section 7.1 Sizing Example – Conservation, Bioretention and Wet Pond

The site data listed below are for the hypothetical residential development (**Table 7.1**).

Table 7.1 Site Data

Total Parcel Area	33.8 acres
Existing Site Cover	Vacant undeveloped woods and grass with an on-site wetland
Existing Soils	59% C soils and 41% D soils with no Soil Slope Phase “D” with unit name inclusive of slopes greater than 25% or Soil Slope Phase “E” or “F”
Depth to Bedrock	15 ft below existing grade
Depth to Seasonal High Water Table	10 ft below existing grade
Wetlands	No existing NYSDEC wetlands on-site Existing federally regulated wetland on-site
Watershed	Does not discharge to a watershed requiring enhanced phosphorus removal
Principal, Primary or Sole Source Aquifer	Does not lie within an aquifer
Hotspot	The proposed development is not a hotspot (**Section 4.14**)
90th percentile rainfall	1.20 inches (**Section 4.2**)
1-year 24-hour rainfall	2.22 inches (NRCC and NRCS joint collaborative website **Section 4.9**)
2-year 24-hour rainfall	2.60 inches (NRCC and NRCS joint collaborative website **Section 4.9**)
10-year 24-hour rainfall	3.74 inches (NRCC and NRCS joint collaborative website **Section 4.9**)
100-year 24-hour rainfall	6.31 inches (NRCC and NRCS joint collaborative website **Section 4.9**)

Part 1. Delineate the Pre-development and Post-development Subcatchment Boundaries

The study area consists of an overall watershed that contains the project site. The overall watershed is broken down into smaller watershed, or subcatchments, to allow for analysis of runoff conditions at several locations throughout the study area. Each of these locations is defined as a Design Point in order to compare the effects resulting from stormwater management facilities proposed as part of the project. A Design Point may include but is not limited to a concentrated point (end section, catch basin, etc.), the entire perimeter of a waterbody or permanent pool (wetland, stream, etc.), the full length of an existing on-site channel that is not being disturbed, or the full length of a natural flow spreader.

A subcatchment is a relatively homogeneous area of land, which produces a volume and rate of runoff unique to that area. The subcatchment boundaries are determined using existing (and proposed under post-development) topography. Subcatchment lines originate at high points on the topography and run perpendicular to the contour lines until reaching a design point. These lines do not intentionally originate or terminate at the project's property boundaries, as runoff may flow onto or off of the site. Areas that will remain undisturbed should be bypassed around proposed stormwater management practices to avoid capture and treatment, maintain existing hydrology and minimize the footprint of proposed practices. Some computer design programs have the capability to delineate subcatchments using established topographic data. The subcatchments generated by these programs are considered approximate and shall be verified by the design engineer for consistency with site conditions. In addition, it is highly recommended that site visits be performed to confirmed delineated watershed divides, drainage paths and design points.

Under the example project the pre-development project site is covered predominately by existing woodlands, with an on-site federally regulated wetland. The pre-development watershed delineation map is provided as **Figure 7.1** with the area highlighted in blue identified as subcatchment ES-1.

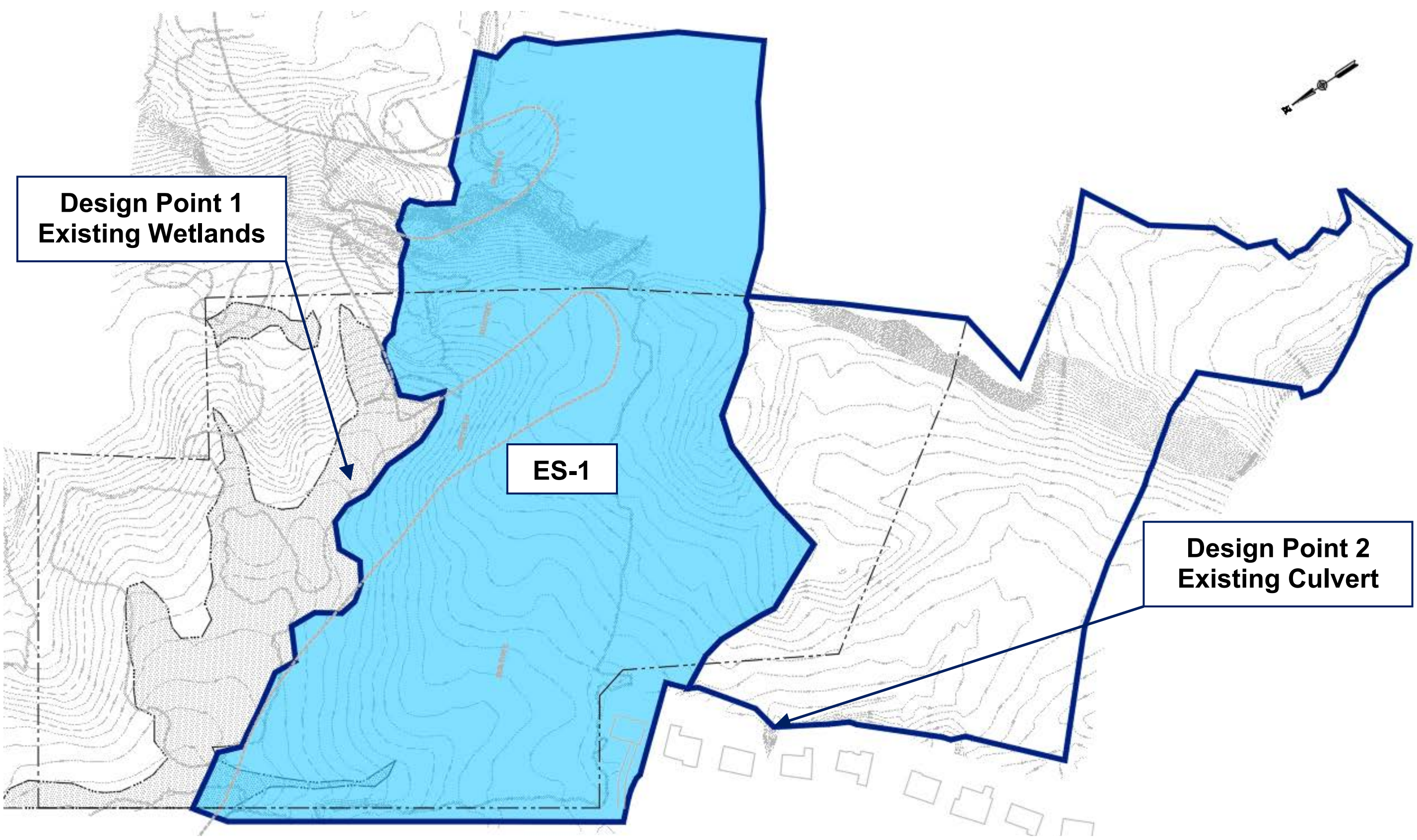


Figure 7.1 Pre-development Watershed Delineation Map

Under the example project the post-development project site will preserve areas of existing woodlands and the on-site federally regulated wetland. The area within the limit of disturbance will be covered predominately by impervious cover from pavement and buildings. The post-development watershed delineation map is provided as **Figure 7.2**, with the area highlighted in blue is identified as subcatchment PS-4.

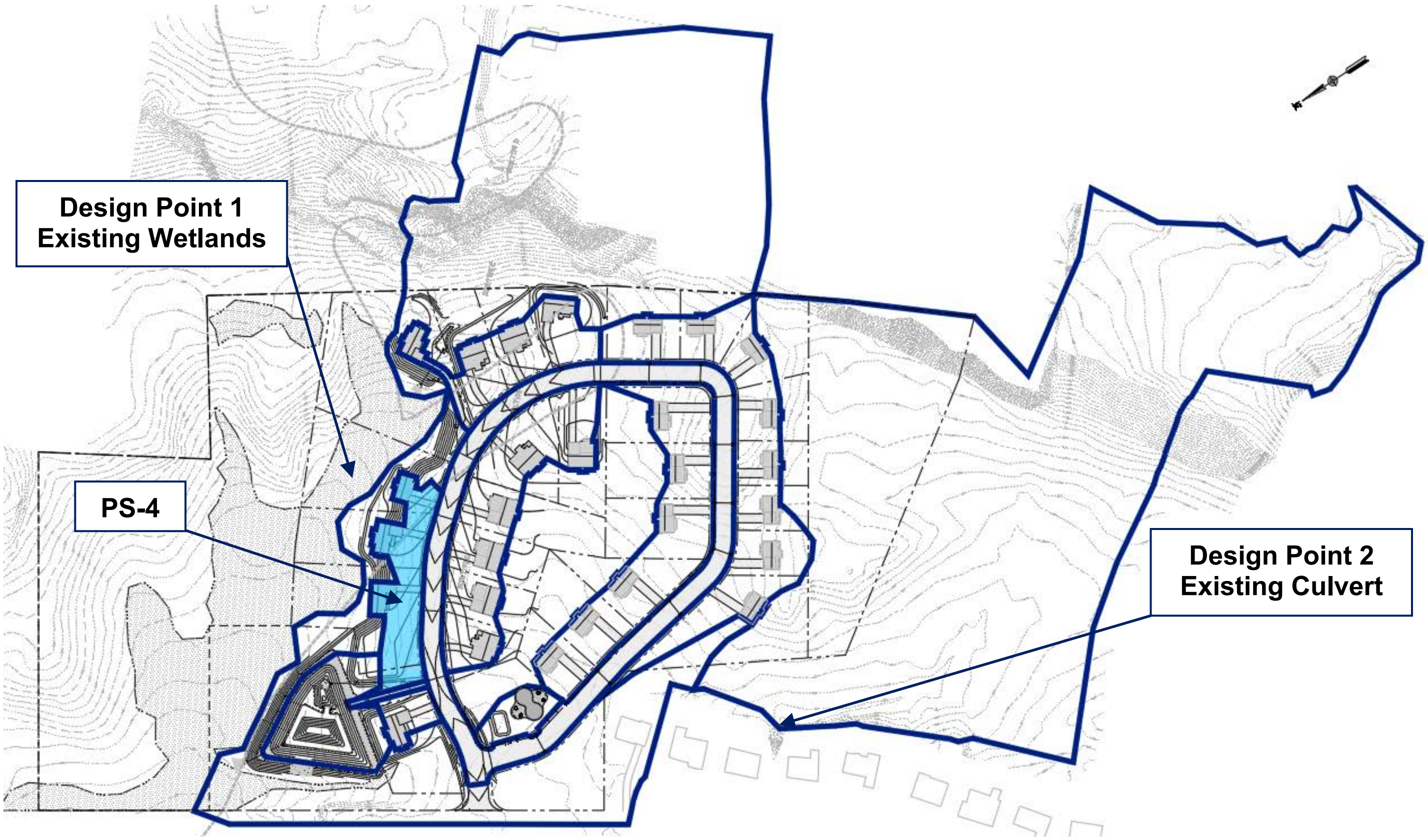


Figure 7.2 Post-development Watershed Delineation Map

Part 2. Determine the Pre-development and Post-development Cover Statistics

Each subcatchment uses a Curve Number (CN) to characterize the runoff properties for a particular HSG and ground cover. Some of these ground cover types can be classified as “Poor”, “Fair” and “Good”. It is the intent when classifying cover that “Poor” represents less than 50% ground cover density, “Fair” represents 50% to 75% ground cover density, and “Good” represents greater than 75% ground cover density. When referring to wood cover, “Poor” represents heavy forest litter, small trees, and brush; “Fair” represents woods with moderate forest litter covering the soil; “Good” represents woods that are undisturbed with litter and brush adequately covering the soil. In addition, the “Woods and Grass” cover type designation is intended to represent areas such as orchards or tree farms. For additional information regarding runoff curve numbers, refer to **TR-55 Chapter 2**.

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into four HSG’s (A,B,C and D) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. High CN values cause most of the rainfall to appear as runoff with minimal losses. Lower values correspond to an increase ability of the soil to retain rainfall and will produce less runoff. **Figure 7.3** and **Figure 7.5**, shown below, provide the overall cover statistics for the pre-development and post-development conditions. **Figure 7.4** and **Figure 7.6**, shown below, provide the cover statistics specific to pre-development subcatchment ES-1 and post-development subcatchment PS-4.

Area (acres)	CN	Description (subcatchment-numbers)
4.430	74	>75% Grass cover, Good, HSG C (ES-1)
0.603	98	Paved parking, HSG C (ES-1)
0.012	98	Paved parking, HSG D (ES-1)
0.053	98	Roofs, HSG C (ES-1)
0.177	98	Water Surface, 0% imp, HSG C (ES-1)
0.111	98	Water Surface, 0% imp, HSG D (ES-1)
35.377	70	Woods, Good, HSG C (ES-1, ES-2)
3.219	77	Woods, Good, HSG D (ES-1)
43.982	**72**	**TOTAL AREA**

Figure 7.3 Overall Pre-development Cover Statistics

Area (sf)	CN	Description
2,326	98	Roofs, HSG C
26,278	98	Paved parking, HSG C
7,728	98	Water Surface, 0% imp, HSG C
4,817	98	Water Surface, 0% imp, HSG D
192,975	74	>75% Grass cover, Good, HSG C
140,204	77	Woods, Good, HSG D
763,723	70	Woods, Good, HSG C
506	98	Paved parking, HSG D
1,138,557	73	Weighted Average
1,109,447		97.44% Pervious Area
29,110		2.56% Impervious Area

Figure 7.4 ES-1 Pre-development Cover Statistics

Area (acres)	CN	Description (subcatchment-numbers)
5.879	74	>75% Grass cover, Good, HSG C (ES-1A, ES-1B, ES-2, PS-10, PS-2, PS-3, PS-4, PS-6, PS-7, PS-8, PS-9)
0.769	80	>75% Grass cover, Good, HSG D (ES-1A, PS-10, PS-3, PS-4, PS-7, PS-9)
0.260	96	Gravel surface, HSG C (ES-1B, ES-1C, PS-4, PS-6, PS-8)
0.009	96	Gravel surface, HSG D (ES-1B)
1.281	98	Paved parking, HSG C (ES-1B, PS-10, PS-2, PS-3, PS-4, PS-5, PS-7, PS-8, PS-9)
0.143	98	Paved parking, HSG D (ES-1B, ES-1C, PS-3, PS-4, PS-7)
1.704	98	Paved roads w/curbs & sewers, HSG C (PS-1)
0.361	98	Paved roads w/curbs & sewers, HSG D (PS-1)
1.571	98	Roofs, HSG C (ES-1B, ES-1C, PS-10, PS-3, PS-4, PS-7, PS-8, PS-9)
0.145	98	Roofs, HSG D (PS-4, PS-7)
0.419	98	Water Surface, 0% imp, HSG C (ES-1B, PS-6)
0.111	98	Water Surface, 0% imp, HSG D (ES-1B)
29.591	70	Woods, Good, HSG C (ES-1A, ES-1B, ES-1C, ES-2)
1.740	77	Woods, Good, HSG D (ES-1B, ES-1C)
43.982	**75**	**TOTAL AREA**

Figure 7.5 Overall Post-development Cover Statistics

Area (sf)	CN	Description
2,654	98	Roofs, HSG C
5,042	98	Roofs, HSG D
1,475	98	Paved parking, HSG C
702	98	Paved parking, HSG D
3,075	80	>75% Grass cover, Good, HSG D
22,392	74	>75% Grass cover, Good, HSG C
36	96	Gravel surface, HSG C
35,376	81	Weighted Average
25,503		72.09% Pervious Area
9,873		27.91% Impervious Area

Figure 7.6 PS-4 Post-development Cover Statistics

Part 3. Calculate the Time of Concentration

A time of concentration (T_c) is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system. Water moves through a watershed as sheet flow, shallow concentrate flow, open channel flow, or a combination of these.

Sheet flow is unconcentrated flow over existing or finish surfaces. In accordance with **Chapter 4,** the length of sheet flow used in T_c calculations is limited to no more than 150 ft for pre-development conditions and no more than 100 ft for post-development conditions. On areas of extremely flat terrain (<1% average slope), this maximum distance is extended to 250 ft for pre-development conditions and 150 ft for post-development conditions. If the start of T_c flow path is unchanged from pre- to post-development conditions, then the sheet flow length shall be identical. The value n is the Manning's roughness coefficient, which represents the friction applied to the flow by the existing or finish surface. When selecting an n value, the value should be what most closely represents the surface cover as this is what would obstruct sheet flow. **Figure 7.7** shows values for n, taken from **TR-55 Chapter 3**:

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Figure 7.7 Reference: TR-55 Table 3-1 Roughness coefficients (Manning's n) for sheet flow

T_c influences the shape and peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing the peak discharge. T_c can be increased as a result of ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or reduction of land slope through grading.

Under the example project, the pre-development times of concentration were determined using hydrologic modeling software. The summarized times of concentration for the pre-development conditions and are provided below in **Figure 7.8**. Information regarding the time of concentration and flow path for ES-1 are provided in **Figure 7.9** and **Figure 7.10**.

Subcatchment ES-1: Runoff Area=1,138,557 sf 2.56% Impervious Runoff Depth=3.45"
Flow Length=1,255' Tc=34.9 min CN=74 Runoff=58.34 cfs 7.509 af

Subcatchment ES-2: Runoff Area=777,278 sf 0.00% Impervious Runoff Depth=3.25"
Flow Length=1,561' Tc=48.5 min CN=72 Runoff=31.66 cfs 4.831 af

Figure 7.8 Overall Pre-development Times of Concentration

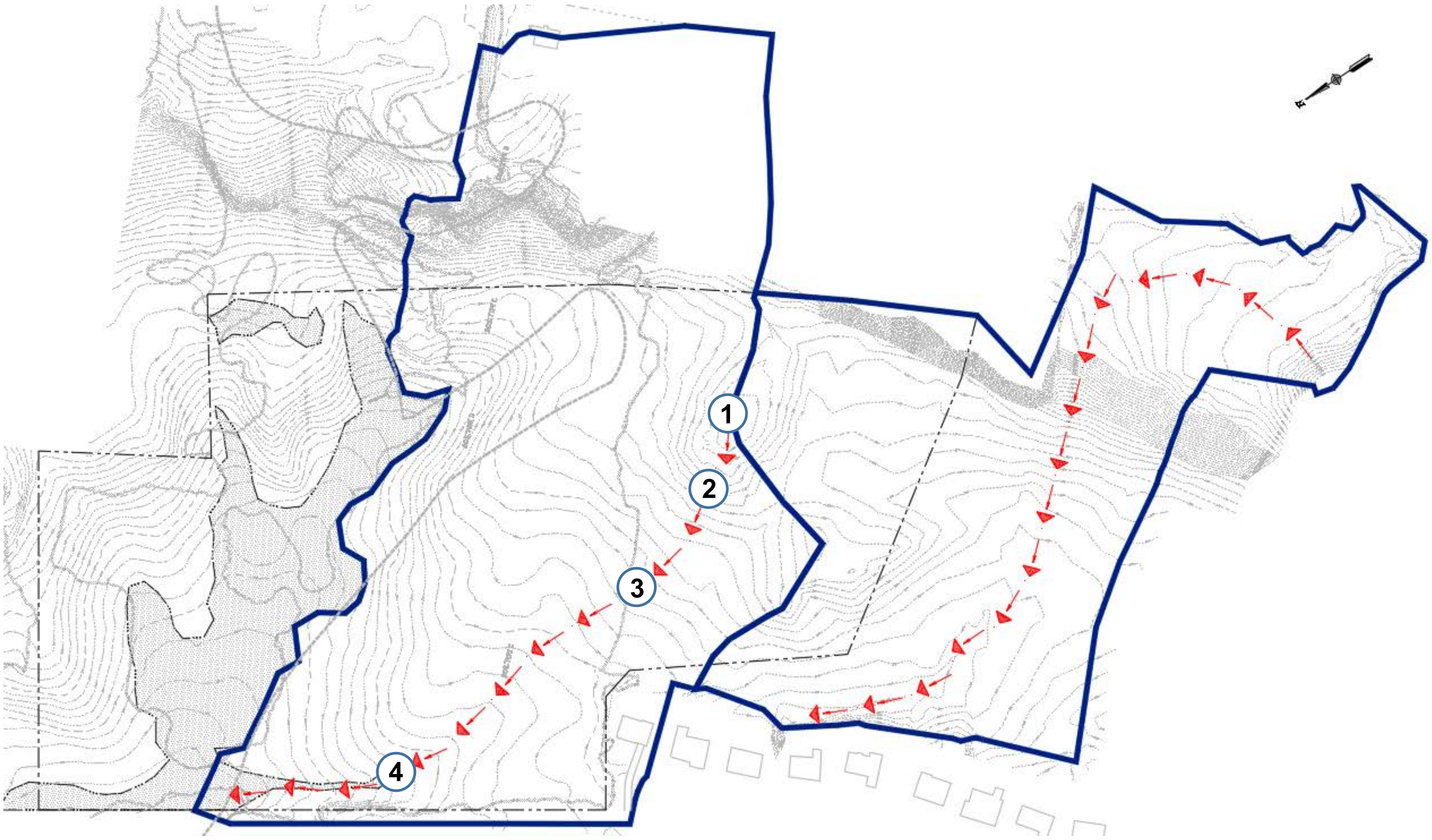


Figure 7.9 ES-1 Pre-development Times of Concentration Flow Path

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.5	100	0.0300	0.12		**Sheet Flow,** Grass: Dense n= 0.240 P2= 2.60"
3.4	275	0.0372	1.35		**Shallow Concentrated Flow,** Short Grass Pasture Kv= 7.0 fps
12.7	535	0.0196	0.70		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
5.3	345	0.0239	1.08		**Shallow Concentrated Flow,** Short Grass Pasture Kv= 7.0 fps
34.9	1,255	Total			

Figure 7.10 ES-1 Pre-development Times of Concentration

Under the example project, the post-development times of concentration were determined using hydrologic modeling software. The summarized times of concentration for the post-development conditions and are provided below in **Figure 7.11**. Information regarding the time of concentration and flow path for PS-4 are provided in **Figure 7.12** and **Figure 7.13**. For times of concentration less than 6 minutes, the minimum Tc applied is 6 minutes (0.1 hours) per **TR-55 Chapter 3**.

Subcatchment ES-1A: Runoff Area=112,641 sf 0.00% Impervious Runoff Depth=3.25"
Flow Length=655' Tc=34.3 min CN=72 Runoff=5.48 cfs 0.700 af

Subcatchment ES-1B: Runoff Area=193,636 sf 14.74% Impervious Runoff Depth=3.96"
Flow Length=993' Tc=39.0 min CN=79 Runoff=10.77 cfs 1.466 af

Subcatchment ES-1C: Runoff Area=368,899 sf 0.64% Impervious Runoff Depth=3.35"
Flow Length=1,069' Tc=58.8 min CN=73 Runoff=13.94 cfs 2.362 af

Subcatchment ES-2: Runoff Area=759,467 sf 0.00% Impervious Runoff Depth=3.25"
Flow Length=1,561' Tc=48.5 min CN=72 Runoff=30.94 cfs 4.720 af

Subcatchment PS-1: Roadway Runoff Area=89,947 sf 100.00% Impervious Runoff Depth=6.07"
Tc=6.0 min CN=98 Runoff=14.88 cfs 1.045 af

Subcatchment PS-10: Outer Lots Runoff Area=97,395 sf 26.06% Impervious Runoff Depth=4.06"
Flow Length=382' Tc=17.1 min CN=80 Runoff=8.19 cfs 0.757 af

Subcatchment PS-2: Bioretention Area & Runoff Area=11,790 sf 29.59% Impervious Runoff Depth=4.17"
Flow Length=114' Slope=0.0175 '/' Tc=17.0 min CN=81 Runoff=1.02 cfs 0.094 af

Subcatchment PS-3: South Lots Runoff Area=73,825 sf 32.36% Impervious Runoff Depth=4.27"
Flow Length=140' Tc=12.4 min CN=82 Runoff=7.44 cfs 0.604 af

Subcatchment PS-4: North Lot Runoff Area=35,376 sf 27.91% Impervious Runoff Depth=4.17"
Flow Length=79' Slope=0.0380 '/' Tc=10.1 min CN=81 Runoff=3.78 cfs 0.282 af

Subcatchment PS-5: Maintenance Access Runoff Area=2,144 sf 100.00% Impervious Runoff Depth=6.07"
Tc=6.0 min CN=98 Runoff=0.35 cfs 0.025 af

Subcatchment PS-6: Wet Pond Runoff Area=39,346 sf 0.00% Impervious Runoff Depth=4.49"
Tc=6.0 min CN=84 Runoff=5.39 cfs 0.338 af

Subcatchment PS-7: East Lots Runoff Area=41,428 sf 41.26% Impervious Runoff Depth=4.81"
Flow Length=92' Slope=0.0500 '/' Tc=10.3 min CN=87 Runoff=5.00 cfs 0.382 af

Subcatchment PS-8: Northeastern Lot Runoff Area=9,306 sf 40.33% Impervious Runoff Depth=4.49"
Flow Length=60' Slope=0.0300 '/' Tc=8.9 min CN=84 Runoff=1.12 cfs 0.080 af

Subcatchment PS-9: Inner Lots Runoff Area=80,661 sf 25.10% Impervious Runoff Depth=4.06"
Flow Length=99' Slope=0.0500 '/' Tc=10.9 min CN=80 Runoff=8.16 cfs 0.627 af

Figure 7.11 Overall Post-development Times of Concentration

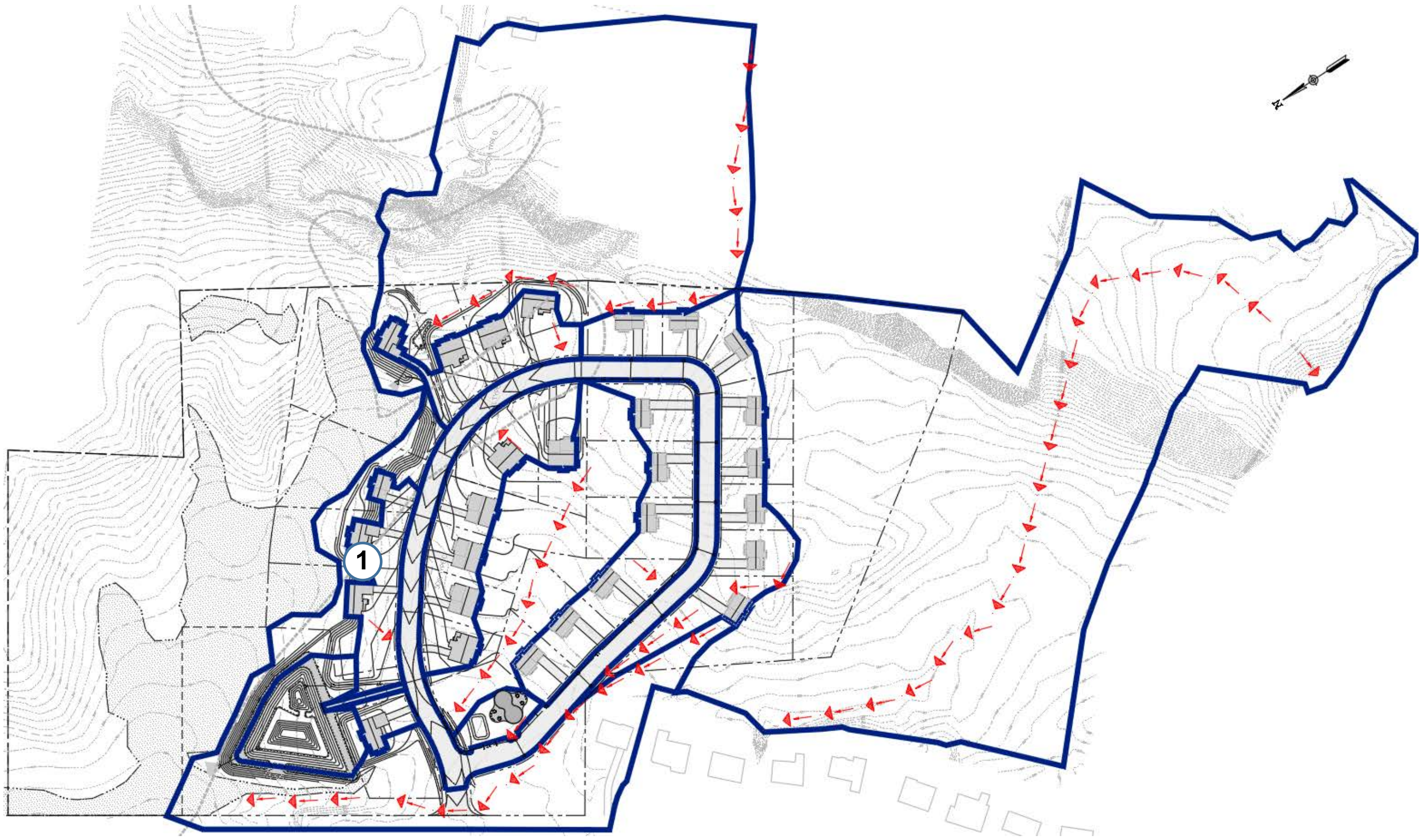


Figure 7.12 PS-4 Post-development Times of Concentration Flow Path

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
10.1	79	0.0380	0.13		**Sheet Flow,** Grass: Dense n= 0.240 P2= 2.60"

Figure 7.13 PS-4 Post-development Times of Concentration

Part 4. Six Step Process

Step 1 – Site Planning

The project site is evaluated for implementation of the green infrastructure planning measures identified in **Table 3.1**, in order to preserve natural resources and reduce impervious cover. **Table 7.2** provides a description of each green infrastructure planning measure, along with a project specific evaluation.

Table 7.2 Evaluation of Green Infrastructure Planning Measures

Practice	Description	Applicable	Project Specific Evaluation
Preservation of Undisturbed Areas	Delineate and protect undisturbed forests, native vegetated areas, riparian corridors, water bodies, wetlands, and natural terrain.	Yes	The proposed site layout has been designed to limit land disturbance to the greatest extent practical. Approximately 9.86+/- Acres of land will remain undisturbed, in its natural state, which accounts for 29% of the total project parcel.
Preservation of Buffers	Delineate and protect naturally vegetated buffers along perennial streams, rivers, shorelines, and wetlands.	N/A	There are no perennial streams, rivers, shorelines, or state regulated wetlands on or adjacent to the project site. As such, this green planning measure does not apply.

Practice	Description	Applicable	Project Specific Evaluation
Reduction of Clearing and Grading	Limit clearing and grading to the minimum amount needed for roads, driveways, foundations, utilities and stormwater management facilities.	Yes	Clearing and grading will be limited to the area of disturbance and will be minimized to the greatest extent practical. The limits of all proposed clearing will be demarcated in the field with orange construction fencing, prior to construction, to prevent unnecessary removal of trees.
Locating Development in Less Sensitive Areas	Avoid sensitive resource areas such as floodplains, steep slopes, erodible soils, wetlands, mature forests and critical habitats by locating development to fit the terrain in areas that will create the least impact.	Yes	The site layout has been designed to avoid sensitive resource areas to the greatest extent practical. The site layout will avoid disturbance to federally regulated wetlands.
Open Space Design	Use clustering, conservation design or open space design to reduce impervious cover, preserve more open space and protect water resources.	Yes	The site layout has been designed to maximize open space. Impervious surfaces have been minimized to the greatest extent practical and approximately 9.86+/- Acres will be maintained as vegetated open space.
Soil Restoration	Restore the original properties and porosity of the soil by deep till and amendment with compost to reduce the generation of runoff and enhance the runoff reduction performance of practices such as downspout disconnections, grass channels, filter strips, and tree clusters.	Yes	Full soil restoration is proposed for all areas of disturbance that will not become hardscape. All areas will be stabilized with seed & mulch, and landscaped areas will be provided.
Roadway Reduction	Minimize roadway widths and lengths, below local requirements, to reduce site impervious area.	No	Roadway widths and lengths have been minimized to the greatest extent practical while still meeting the municipal roadway specifications for dedication.
Sidewalk Reduction	Minimize sidewalk lengths and widths, below local requirements, to reduce site impervious area.	N/A	There are no sidewalks proposed as part of this project. As such, this green planning measure does not apply.
Driveway Reduction	Minimize driveway lengths and widths, below local requirements, to reduce site impervious area.	Yes	Driveway lengths have been minimized to the greatest extent practical. Proposed house locations have been placed at the minimum lot setback line to reduce driveway length.
Cul-de-sac Reduction	Minimize the number of cul-de-sacs and incorporate landscaped areas to reduce their impervious cover.	No	There are no cul-de-sacs proposed on the project site.
Building Footprint Reduction	Reduce the impervious footprint of residences and commercial buildings by using alternate or taller buildings while maintaining the same floor to area ratio.	N/A	The proposed houses shown on the plan are schematic to demonstrate intent. Building footprints will be determined per individual lot.
Parking Reduction	Reduce imperviousness on parking lots by eliminating unneeded spaces providing compact car spaces and efficient parking lanes, reducing stall dimensions below local requirements, using porous pavement surfaces in overflow parking areas, and using multi-storied parking decks where appropriate.	Yes	The number of parking stalls has been minimized to provide adequate access to the playground while reducing impervious cover to the greatest extent. In an effort to further reduce impervious area, the design proposes reducing the parking stall dimensions.

Step 2 – Determine Water Quality Treatment Volume (WQv)

The required WQv for new development is calculated per **Chapter 4** and sized for the contributing area to the three SMPs being applied. Upland area, that currently drains onto the project site from the adjacent properties, is being bypassed, using diversion swales, around the SMPs to the Design Points. As such, these areas are excluded from the contributing area used in the required WQv calculation.

This design example is for a residential subdivision that will utilize conservation of natural areas, filtration bioretention and a wet pond for treatment and attenuation of stormwater runoff. The required WQv calculation includes the contributing area for all three of these practices: 9.86 acres for conservation, 0.27 acres for bioretention and 10.78 acres for the wet pond. The remaining 5.64 acres of the watershed to Design Point 1 is not being modified from pre- to post-development conditions and is therefore being bypassed around the stormwater management practices directly to the design point. The contributing impervious area includes the impervious area tributary to the bioretention and wet pond. As impervious area is not permitted, per **Chapter 5**, to discharge to conservation areas, there is no contributing impervious area for the conservation.

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{4.50\ acres}{20.91\ acres}\ x\ 100$$

$$I = 21.5\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 21.5)$$

$$R_V = 0.24$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.20\ inches\ x\ 0.24\ x\ 20.91\ acres}{12}$$

$$\boldsymbol{WQ_V = 0.502\ af\ (21{,}860\ cf)}$$

Step 3 – Apply RR Techniques & Standard SMPs with RRv Capacity to Reduce Total WQv

Chapter 4 states that runoff reduction shall be achieved through infiltration, groundwater recharge, reuse, recycle, and/or evaporation/evapotranspiration of 100% of the post-development water quality volume to replicate pre-development hydrology. Runoff control techniques provide treatment in a distributed manner before runoff reaches the collection system, by maintaining pre-construction infiltration, peak runoff flow, discharge volume, as well as minimizing concentrated flow. This can be accomplished by applying a combination of Area Runoff Reduction Techniques, Volume Runoff Reduction Techniques and standard Stormwater Management Practices (SMPs) with RRv capacity.

As highlighted in blue, in **Figure 7.14** below, the project proposes placing 9.86-acres into permanent conservation. As such, the conserved area can be subtracted from the total area used in the required WQv calculation to achieve a reduced WQv. The difference between the required WQv and reduced WQv is the RRv provided by this practice.

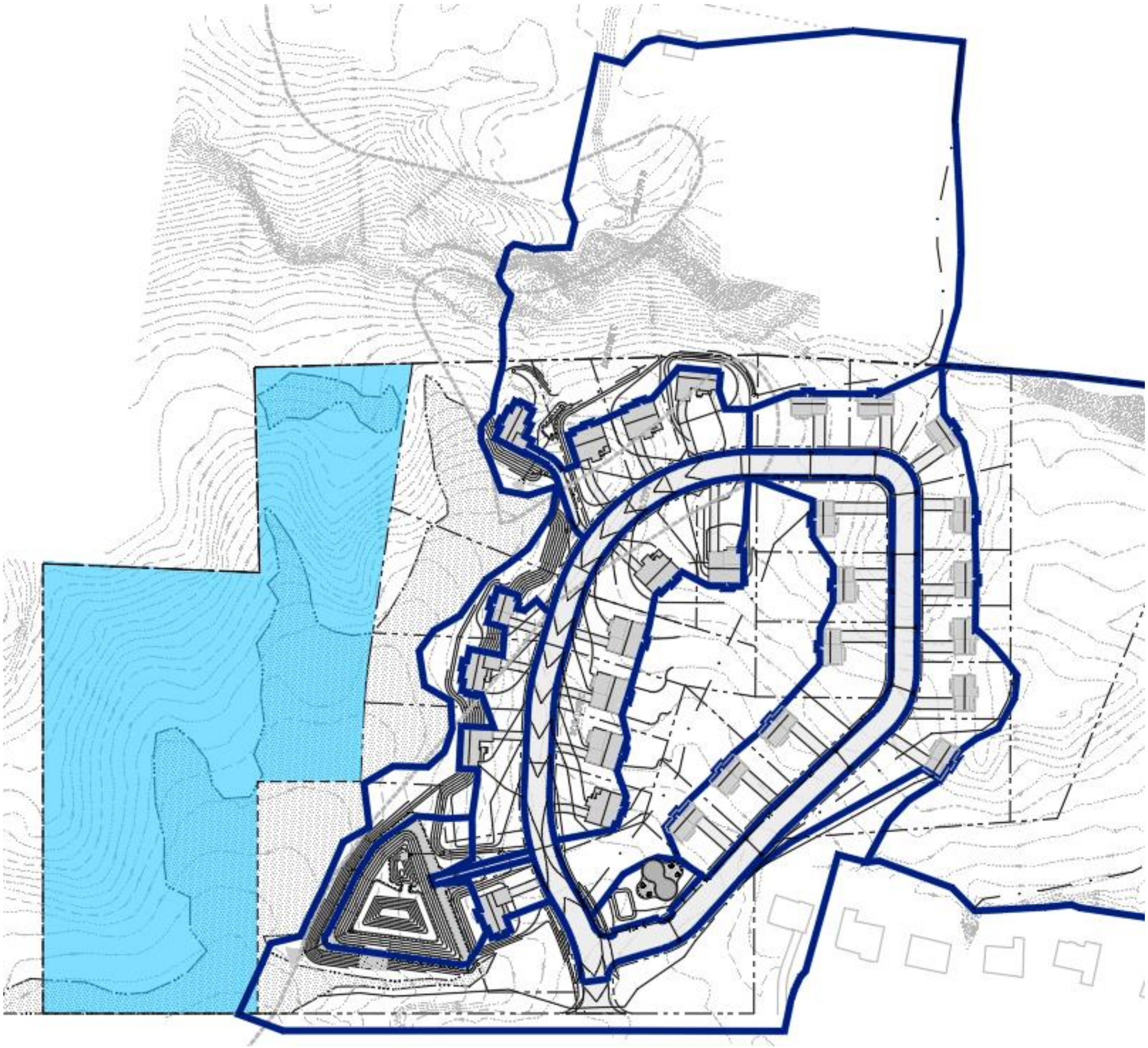


Figure 7.14 Post-development Conservation of Natural Areas

$$R_V = 0.24\ (taken\ from\ WQv\ required\ calculation)$$

$$Area\ Reduction\ WQ_V = \frac{P\ x\ R_V\ x\ (A - Conserved\ A)}{12}$$

$$Area\ Reduction\ WQ_V = \frac{1.20\ inches\ x\ 0.24\ x\ (20.91 - 9.86)\ acres}{12}$$

$$Area\ Reduction\ WQ_V = 0.265\ af\ (11{,}552cf)$$

$$RR_V\ Provided = Required\ WQ_V - Area\ Reduction\ WQ_V$$

$$RR_V\ Provided = 21{,}860\ cf - 11{,}552\ cf$$

$$\boldsymbol{RR_V\ Provided = 10{,}308\ cf}$$

Since the RRv provided by Area Reduction Techniques is not equal to the required WQv, calculated in **Step 2**, a Standard SMP with RRv Capacity is proposed. As highlighted in blue, in **Figure 7.15** below, the proposed bioretention will be pretreated with a pea gravel diaphragm and 25 ft grass filter strip. The bioretention design assumes a 2.5 ft media depth and 6 inches maximum of ponding during the WQv storm event. The provided filter area must be greater than or equal to the calculated required filter surface area shown below.

Figure 7.15 Post-development Filtration Bioretention Area

The required WQv for the area tributary to the bioretention needs to be calculated to determine the required filter area:

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{0.080\ acres}{0.271\ acres}\ x\ 100$$

$$I = 29.5\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 29.5)$$

$$R_V = 0.32$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.20\ inches\ x\ 0.32\ x\ 0.271\ acres}{12}$$

$$WQ_V = 0.009\ af\ (378\ cf)$$

The required filter area is calculated using Darcy's Law:

$$A_f = \frac{WQ_v \; x \; d_f}{k \; x \; (h_f + d_f) \; x \; t_f}$$

$$A_f = \frac{378 \; cf \; x \; 2.5 \; ft}{1 \frac{ft}{day} x \; (0.5 \text{ ft} + 2.5 \text{ ft}) \; x \; 2 \text{ days}}$$

$$\boldsymbol{A_f = 158 \text{ sf}}$$

The proposed bioretention is sized to provide 711 sf of filter area, which is greater than the required 158 sf filter area. Therefore, it is appropriately sized to capture, retain and filter the WQv storm event.

Based on **Section 4.4,** for practices with underdrains that require sizing the surface area of the filter bed using Darcy's Law, the surface area of the filter bed can be oversized to provide additional storage volume and receive additional RRv credit up to 100% of the WQv required. The total RRv credit is the percentage, as noted in **Tables 3.6 and 3.7**, applied to the storage volume provided. The storage volume provided is considered the volume within the filter media and the volume of ponding occurring during the WQv event. The RRv credit provided by the bioretention area is calculated as shown below:

$$RR_V = (Volume \; of \; Filter \; Media + Volume \; of \; Ponding) x \; 0.40$$

$$RR_V = (1{,}778 \text{ cf} + 412 \text{ cf}) \; x \; 0.40$$

$$\boldsymbol{RR_V = 876 \text{ cf}}$$

However, because the total RRv credit cannot exceed 100% of the WQv required, the RRv provided by the bioretention area is 378 cf.

Table 7.3 and **Table 7.4** demonstrate a summary of the RR techniques being applied for this project, and both the water quality and runoff reduction volumes provided:

Table 7.3 Summary of Area Reduction RR Techniques being Applied

RR Technique	NYSDEC Design Variant	RRv Capacity	WQv Required (cf)	RRv Provided (cf)	Total WQv Treated (cf)	WQv Provided (cf)
Conservation of Natural Areas	RR-1	-	-	10,308	-	-

Table 7.4 Summary of Volume Reduction RR Techniques and Standard SMPs with RRv Capacity being Applied

RR Technique	NYSDEC Design Variant	RRv Capacity	WQv Required (cf)	RRv Provided (cf)[1]	WQv Treated[2] (cf)	Total Treatment Provided[3] (cf)
Filtration Bioretention	F-5	40%	378	378	0	378

Footnotes
[1]RRv Provided = RRv Capacity x WQv Required
[2]WQv Treated = WQv Required – RRv Provided
[3]TotalTreatment Provided = WQv Treated + RRv Provided

Table 7.5 provides a summary of the RRv provided:

Table 7.5 RRv Summary

RR Required = WQv Required (cf)	RRv Provided (cf)	% RRv Provided[1]
21,860	10,686	49

Footnotes
[1]%RRv Provided = (RRv Provided / RRv Required) x 100

As indicated in **Table 7.5**, the RRv provided is not greater than or equal to the RRv required for the project site. A good faith effort has been made to reduce runoff to the greatest extent practical. However, the project site has soils with an infiltration rate less than 0.5 inch/hr, which prevents reduction of the total WQv. **Table 7.6** provides a project specific evaluation for each RR technique and standard SMP with RRv capacity, demonstrating why these practices are infeasible.

Table 7.6 Evaluation of Runoff Reduction Techniques and Standard SMPs with RRv Capacity

Design Variant	Practice	Description	Applicable	Project Specific Evaluation
RR-1	Conservation of Natural Areas	Retain the pre-development hydrologic and water quality characteristics of undisturbed natural areas by permanently conserving these areas on a site. Undisturbed natural areas include: forest retention areas; reforestation areas; stream and river corridors; shorelines; wetlands, vernal pools, and associated vegetated buffers; and undisturbed open space.	Yes	Approximately 9.68+/- Acres will remain undisturbed, in its natural state, which accounts for 29% of the total property. The pre-development hydrologic and water quality characteristics of the undisturbed natural areas will be maintained.
RR-2	Sheet Flow to Riparian Buffers or Filter Strips	Undisturbed natural areas such as forested conservation areas and stream buffers or vegetated filter strips and riparian buffers can be used to treat and control stormwater runoff from portions of development.	No	The project proposes Conservation of Natural Areas and treatment by Standard SMPs with and without RRv capacity. In addition, Riparian Buffers are not present on the site.
RR-3	Tree Planting/ Tree Pit/ Tree Trench	Plant or conserve trees to reduce stormwater runoff, increase nutrient uptake, and provide bank stabilization. Trees can be used for applications such as landscaping, stormwater management practice areas, and conservation areas.	No	The project proposes the preservation of existing mature trees, as well as the planting of numerous trees throughout the site, in order to reduce stormwater runoff and increase nutrient uptake. However, credit for these trees will not be taken toward an area reduction in the RRv calculations.
RR-4	Disconnection of Rooftop Runoff	Direct runoff from residential rooftop areas and upland overland runoff flow to designated pervious areas to reduce runoff volumes and rates.	No	The building roof(s) will be directed to downspouts with splash blocks, which will promote sheet flow and vegetative filtering. However, credit for rooftop disconnect will not be taken toward an impervious area reduction in the RRv calculations.
RR-5	Vegetated Swale	The natural drainage paths, or properly designed vegetated channels, can be used instead of constructing underground storm sewers or concrete open channels to increase time of concentration, reduce the peak discharge, and provide infiltration.	No	The project site has C and D type soils and application of different RR techniques and Standard SMPs with RRv capacity would provide a greater benefit.
RR-6	Rain Garden	Manage and treat small volumes of stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression.	No	Due to the limited tributary area to rain gardens (≤ 1,000SF), a bioretention facility will be implemented instead of rain gardens.
RR-7	Stormwater Planters	Small landscaped stormwater treatment devices that can be designed as infiltration or filtering practices. Stormwater planters use soil infiltration and biogeochemical processes to decrease stormwater quantity and improve water quality.	No	The stormwater management approach for this project is intended to provide a more natural aesthetic that is consistent with the wooded surrounding. Since, stormwater planters have significant maintenance considerations and a more structured aesthetic, they have not been proposed for this project.

Design Variant	Practice	Description	Applicable	Project Specific Evaluation
RR-8	Rain Barrels/ Cisterns	Capture and store stormwater runoff to be used for irrigation systems or filtered and reused for non-contact activities.	No	Rain Barrels/Cisterns are not proposed on-site due to the need for active management/maintenance and initial capital cost. In addition, the cold climate of the project area would require additional protection measures from freezing.
RR-9	Porous Pavement	Pervious types of pavements that provide an alternative to conventional paved surfaces, designed to infiltrate rainfall through the surface, thereby reducing stormwater runoff from a site and providing some pollutant uptake in the underlying soils.	No	Porous pavement is not proposed as part of this project due to low permeability of on-site soils, as well as concerns regarding winter maintenance.
RR-10	Green Roofs	Capture runoff by a layer of vegetation and soil installed on top of a conventional flat or sloped roof. The rooftop vegetation allows evaporation and evapotranspiration processes to reduce volume and discharge rate of runoff entering conveyance system.	No	A green roof is not proposed on-site due to significant structural, insurance, and maintenance considerations.
RR-11	Stream Daylighting	Stream Daylight previously-culverted/piped streams to restore natural habitats, better attenuate runoff by increasing the storage size, promoting infiltration, and help reduce pollutant loads.	N/A	No stream daylighting opportunities are present on this site.
I-1	Infiltration Trench	Excavated, stone-filled trenches designed to capture and temporarily store runoff in the stone reservoir to promote infiltration. Can be constructed as sheet flow to a ground surface depression or piped flow discharged directly into the trench.	No	Infiltration is not proposed due to poor draining soils.
I-2	Infiltration Basin	Vegetated excavations designed to capture and infiltrate the WQv. Can be designed off-line to bypass larger flows to downstream flood control facilities or as combined infiltration/flood control facilities by providing temporary detention ponding.	No	Infiltration is not proposed due to poor draining soils.
I-3	Dry Well	Underground structures designed to capture, treat, and infiltrate runoff from small drainage areas (rooftop only) that have low sediment or pollutant loadings. Larger stormwater volumes can be bypassed directly to a flood control facility.	No	Infiltration is not proposed due to poor draining soils.
I-4	Underground Infiltration	Underground, proprietary systems designed to capture and infiltrate the WQv, reduce runoff, remove fine sediment and associated pollutants, recharge groundwater, and attenuate peak flows.	No	Infiltration is not proposed due to poor draining soils.
F-4	Infiltration Bioretention	Shallow landscaped depressions where stormwater flows into the practice, ponds at the surface, and gradually filters through the media to remove pollutants. Filtered runoff infiltrates into the surrounding soil.	No	Infiltration is not proposed due to poor draining soils.

Design Variant	Practice	Description	Applicable	Project Specific Evaluation
F-5	Filtration Bioretention	Shallow landscaped depressions where stormwater flows into the practice, ponds at the surface, and gradually filters through the media to remove pollutants. Filtered runoff is collected by an underdrain system and discharges to the storm sewer system or directly to receiving waters.	Yes	Filtration Bioretention has been applied to this project due to low infiltrating soils and the ability to use underdrains.
F-6	Bioslope	Specialized media filtration typically used in longitudinal applications to treat stormwater along an impervious area (road, parking lot, etc.)	No	Due to the minimal size of the parking lot and wing curbs along the road, sheet flow to a bioslope is not practical on this project.
O-1	Dry Swale	Designed to temporarily hold the WQv in a pool or series of pools created by permanent check dams. The soil bed consists of native soils or highly permeable fill material, underlain by an underdrain system. Pollutants are removed through sedimentation, nutrient uptake, and infiltration.	No	Due to the minimal size of the parking lot and wing curbs along the road, sheet flow to a dry swale is not practical on this project.

Step 4 – Determine the Minimum RRv Required

Projects that cannot achieve 100% of the runoff reduction requirement due to site limitations, shall provide a minimum runoff reduction volume, per **Chapter 4**. The project has two different HSGs on site, therefore the Specific Reduction Factor (S) was calculated referencing **Chapter 4 Section 4.4**. The minimum RRv must be calculated for the impervious area proposed in each HSG:

$$R_V = 0.05 + (0.009 \; x \; 100)$$

$$R_V = 0.95$$

$$S = \frac{(Aic \; in \; HSG \; A \; x \; 0.55) + (Aic \; in \; HSG \; B \; x \; 0.40 \; + (Aic \; in \; HSG \; C \; x \; 0.30) + (Aic \; in \; HSG \; D \; x \; 0.20 \; acres)}{Aic}$$

$$S = \frac{(0 \; acres \; x \; 0.55) + (0 \; acresx \; 0.40) + (3.40 \; acres \; x \; 0.30) + (1.10 \; acres \; x \; 0.20 \; acres)}{4.50 \; acres}$$

$$S = \; 0.28$$

$$RR_{Vmin} = \frac{P \; x \; R_v \; x \; Aic \; x \; S}{12}$$

$$RR_{Vmin} = \frac{1.20 \; inches \; x \; 0.95 \; x \; 4.50 \; acres \; x \; 0.28}{12}$$

$$RR_{Vmin} = \; 0.12 \; af \; (5{,}214 \; cf)$$

Table 7.7 Minimum RRv Summary

Minimum RRv Required (cf)	RRv Provided (cf)	[1]% of Minimum RRv Provided
5,214	10,686	205

Footnotes
[1]%Min. RRv Provided = (RRv Provided / Min. RRv Required) x 100

As indicated in **Table 7.7**, the RRv provided is greater than the minimum RRv required for the project site. Therefore, the runoff reduction volume criteria have been met for the project.

Step 5 – Apply Standard Stormwater Management Practices to Address Remaining WQv

If the entire WQv is not treated through implementation of RR techniques and standard SMPs with RRv capacity, the design must achieve the remaining WQv through the standard SMPs listed in **Table 3.3**.

Table 7.8 Summary of WQv Provided

Step 2 – WQv Required (cf)	Step 3 – WQv reduction by RR Techniques & Standard SMPs with RRv Capacity (cf)	Step 5 – Reduced WQv to be Treated by Standard SMPs (cf)
21,860	10,686	11,174

Based upon the results listed in **Table 7.8**, the entire WQv has not been treated by application of RR techniques and standard SMPs with RRv capacity. As such, a wet pond (Design Variant P-2), has been incorporated into the stormwater management plan for this project, to meet the WQv objective.

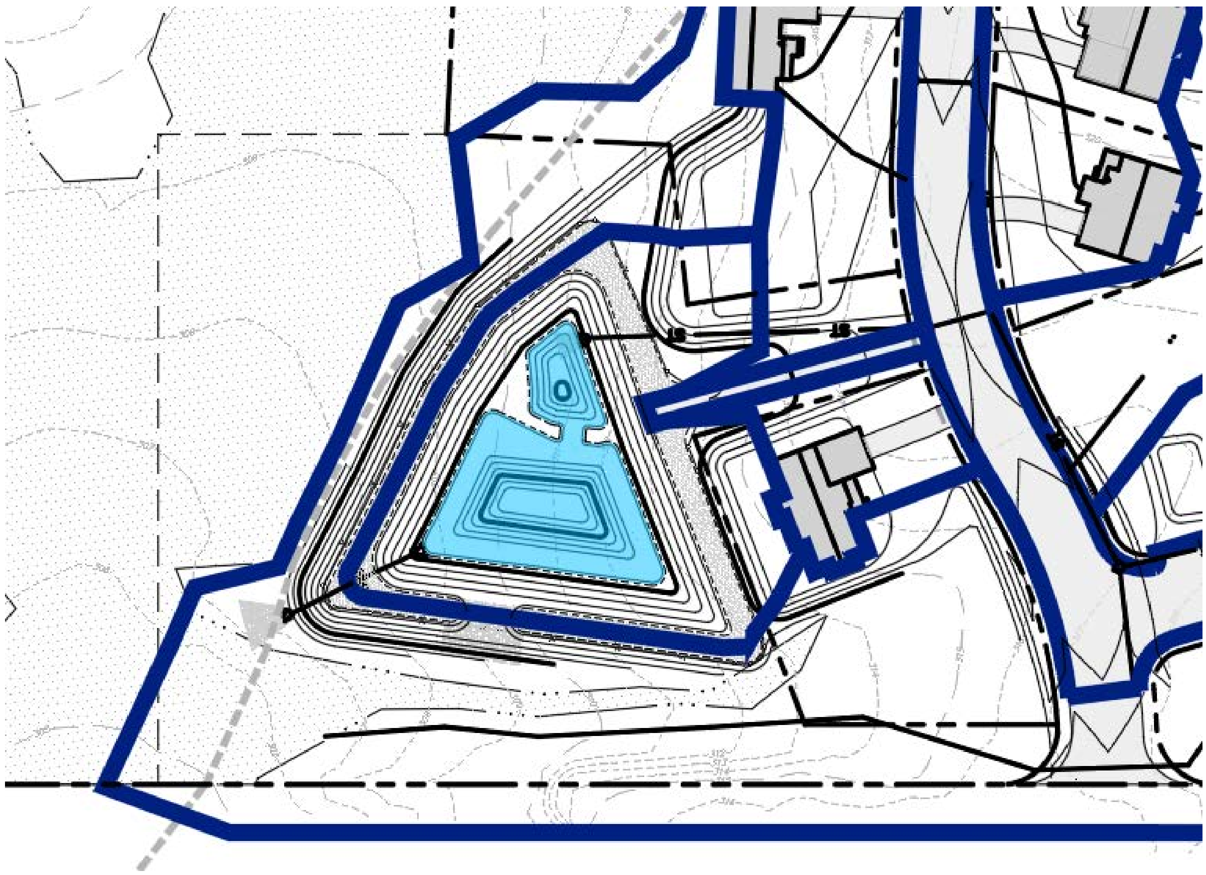


Figure 7.16 Post-development Wet Pond

Per **Chapter 6 Section 6.1.1** the minimum contributing area for Design Variant P-2 is 25 acres. However, the minimum contributing area can be reduced to 10 acres if a water balance calculation is performed. The water balance calculation, as shown in **Chapter 6 Section 6.1.4.2**, provides a required minimum permanent pool depth to accommodate the reduced tributary area, as shown below:

$$DP \geq ET + INF + RES$$

$$DP \geq 5\ inches + 10.1\ inches + 36\ inches$$

$$DP \geq 51.1\ inches\ (4.3\ ft)$$

The pond design proposes a permanent pool depth of 4.5 ft and, as such, meets the water balance requirement for reducing the contributing area to a minimum of 10 acres.

Volume	Invert	Avail.Storage	Storage Description
#1	305.00'	0 cf	**Permanent Pool (Forebay) (Prismatic)** Listed below (Recalc) 3,072 cf Overall x 0.0% Voids
#2	303.00'	0 cf	**Permanent Pool (Pond) (Prismatic)** Listed below (Recalc) 17,032 cf Overall x 0.0% Voids
#3	309.50'	87,460 cf	**Extended Detention (Prismatic)** Listed below (Recalc)
		87,460 cf	Total Available Storage

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)	
305.00	49	0	0	
306.00	278	164	164	
307.00	545	412	575	
308.00	889	717	1,292	
309.00	1,282	1,086	2,378	
309.50	1,495	694	3,072	**Volume #1**

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)	
303.00	560	0	0	
304.00	945	753	753	
305.00	1,410	1,178	1,930	
306.00	1,953	1,682	3,612	
307.00	2,575	2,264	5,876	
308.00	3,276	2,926	8,801	
309.00	6,465	4,871	13,672	
309.50	6,975	3,360	17,032	**Volume #2**

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
309.50	10,583	0	0
310.00	12,621	5,801	5,801
311.00	14,913	13,767	19,568
312.00	17,347	16,130	35,698
313.00	19,930	18,639	54,337
314.00	22,900	21,415	75,752
314.50	23,933	11,708	87,460

Figure 7.17 Wet Pond Volume Distribution

Table 7.9 and **Table 7.10** summarize both the WQv requirements and the treatment volumes provided in accordance with **Table 6.4**.

Table 7.9 Summary of Pond WQ Practices

NYSDEC Design Variant	Step 5 - Calculated WQv (cf)	Required WQv Distribution		Provided WQv Distribution			
		Permanent Pool	Extended Detention	Permanent Pool[1]		Extended Detention[2]	
		(min %)	(max %)	cf	%	cf	%
P-2	11,174	100	0	20,104	100	0	0

Footnotes
[1]Permanent pool distribution includes pretreatment permeant volume and treatment permanent pool volume
[2]Extended detention distribution excludes extended detention above pretreatment

Table 7.10 Summary of WQ Practices

NYSDEC Design Variant	Step 5 - Calculated WQv (cf)	Pretreatment Volume Required (% of WQv)[1]	Treatment Volume Provided (cf)[2]	Pretreatment Volume Provided (cf)
P-2	11,174	10	8,102	3,072

Footnotes
[1]Refer to Section 6.1.3
[2]Although 17,032 cf of volume is available after pretreatment, treatment provided cannot exceed 100% of the tributary required WQv.

Step 6 – Apply Volume and Peak Rate Control

Chapter 4 of the Design Manual requires that projects meet three separate stormwater quantity criteria:

1. The Channel Protection (CPv) requirement is designed to protect stream channels from erosion. This is accomplished by providing 24 hours of extended detention for the 1-year, 24-hour storm event. The CPv detention time is the center of mass detention time through each stormwater management practice.

2. The Overbank Flood Control (Qp) requirement is designed to prevent an increase in the frequency and magnitude of flow events that exceed the bank-full capacity of a channel, and therefore must spill over into the floodplain. This is accomplished by providing detention storage to ensure that, at each design point, the post-development 10-year 24-hour peak discharge rate does not exceed the corresponding pre-development rate.

3. The Extreme Flood Control (Qf) requirement is designed to prevent the increased risk of flood damage from large storm events, to maintain the boundaries of the pre-development 100-year floodplain, and to protect the physical integrity of stormwater management practices. This is accomplished by providing detention storage to ensure that, at each design point, the post-development 100-year 24-hour peak discharge rate does not exceed the corresponding pre-development rate.

In order to demonstrate that the NYSDEC detention requirements are being met, a hydrologic and hydraulic analysis of the pre- and post-development conditions needs to be performed using the Natural Resources Conservation Service Technical Release 20 (TR-20) and Technical Release 55 (TR-55) methodologies. For the example project hydraulic and hydrologic modeling software, HydroCAD, developed by HydroCAD Software Solutions LLC of Tamworth, New Hampshire, was used.

A comparison of the pre- and post-development watershed conditions was performed for all design points and storm events evaluated herein. For all design points and design storms, this comparison demonstrates that the peak rate of runoff will not be increased. Therefore, the project will not have a significant adverse impact on the adjacent or downstream properties or receiving water courses.

Table 7.11 Summary of Pre- and Post-development Peak Discharge Rates

Design Point	10-year 24-hour storm event		100-year 24-hour storm event	
	Pre (cfs)	Post (cfs)	Pre (cfs)	Post (cfs)
1	21.30	17.71	56.58	52.40
2	10.25	10.02	29.65	28.97

For each stormwater management facility that provides detention, **Table 7.12** presents the center of mass detention time for the 1-year 24-hour storm event. As shown below, the wet pond does not meet the required 24-hour detention time. However, the project provides the minimum CPv orifice size allowed, per **Chapter 4**. As such the CPv requirement is waived.

Table 7.12 Center of Mass Detention for the 1-year 24-hour Storm

NYSDEC Design Variant	Center of Mass Detention time for the 1-year Storm (hours)		Diameter of the CPv Orifice (inches)	
	Required	Provided	Minimum allowable to achieve the required center of mass detention time[1]	Provided
P-2	24	13.7	3	3

Footnotes
[1]Per **Chapter 4** where a CPv control orifice is provided, the minimum orifice size shall be 3 inches, with acceptable external trash rack or internal orifice protection.

Summary for Pond P1: Wet Pond (w/ Forebay & Outlet Control)

```
Inflow Area =     10.777 ac, 40.97% Impervious, Inflow Depth = 1.03"   for 1-yr event
Inflow      =     10.52 cfs @  12.06 hrs, Volume=    0.923 af
Outflow     =      0.34 cfs @  18.49 hrs, Volume=    0.923 af, Atten= 97%, Lag= 386.3 min
Primary     =      0.34 cfs @  18.49 hrs, Volume=    0.923 af
Secondary   =      0.00 cfs @   0.00 hrs, Volume=    0.000 af

Routing by Dyn-Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.01 hrs
Peak Elev= 311.30' @ 18.49 hrs  Surf.Area= 26,237 sf  Storage= 24,219 cf
Flood Elev= 314.50'  Surf.Area= 34,516 sf  Storage= 87,460 cf

Plug-Flow detention time= (not calculated: outflow precedes inflow)
Center-of-Mass det. time= 822.3 min ( 1,658.7 - 836.4 )
```

Figure 7.18 Center of Mass Detention Time for the 1-year 24-hour Storm

Device	Routing	Invert	Outlet Devices
#1	Primary	309.16'	**24.0" Round Culvert** L= 36.0' CPP, end-section conforming to fill, Ke= 0.500 Inlet / Outlet Invert= 309.16' / 307.25' S= 0.0531 '/' Cc= 0.900 n= 0.012 Corrugated PE, smooth interior, Flow Area= 3.14 sf
#2	Device 1	309.16'	**3.0" Vert. Primary Orifice** C= 0.600 Limited to weir flow at low heads
#3	Device 1	311.30'	**36.0" W x 12.0" H Vert. Secondary Orifice** C= 0.600 Limited to weir flow at low heads
#4	Device 1	312.12'	**4.0' long x 0.5' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 Coef. (English) 2.80 2.92 3.08 3.30 3.32
#5	Secondary	313.50'	**12.0' long x 14.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 Coef. (English) 2.64 2.67 2.70 2.65 2.64 2.65 2.65 2.63

Figure 7.19 Wet Pond Outlet Devices

Section 7.2 Sizing Example – Filtration Bioretention & Infiltration Basin for Treatment of Stormwater Hotspot

Figure 7.20 below shows a proposed commercial development including a parking lot and an associated garden center. The existing soils on the site are HSG A soils with an infiltration rate of 8.0 in/hr.

The site stormwater is divided into two subcatchments as shown in the figure. Subcatchment 1 contains the proposed garden center and surrounding area. The stormwater from subcatchment 1 is treated by the proposed lined filtration bioretention before discharging by conveyance pipe to the proposed infiltration basin. Subcatchment 2 contains the proposed box store and parking lot. The stormwater from this subcatchment is conveyed via a closed storm sewer network to the proposed infiltration basin.

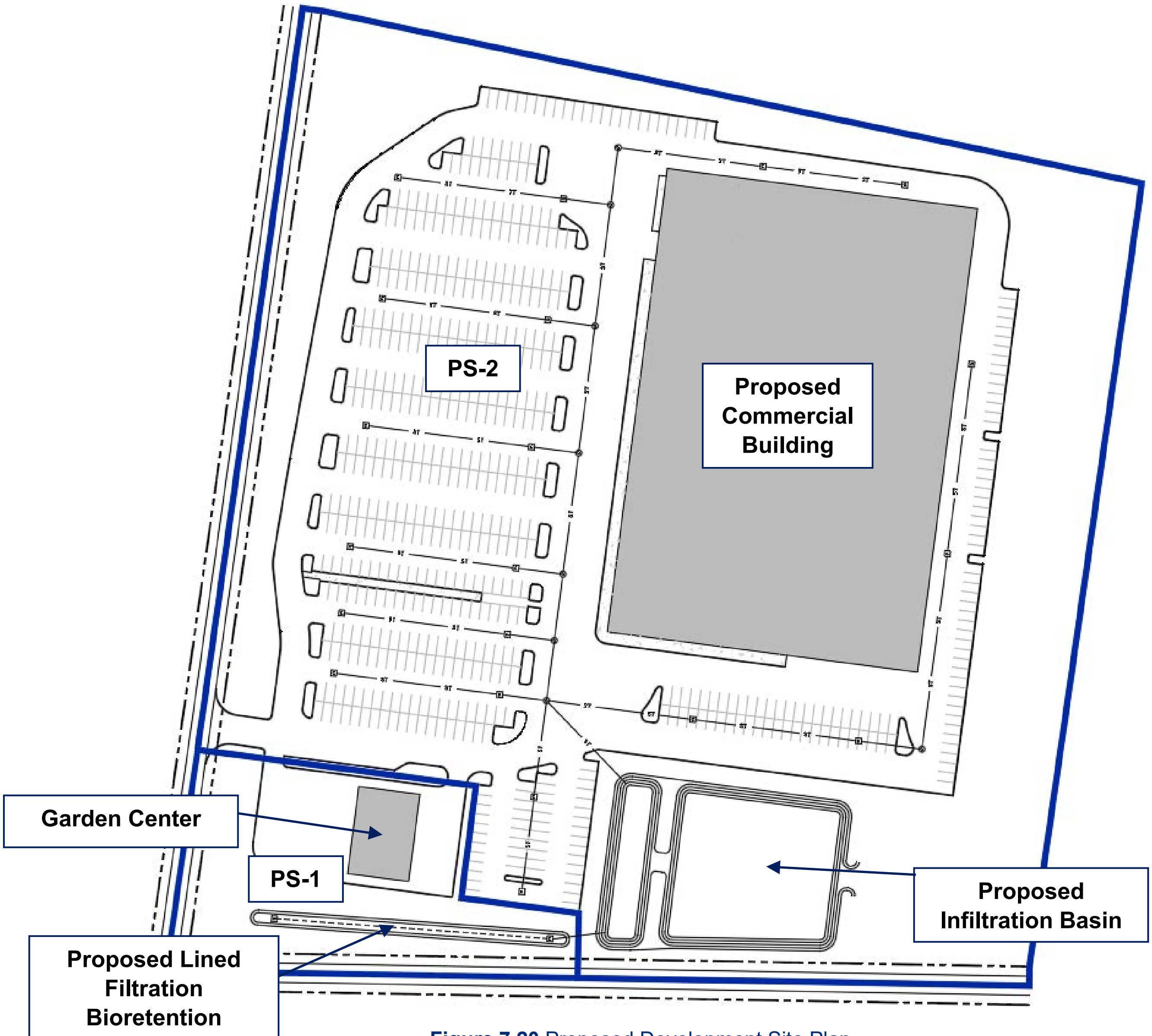


Figure 7.20 Proposed Development Site Plan

Step 1 – Site Planning

An example of site planning has been provided in **Section 7.1**.

Step 2 – Calculate Water Quality Treatment Volume (WQv)

The garden center is considered a level 1 stormwater hotspot, in accordance with **Chapter 4 Table 4.3**. As such, infiltration as treatment for this practice is prohibited. Per **Chapter 6**, runoff from designated stormwater hotspots shall not be directed to an infiltration practice, unless two treatment practices in series (i.e. non-infiltration SMP followed by an infiltration practice) are provided, both of which are sized to treat the entire WQv. Pretreatment for each practice in series is required and the amount of pretreatment shall conform to the practice specific requirements of **Chapters 5** and **6**. A lined filtration bioretention will be used to treat stormwater from the garden center before it is discharged into the infiltration basin.

Per **Chapter 4**, when a development project includes an activity designated as a stormwater hotspot, consideration must be taken to isolate the hotspot from the remaining watershed. The hotspot will be isolated through appropriate site grading to divert stormwater from the upgradient surrounding areas away from the hotspot and towards the closed storm sewer network to be discharged directly to the infiltration basin. Additionally, the hotspot will be captured at the source and conveyed to the proposed lined filtration bioretention for treatment. Finally, all tributary area to the filtration bioretention will be subject to the same treatment requirements as the hotspot. Through these measures the criteria for isolating the stormwater hotspot have been met according to **Section 4.14** of **Chapter 4**.

Calculate the required WQv for the proposed filtration bioretention per **Chapter 4**:

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{0.72\ acres}{1.69\ acres}\ x\ 100$$

$$I = 42.6\%$$

$$R_V = 0.05 + (0.009\ x\ I)$$

$$R_V = 0.05 + (0.009\ x\ 42.6)$$

$$R_V = 0.43$$

$$WQ_V = \frac{P\ x\ R_V\ x\ A}{12}$$

$$WQ_V = \frac{1.20\ inches\ x\ 0.43\ x\ 1.69\ acres}{12}$$

$$\boldsymbol{WQ_V = 0.073\ af\ (3,166\ cf)}$$

Since the garden center is a stormwater hotspot, the stormwater runoff from PS-1must be treated by a non-infiltration practice before being directed to the infiltration basin. Due to this, the required WQv for the infiltration basin must take into account the areas of both subcatchments PS-1 and PS-2. If there was not a hotspot in PS-1 then having two practices in series would not be required and the WQv for the infiltration basin would only take into account PS-2 even if the practices were proposed in series.

Calculate the required WQv for the proposed infiltration basin per **Chapter 4**:

$$I = \frac{A_{imp}}{A}\ x\ 100$$

$$I = \frac{12.36\ acres}{19.20\ acres}\ x\ 100$$

$$I = 64.4\%$$

$$R_V = 0.05 + (0.009 \ x \ I)$$

$$R_V = 0.05 + (0.009 \ x \ 64.4)$$

$$R_V = 0.63$$

$$WQ_V = \frac{P \ x \ R_V \ x \ A}{12}$$

$$WQ_V = \frac{1.20 \ inches \ x \ 0.63 \ x \ 19.20 \ acres}{12}$$

$$WQ_V = \mathbf{1.210 \ af \ (52,690 \ cf)}$$

Step 3 – Apply RR Techniques and Standard SMPs with RRv Capacity to Reduce Total WQv

Chapter 4 states that runoff reduction shall be achieved through infiltration, groundwater recharge, reuse, recycle, and/or evaporation/evapotranspiration of 100% of the post-development water quality volume to replicate pre-development hydrology. Runoff control techniques provide treatment in a distributed manner before runoff reaches the collection system, by maintaining pre-construction infiltration, peak runoff flow, discharge volume, as well as minimizing concentrated flow. This can be accomplished by applying a combination of Runoff Reduction Techniques, and standard Stormwater Management Practices (SMPs) with RRv capacity.

Calculate the bioretention required filter area using Darcy's Law and the filtration bioretention WQv calculated in **Step 2**:

$$A_f = \frac{WQ_v \ x \ d_f}{k \ x \ (h_f + d_f) \ x \ t_f}$$

$$A_f = \frac{3{,}166 \ cf \ x \ 2.5 \ ft}{1 \frac{ft}{day} x \ (0.5 \text{ ft} + 2.5 \text{ ft}) \ x \ 2 \text{ days}}$$

$$\boldsymbol{A_f} = \mathbf{1,319 \ sf}$$

As shown in **Figure 7.21**, the proposed lined bioretention is sized to provide 3,266 sf of filter area, which is greater than the required 1,319 sf filter area. Therefore, it is appropriately sized to capture, retain and filter the WQv storm event from the proposed hot spot.

Based on **Section 4.4,** for practices with underdrains that require sizing the surface area of the filter bed using Darcy's Law, the surface area of the filter bed can be oversized to provide additional storage volume and receive additional RRv credit up to 100% of the WQv required. The total RRv credit is the percentage, as noted in **Tables 3.6 and 3.7**, applied to the storage volume provided. The storage volume provided is considered the volume within the filter media and the volume of ponding occurring during the WQv event. The RRv credit provided by the bioretention area is calculated as shown below:

$$RR_V = (Volume \ of \ Filter \ Media + Volume \ of \ Ponding) x \ 0.40$$

$$RR_V = (8{,}165 \text{ cf} + 5{,}460 \text{ cf}) \ x \ 0.40$$

$$\boldsymbol{RR_V} = \mathbf{5,450 \ cf}$$

However, because the total RRv credit cannot exceed 100% of the WQv required, the RRv provided by the bioretention area is 3,166 cf.

As shown in **Figure 7.21** below, the proposed infiltration basin has a proposed bottom area of 23,502 sf and will be pretreated with a forebay. The infiltration basin design assumes a 3 ft depth.

Calculate the required infiltration basin bottom area using the infiltration basin WQv calculated in **Step 2**:

$$A_b = \frac{WQ_v}{d_b}$$

$$A_b = \frac{52{,}690\ cf}{3\ ft}$$

$$\boldsymbol{A_b = 17{,}563\ sf}$$

The proposed bottom area is greater than required. As such, the infiltration basin meets the design criteria.

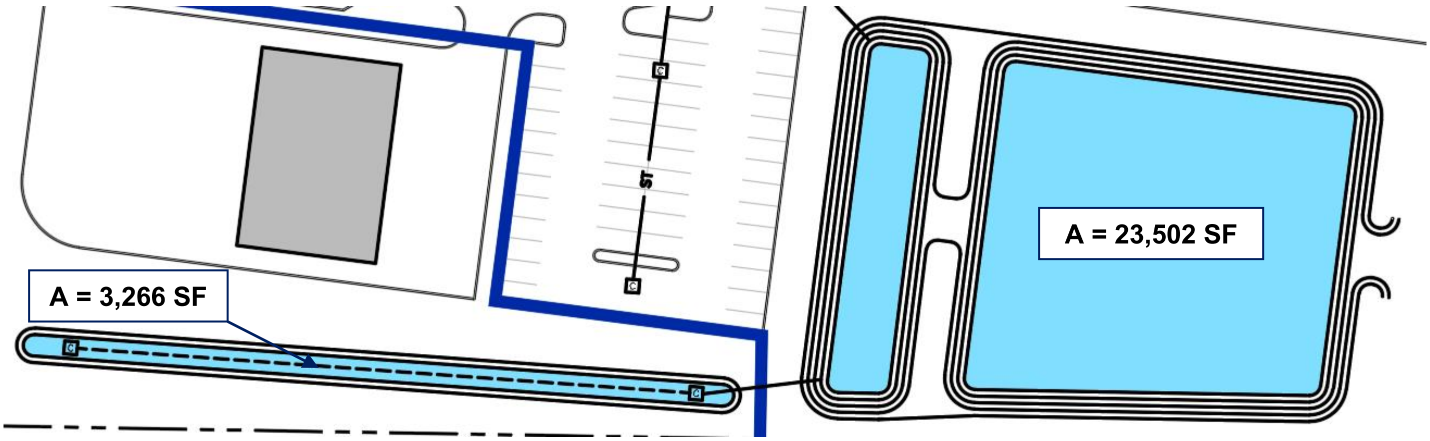


Figure 7.21 Proposed Bioretention and Infiltration Basin

Table 7.13 demonstrates a summary of the RR techniques being applied for this project, and both the water quality and runoff reduction volumes provided:

Table 7.13 Summary of RR Techniques and Standard SMPs with RRv Capacity being Applied

RR Technique	NYSDEC Design Variant	RRv Capacity	WQv Required (cf)	RRv Provided (cf)[1]	WQv Treated[2] (cf)	Total Treatment Provided[3] (cf)
Filtration Bioretention	F-5	40%	3,166	3,166	0	3,166
Infiltration Basin	I-2	100%	52,690	52,690	0	52,690

Footnotes
[1]RRv Provided = RRv Capacity x WQv Required
[2]WQv Treated = WQv Required – RRv Provided
[3]TotalTreatment Provided = WQv Treated + RRv Provided

Table 7.14 provides a summary of the RRv provided. It should be noted that because the filtration bioretention is tributary to the infiltration basin, RRv credit cannot be taken for the filtration bioretention since it is the first practice in series.

Table 7.14 RRv Summary

RR Required = WQv Required (cf)	RRv Provided (cf)	% RRv Provided[1]
52,690	52,690	100

Footnotes
[1]%RRv Provided = (RRv Provided / RRv Required) x 100

Step 4 – Calculate the Minimum RRv Required

As previously discussed, the RRv provided is equal to the RRv required for this project. As such, the runoff reduction volume criteria has been met, and the minimum RRv is not applicable.

Step 5 – Apply Standard SMPs to Address Remaining WQv

As previously discussed, 100% of the required WQv is being provided and the minimum RRv is being reduced through RRv practices. As such, the water quality and runoff reduction volume criteria have been met and no other standard SMPs are required.

Step 6 – Apply Volume and Peak Rate Control

An example of applying volume and peak rate control has been provided in **Section 7.1**.

Section 7.3 Sizing Example – Dry Swale

As shown in **Figure 7.22**, this design example is for a residential subdivision that will utilize dry swales for treatment and conveyance of stormwater runoff. This example assumes a HSG B for the site, which allows for 40% RRv capacity in accordance with **Table 3.7.** The contributing area to the dry swales includes the residential road, driveways, homes, and lawn for a total of 11.05 acres, 3.62 acres of which is impervious cover.

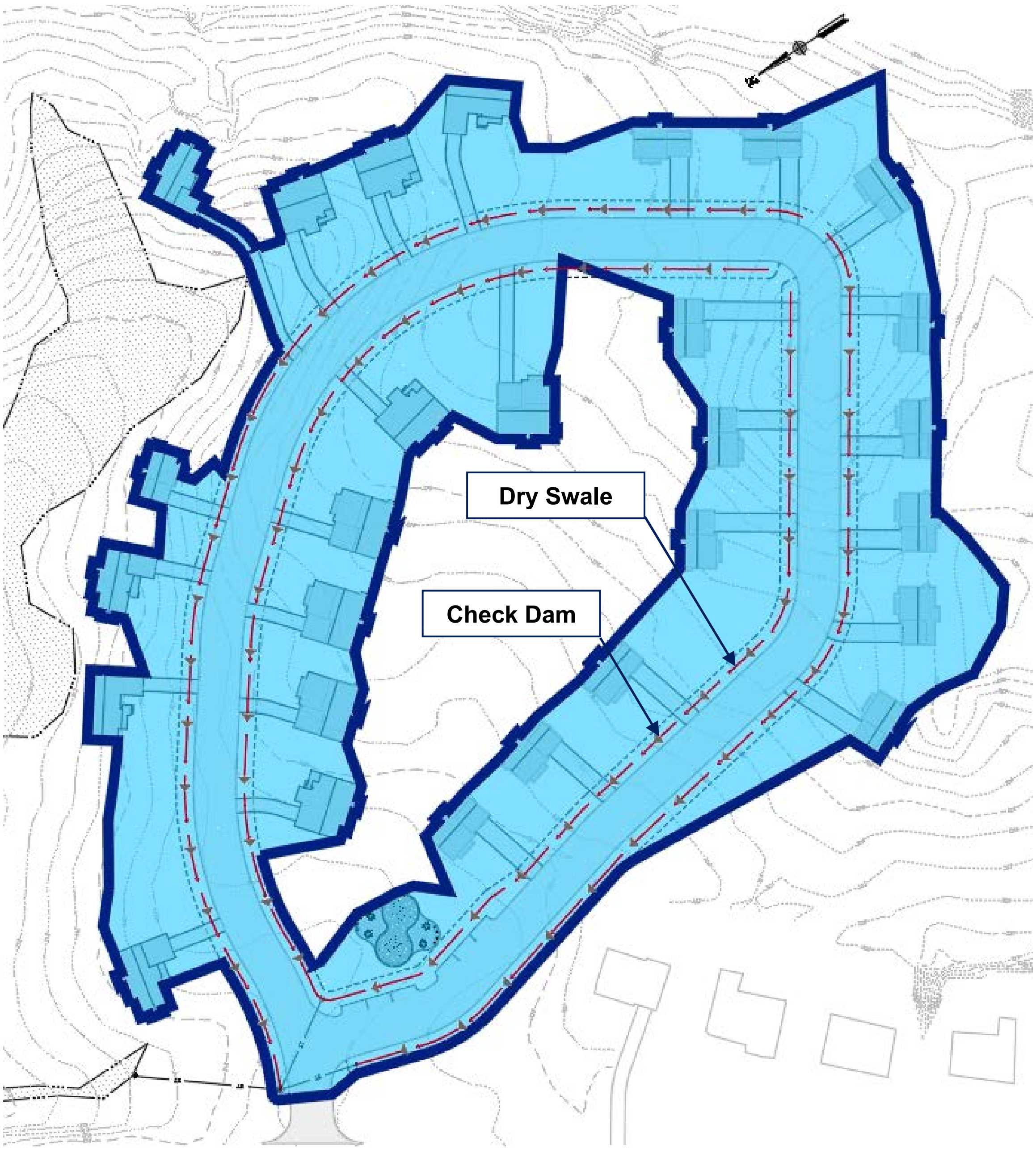


Figure 7.22 2-Year Flow Depth in Dry Swale

Step 1 – Site Planning

An example of site planning has been provided in **Section 7.1**.

Step 2 – Calculate Water Quality Treatment Volume (WQv)

Calculate the required WQv for new development per **Chapter 4**:

$$I = \frac{A_{imp}}{A} \ x \ 100$$

$$I = \frac{3.62 \ acres}{11.05 \ acres} \ x \ 100$$

$$I = 32.8\%$$

$$R_V = 0.05 + (0.009 \ x \ I)$$

$$R_V = 0.05 + (0.009 \ x \ 32.8)$$

$$R_V = 0.345$$

$$WQ_V = \frac{P \ x \ R_V \ x \ A}{12}$$

$$WQ_V = \frac{1.20 \ x \ 0.345 \ x \ 11.05 \ acres}{12}$$

$$\boldsymbol{WQ_V = 16,616 \ cf \ (0.381 \ af)}$$

Step 3 – Apply RR Techniques and Standard SMPs with RRv Capacity to Reduce Total WQv

Chapter 4 states that runoff reduction shall be achieved through infiltration, groundwater recharge, reuse, recycle, and/or evaporation/evapotranspiration of 100% of the post-development water quality volume to replicate pre-development hydrology. Runoff control techniques provide treatment in a distributed manner before runoff reaches the collection system, by maintaining pre-construction infiltration, peak runoff flow, discharge volume, as well as minimizing concentrated flow. This can be accomplished by applying a combination of Runoff Reduction Techniques, and standard Stormwater Management Practices (SMPs) with RRv capacity.

The proposed dry swale has a 3 ft bottom, 3:1 side slopes, 2 ft swale depth, a WQv max. flow depth of 1 ft, 2.0% slope, a proposed length of 2,096 ft and will be pretreated by a grass filter strip and pea gravel diaphragm. in accordance with **Chapter 6**. Below are the calculations for the dry swale to determine the required length. The dry swale design needs to meet or exceed the minimum length required and provide enough storage behind the check dams to meet or exceed the required WQv.

Calculate the top width of the channel, using the swale depth as the height:

$$W_{Top} = b + (2 \ x \ Side \ Slope) \ x \ C_H$$

$$W_{Top} = 3 \ ft + (2 \ x \ 3) \ x \ 2 \ ft$$

$$W_{Top} = 15 \ ft$$

Calculate the area of the channel, using the flow depth as the height:

$$A = \frac{C_H \ x \ (b + W_{Top})}{2}$$

$$A = \frac{1 \ ft \ x \ (3 \ ft + 15 \ ft)}{2}$$

$$A = 9 \ sf$$

Calculate the required length of swale based on the required WQv and calculated area:

$$L_r = \frac{WQ_V}{A_{Trap}}$$

$$L_r = \frac{16{,}616\ cf}{9\ sf}$$

$$L_r = 1{,}846\ ft$$

Verify that the proposed swale length is greater than or equal to the required swale length:

$$L_p \geq L_r$$

$$\mathbf{2,096\ ft \geq 1,846\ ft}$$

$$\textit{Therefore, the dry swale design meets the required minimum length}$$

Calculate the channel volume using the calculated area and proposed swale length:

$$V_C = L_p\ x\ A$$

$$V_C = 2{,}096\ ft\ x\ 9\ sf$$

$$V_C = 18{,}864\ cf$$

Verify that the channel volume provided is greater than or equal to the required WQv:

$$V_C \geq WQ_V$$

$$\mathbf{18,864\ cf \geq 16,616\ cf}$$

$$\textit{Therefore, the proposed dry swale meets the required } WQ_V \textit{ for this practice}$$

Calculate the required check dam spacing within the swale using the proposed check dam height and slope:

$$C_S = \frac{C_H}{S_L}$$

$$C_S = \frac{1\ ft}{0.02\ ft/ft}$$

$$C_S = 50\ ft$$

Calculate the number of check dams required using the proposed swale length and calculated spacing:

$$C = \frac{L_p}{C_S}$$

$$C = \frac{2{,}096\ ft}{50\ ft}$$

$$C = 42\ \textit{check dams required}$$

Using computer modeling, as shown in **Figure 7.23**, the peak water surface elevation during the 2-year storm event is 0.60 ft above the bottom of dry swale.

Inflow Area = 11.050 ac, 32.76% Impervious, Inflow Depth = 0.62" for 2-yr event
Inflow = 8.42 cfs @ 12.05 hrs, Volume= 0.573 af
Outflow = 2.31 cfs @ 12.52 hrs, Volume= 0.573 af, Atten= 73%, Lag= 28.3 min

Routing by Dyn-Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.01 hrs
Max. Velocity= 0.79 fps, Min. Travel Time= 44.0 min
Avg. Velocity = 0.19 fps, Avg. Travel Time= 179.7 min

Peak Storage= 6,093 cf @ 12.52 hrs
Average Depth at Peak Storage= 0.60' , Surface Width= 6.62'
Bank-Full Depth= 2.00' Flow Area= 18.0 sf, Capacity= 27.68 cfs

Figure 7.23 2-Year Flow Depth in Dry Swale

Using the graph from **Appendix G**, as shown in **Figure 7.24**, determine the Manning's number within the dry swale based on the 2-year flow depth.

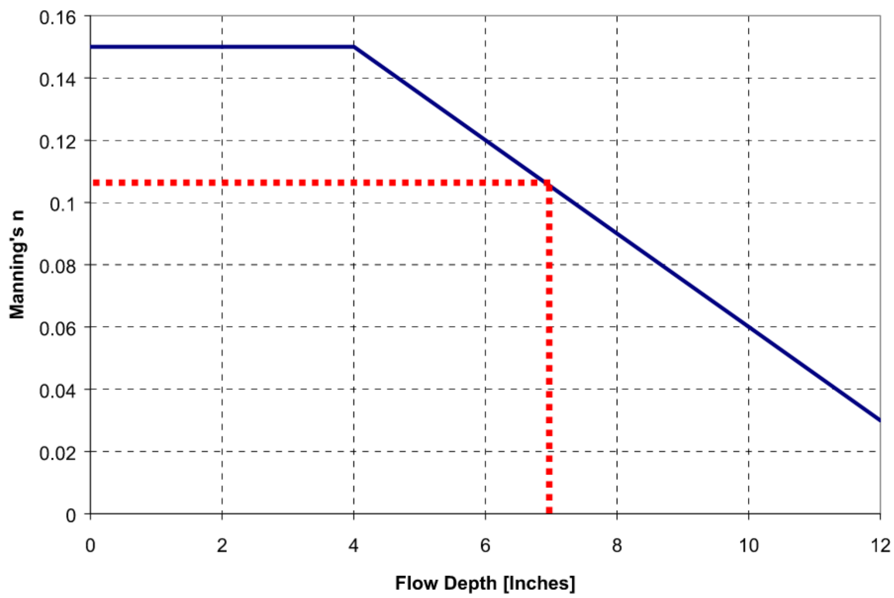


Figure 7.24 2-Year Manning's Number (Refer to Appendix G)

Calculate the 2-yr velocity, using a Manning's number from **Appendix G**, the 2-year flow depth and channel slope:

$$V = \frac{1.49}{n} \, x \, D_2{}^{2/3} \, x \, S_L{}^{1/2}$$

$$V = \frac{1.49}{0.11} \, x \, 0.60^{2/3} \, ft \, x \, 0.02^{1/2} \, ft/ft$$

$$V = 1.37 \, fps$$

Based on the above, the 2-yr velocity is less than 5 fps and meets the requirement for non-erosive conditions.

Using computer modeling, as shown in **Figure 7.25**, the peak water surface elevation during the 10-year storm event is 1.04 ft above the bottom of the dry swale. The swale configuration uses a 2 ft channel depth, therefore during the 10-year storm there is at least 6 inches of freeboard.

```
Inflow Area =    11.050 ac, 32.76% Impervious, Inflow Depth = 1.34"  for 10-yr event
Inflow   =    19.59 cfs @  12.04 hrs, Volume=      1.237 af
Outflow  =     6.83 cfs @  12.30 hrs, Volume=      1.237 af, Atten= 65%, Lag= 15.6 min

Routing by Dyn-Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.01 hrs
Max. Velocity= 1.07 fps, Min. Travel Time= 32.7 min
Avg. Velocity = 0.22 fps, Avg. Travel Time= 158.2 min

Peak Storage= 13,394 cf @ 12.30 hrs
Average Depth at Peak Storage= 1.04' , Surface Width= 9.26'
Bank-Full Depth= 2.00' Flow Area= 18.0 sf, Capacity= 27.68 cfs
```

Figure 7.25 10-Year Flow Depth in Dry Swale

As shown above, all design criteria for the dry swale have been met. Therefore, the proposed dry swale provides 40% of the required WQv toward runoff reduction, and the remaining volume has been treated to meet the water quality criteria.

Table 7.15 demonstrates a summary of the RR techniques being applied for this project, and both the water quality and runoff reduction volumes provided:

Table 7.15 Summary of RR Techniques and Standard SMPs with RRv Capacity Being Applied

RR Technique	NYSDEC Design Variant	RRv Capacity	WQv Required (cf)	RRv Provided (cf)[1]	WQv Treated[2] (cf)	Total Treatment Provided[3] (cf)
Dry Swale (HSG B)	O-1	40%	16,616	6,646	9,970	16,616

Footnotes
[1]RRv Provided = RRv Capacity x WQv Required
[2]WQv Treated = WQv Required – RRv Provided
[3]TotalTreatment Provided = WQv Treated + RRv Provided

Table 7.16 provides a summary of the RRv provided:

Table 7.16 RRv Summary

RR Required = WQv Required (cf)	RRv Provided (cf)	% RRv Provided[1]
16,616	6,646	40

Footnotes
[1]%RRv Provided = (RRv Provided / RRv Required) x 100

Step 4 – Calculate the Minimum RRv Required

The proposed design does not meet 100% RRv provided, as such calculating the minimum RRv is required. An example of calculating the minimum RRv required is provided in **Section 7.1**.

Step 5 – Apply Standard SMPs to Address Remaining WQv

An example of applying standard SMPs to address the remaining WQv required is provided in **Section 7.1**.

Step 6 – Apply Volume and Peak Rate Control

An example of applying volume and peak rate control has been provided in **Section 7.1**.

Section 7.4 Sizing Example – Multiple Dry Wells in Series

As shown in **Figure 7.26**, this design example is for a portion of a residential subdivision that will utilize multiple dry wells in series for treatment of stormwater runoff. This example assumes a HSG B for the site and an underlying soil infiltration rate of 5.0 inch/hr. The contributing area to the dry wells includes a portion of the residential road, driveways, homes, and lawn for a total of 1.774 acres, 0.773 acres of which is impervious cover.

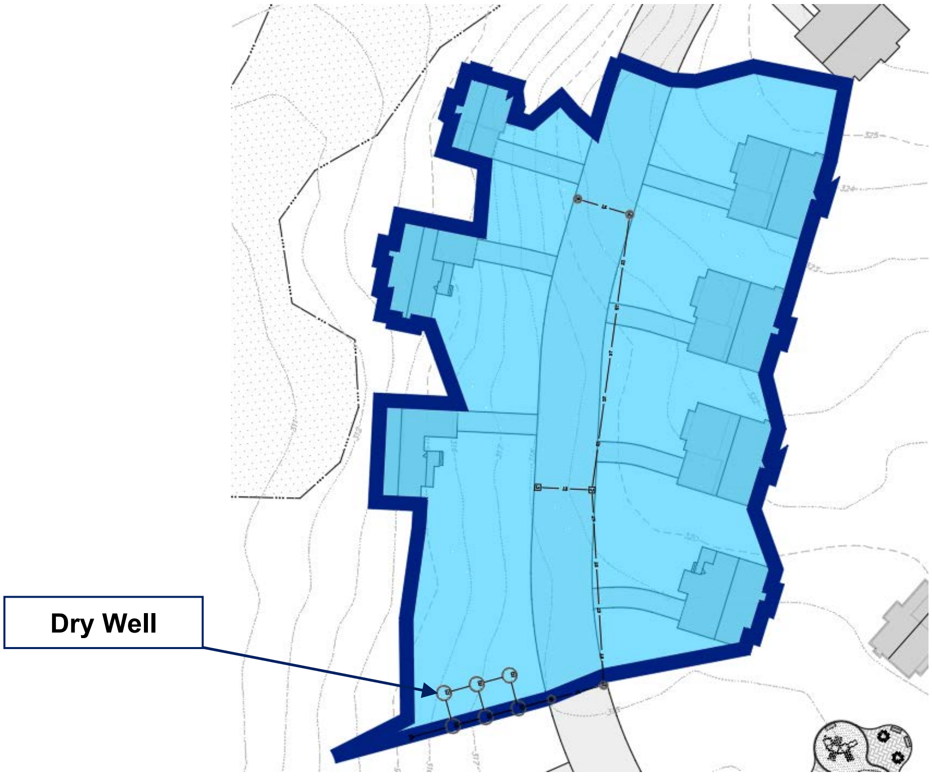


Figure 7.26 Dry Well Contributing Area

Step 1 – Site Planning

An example of site planning has been provided in **Section 7.1**.

Step 2 – Calculate Water Quality Treatment Volume (WQv)

Calculate the required WQv for new development per **Chapter 4**:

$$I = \frac{A_{imp}}{A} \; x \; 100$$

$$I = \frac{0.773 \; acres}{1.774 \; acres} \; x \; 100$$

$$I = 43.6\%$$

$$R_V = 0.05 + (0.009 \; x \; I)$$

$$R_V = 0.05 + (0.009 \; x \; 43.6\%)$$

$$R_V = 0.442$$

$$WQ_V = \frac{P \; x \; R_V \; x \; A}{12}$$

$$WQ_V = \frac{1.20 \; x \; 0.442 \; x \; 1.774 \; acres}{12}$$

$$\boldsymbol{WQ_V = 0.078 \; af \; (3{,}416 \; cf)}$$

Step 3 – Apply RR Techniques and Standard SMPs with RRv Capacity to Reduce Total WQv

Chapter 4 states that runoff reduction shall be achieved through infiltration, groundwater recharge, reuse, recycle, and/or evaporation/evapotranspiration of 100% of the post-development water quality volume to replicate pre-development hydrology. Runoff control techniques provide treatment in a distributed manner before runoff reaches the collection system, by maintaining pre-construction infiltration, peak runoff flow, discharge volume, as well as minimizing concentrated flow. This can be accomplished by applying a combination of Runoff Reduction Techniques, and standard Stormwater Management Practices (SMPs) with RRv capacity.

The contributing area is greater than 0.50 acre, therefore multiple dry wells in series will be used. For this example, the underlying soil infiltration rate is 5.0 inch/hr, therefore 25% of the required WQv must be provided for pretreatment. Pretreatment for the dry wells will be provided by a sedimentation chamber (catch basin with 2 ft deep sump), in accordance with **Section 6.4.3**.

Calculate the required surface area for the pretreatment sedimentation chamber:

$$A_s = 0.066\ x\ WQv$$
$$A_s = 0.066\ x\ 3{,}416\ cf$$
$$A_s = 225\ sf$$

Calculate the maximum depth for the pretreatment sedimentation chamber:

$$d_s = \frac{(p\ x\ WQ_V)}{A_s}$$
$$d_s = \frac{(0.25\ x\ 3{,}416\ cf)}{225\ sf}$$
$$d_s = 3.8\ ft$$

If the proposed depth for the pretreatment sedimentation chamber is less than the maximum depth, calculate the new minimum surface area of sedimentation chamber:

$$A_s = \frac{WQ_v}{d_s\ proposed}$$
$$A_s = \frac{3{,}416\ cf}{2\ ft}$$
$$A_s = 1{,}708\ sf$$

The example proposes multiple sedimentation chambers to meet the minimum surface area. The percentage of the surface area provided by each structure would correlate to the percentage of contributing impervious area to each structure.

Each proposed dry well has an 8ft inside diameter, 8 ft height, 4 inch wall thickness, and a 1 ft stone reservoir thickness in accordance with **Chapter 6**. Below are the calculations for the dry well to determine the provided volume. The dry well design must meet or exceed the required WQv.

Calculate the inside volume of the dry well:

$$V_i = \pi\ x\ r^2\ x\ H$$
$$V_i = \pi\ x\ 4^2\ ft\ x\ 8\ ft$$
$$V_i = 402.2\ cf$$

Calculate the volume of the stone around the dry well:

$$V_s = \left(\pi\ x\ (r^2 + 2t + 2t_s) x\ (H + 2t_s)\right)\ x\ 0.40$$
$$V_s = \left(\pi\ x\ (4^2\ ft + (2\ x\ .25\ ft) + (2\ x\ 1\ ft)) x\ (8\ ft + (2\ x\ 1 ft))\right)\ x\ 0.40$$
$$V_s = 209.3\ cf$$

Calculate the dry well volume provided using the calculated inside volume and volume of the stone:

$$V_W = V_i + V_s$$
$$V_W = 402.2\ cf + 209.3\ cf$$
$$V_W = 611.5\ cf$$

Calculate the WQv provided by multiplying the dry well volume by the number of dry wells proposed:

$$WQ_V = N\ x\ V_W$$
$$WQ_V = 6\ x\ 611.5\ cf$$
$$WQ_V = 3{,}669\ cf$$

Verify that the WQv provided is greater than or equal to the required WQv:

$$\mathbf{3,669\ cf \geq 3,416\ cf}$$

$$Therefore, the\ dry\ well\ design\ meets\ the\ required\ WQv\ volume$$

Table 7.17 demonstrates a summary of the RR techniques being applied for this project, and both the water quality and runoff reduction volumes provided:

Table 7.17 Summary of RR Techniques and Standard SMPs with RRv Capacity being Applied

RR Technique	NYSDEC Design Variant	RRv Capacity	WQv Required (cf)	RRv Provided (cf)[1]	WQv Treated[2] (cf)	Total Treatment Provided[3] (cf)
Dry Well	I-3	100%	3,416	3,416	0	3,416

Footnotes
[1]RRv Provided = RRv Capacity x WQv Required
[2]WQv Treated = WQv Required – RRv Provided
[3]TotalTreatment Provided = WQv Treated + RRv Provided

Table 7.18 provides a summary of the RRv provided:

Table 7.18 RRv Summary

RR Required = WQv Required (cf)	RRv Provided (cf)	% RRv Provided[1]
3,416	3,416	100

Footnotes
[1]%RRv Provided = (RRv Provided / RRv Required) x 100

Step 4 – Calculate the Minimum RRv Required

As previously discussed, the RRv provided is equal to the RRv required for this project. As such, the runoff reduction volume criteria has been met, and the minimum RRv is not applicable.

Step 5 – Apply Standard SMPs to Address Remaining WQv

As previously discussed, 100% of the required WQv is being provided an the minimum RRv is being reduced through RRv practices. As such, the water quality and runoff reduction volume criteria have been met and no other standard SMPs are required.

Step 6 – Apply Volume and Peak Rate Control

An example of applying volume and peak rate control has been provided in **Section 7.1**.

Chapter 8: Urban Stormwater Management

This Chapter presents guidance for implementation of runoff reduction techniques and applicable SMPs, in both new development and redevelopment projects located in urban areas.

Urbanization has altered the hydrologic cycle through increased development density. High quantities of impervious surfaces have led to reduced groundwater recharge, increased rates and volumes of runoff, higher potential for flooding, and increased pollutant loading. A key component of the urban environment is the roadway network, which constitutes a large percentage of impervious cover and produces significant quantities of polluted stormwater runoff. Consequently, application of runoff reduction techniques and applicable SMPs into roadway design or retrofit, presents a sizeable opportunity to improve stormwater quality and quantity by capturing, treating, and promoting groundwater recharge at the source. In this way, stormwater runoff is being integrated into urban roadway design as a resource, instead of a waste product requiring costly conveyance and/or downstream treatment by municipal facilities. Runoff reduction techniques and applicable SMPs, can also be applied as a retrofit to an existing urban roadway network to provide localized storage and reduce flows to existing conveyance systems that may be underperforming. Urban stormwater management can provide the added benefits of improved air quality, reduced urban heat island effect, and enhanced safety and walkability.

Section 8.1 NYSDOT Urban Roadway Classification

The New York State Department of Transportation (NYSDOT) has developed functional classifications for urban roadways statewide. The functional classifications categorize roadways by level of significance within the overall network, character of traffic flow (vehicle, bicycle, and/or pedestrian), and access provided to adjacent properties. Designated “Urban Areas” and urban roadway functional classifications can be easily identified using the NYSDOT Functional Class Viewer system (https://www.dot.ny.gov/gisapps/functional-class-maps). The “Urban Area” boundaries, as shown on the Functional Class Viewer, may not be inclusive of all qualifying urban areas. A summary of the NYSDOT Urban Roadway Functional Classifications can be found in **Table 8.1**.

Table 8.1 NYSDOT Urban Roadway Classifications

Type	Description
Urban Principal Arterial (F11, F12, F14)	Encompasses interstates and other freeways and expressways. Design speeds typically range from 50 to 70 mph. Due to the travel density and design speeds, traffic calming and speed reduction measures are generally not applicable, and on-street parking is generally not allowed.
Urban Minor Arterial (F-16)	Carry large traffic volumes within and through urban areas, but do not have the capacity or significance of Urban Principal Arterials. They serve major areas of activity, carrying a high proportion of an area’s traffic on a small proportion of the area’s lane mileage. Design speeds typically range from 30 to 45 mph. Traffic calming and speed reduction measures are generally applicable, and on-street parking is generally allowed in commercial areas.
Urban Collector (F-17, F-18)	Link neighborhoods or areas of homogeneous land use with Principal or Minor Arterials, serving the dual function of land access and traffic circulation. They are generally not intended to serve regional trips and generally do not provide route continuity for more than a few miles. Design speeds typically range from 30 to 45 mph. Traffic calming and speed reduction measures are generally applicable and on-street parking is generally allowed in commercial, industrial and some residential areas. On-street bicycle lanes may be provided with a dedicated preferential travel lane. Sidewalks can be included on both sides of the roadway and separated from vehicle lanes by a buffer strip.
Urban Local (F-19)	Designated local roadways that provide direct vehicle, bicycle, and pedestrian connections between adjacent neighborhoods, and between neighborhoods and commercial areas. They do not serve trans-regional trips and provide no route continuity beyond the areas they serve. Design speeds are typically less than 30 mph. Traffic calming and speed reduction measures may be used as warranted by adjacent land uses and traffic characteristics. On-street parking will generally be allowed where adequate roadway width is available. On-street bicycle lanes may be provided with a dedicated preferential travel lane. Sidewalks can be included on both sides of the road and separated from vehicle lanes by a buffer strip.
Urban Access	Typically, a focal point of an urban environment, providing pedestrian and bicycle access only. Vehicle access is generally prohibited, with the exception of emergency vehicles. This class is not included in the NYSDOT Functional Classifications; nor is it included on the Functional Class Viewer.

Section 8.2 Urban Practice Suitability

The Urban Practice Suitability Matrix (**Table 8.2**) allows the designer to perform an initial evaluation of practices most suitable for a given roadway classification. Practices listed below are not exhaustive of all types of runoff reduction techniques or applicable SMPs. Other runoff reduction techniques may be evaluated, designed and implemented depending on the need or context.

Table 8.2 Urban Practice Suitability Matrix

Technique		Urban Principal Arterial	Urban Minor Arterial	Urban Collector	Urban Local	Urban Access
Tree Planting	Tree Pit	Medium	High	High	High	High
	Tree Trench	Medium	Medium	High	High	High
Rain Garden		Low	Low	Low	Medium	High
Stormwater Planter		Medium	Medium	High	High	High
Porous Pavement	Porous Pavement/ Porous Concrete	Low	Low	Low	High	High
	Porous Paver Roadway	Low	Low	Low	High	High
	Porous Paver/ Flexible Porous Pavement Pedestrian Applications	Medium	Medium	High	High	High
	Porous Pavement/ Porous Concrete Gutter	Medium	Medium	High	High	Medium
Bioretention Bumpout		Medium	High	High	High	High
Bioslope		High	High	Medium	Low	Low
Underground Infiltration Systems		Low	Low	Medium	High	High

Section 8.3 Implementation of Urban Stormwater Management Practices

Urban stormwater management practices must consider potential design constraints, interaction with vehicles, bicycles and pedestrians, and how they can be uniquely integrated into urban design. The following descriptions outline how runoff reduction techniques and applicable SMPs can be implemented in urban environments. In order to meet the water quality requirements, set forth in this Design Manual, the practices must conform to the sizing criteria presented in **Chapter 4**, or **Chapter 9** (if applicable), and must be constructed in accordance with the performance criteria in **Chapters 5** or **6**.

While considering the implementation of urban stormwater management practices, it is imperative to recognize potential constraints and considerations of practices and the interaction a practice may have with vehicles, bicycles and pedestrians. **Figure 8.1** demonstrates the different zones identified in urban settings used for urban stormwater management practice:

- Building Use Zone: the area between the building front or property line and the pedestrian zone. This zone is intended to buffer pedestrians from doorways and appurtenances.
- Pedestrian Zone: the area primarily utilized for pedestrian travel. This zone shall be free of obstacles, protruding objects, and vertical obstructions for pedestrians.
- Buffer Zone: the area between the pedestrian zone and roadway. This zone is typically utilized for urban stormwater management, utilities, landscaping, public signage, transit stops, and streetscape amenities to keep the pedestrian zone free of obstacles.

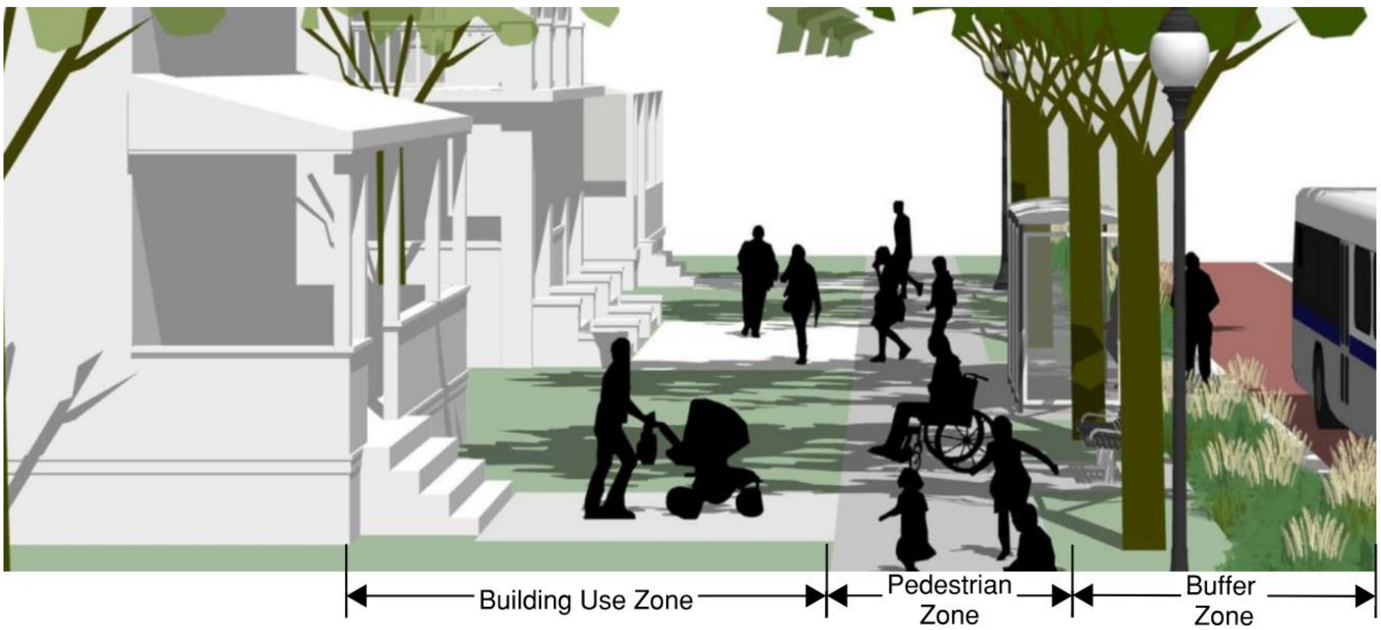


Figure 8.1 Urban Stormwater Management Implementation Zones (City of Albany Complete Streets Policy & Design Manual, 2016)

Tree Planting: Tree Pit

Tree pits can be applied as a volume reduction practice for urban stormwater management. This practice has the potential to enhance streetscapes, increase the overall urban forest canopy, improve air quality, reduce the urban heat island effect, and provide wildlife habitat.

Figure 8.2 Tree Pit installed in Cohoes, NY

Potential Constraints and Considerations

- Tree pits have a limited stormwater management capacity.
- Tree species shall be chosen based on:
  - Hardiness zone;
  - Allowable growth area for both canopy and root structure;
  - Frequency and degree of maintenance; and
  - Typical life expectancy and disease resistance.
- Trees shall not be planted in front of steps, doorways, or alleyways.
- Trees with narrow canopies, that do not reduce intersection visibility, shall be used in medians and near intersections.
- Interface between trees and utilities, both above and below ground.
- Volume of soil required to achieve treatment capacity and support mature tree growth.
- Non-compacted soil media shall be provided within the limits of the open surface area of the tree pit. Where space allows, structural soil shall be extended beyond the non-compacted soil media to allow for root growth into adjacent areas. Structural soil shall be designed with adequate bearing capacity to support sidewalks and other pedestrian amenities.
- Tree pits shall be located and designed to allow maintenance workers and equipment to safely navigate around the practice.

Interaction with Vehicles, Bicycles and Pedestrians

- Street trees provide the benefit of shade and a physical separation between pedestrians and vehicle traffic.
- Tree pits must consider accessibility requirements:
  - The pedestrian zone shall meet accessible minimum width requirements.
  - The pedestrian zone shall meet the accessible changes in level requirements.
  - Tree pits may protrude into the pedestrian zone when the surface of the pit (tree grate, flexible porous pavement, etc.) meets accessibility requirements.
  - If the tree pit has a recessed elevation, then a protective barrier shall be provided to restrict pedestrian access.

Urban Design Integration

- Tree pits are best suited for source control treatment of directly adjacent impervious surfaces. Typical applications include pedestrian hardscapes, road rights-of-way, and medians. Refer to **Figure 8.3** for application examples.

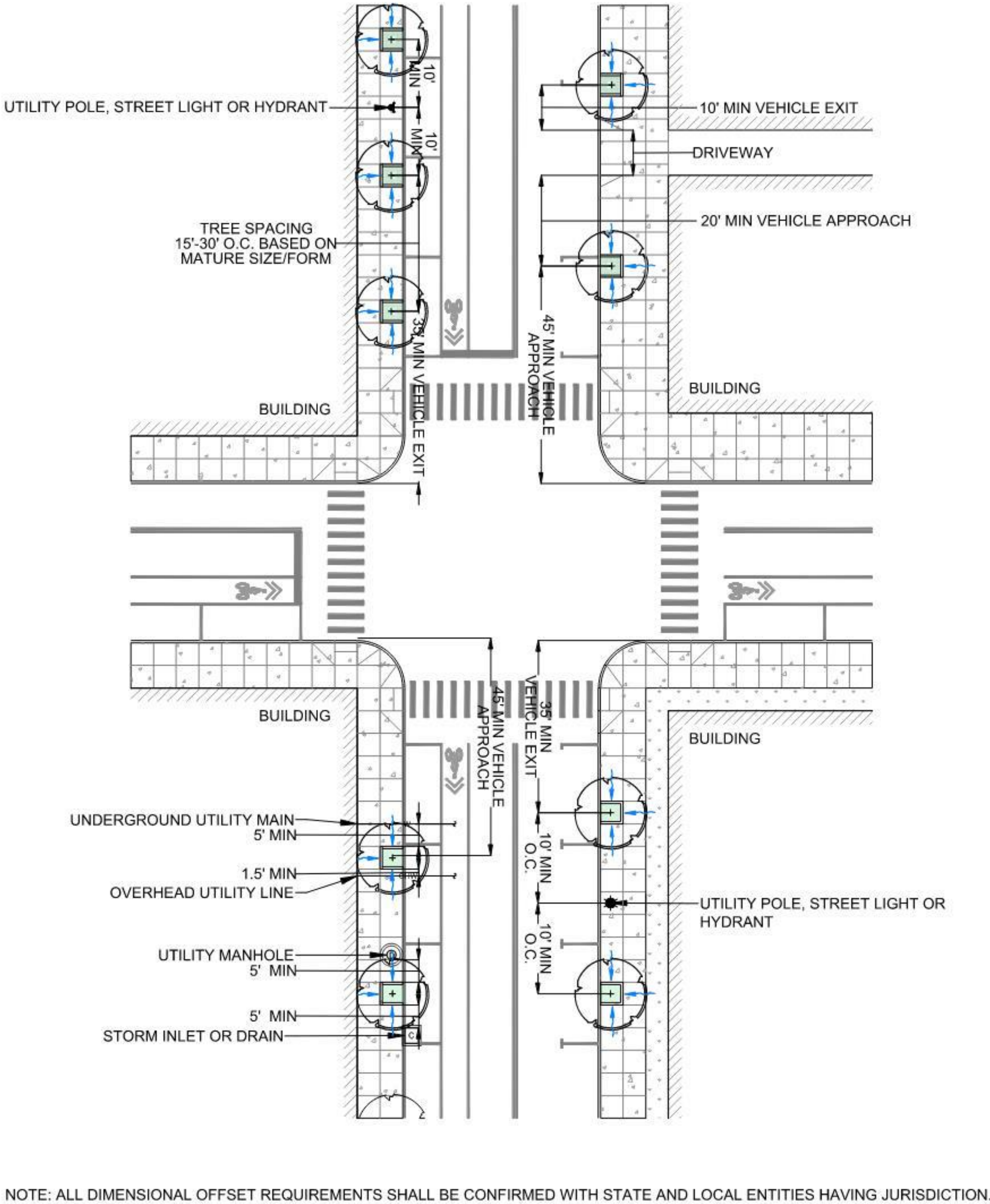


Figure 8.3 Tree Pit Configuration at Urban Intersection

Tree Planting: Tree Trench

Tree trenches can be applied as a volume reduction practice for urban stormwater management. This practice has the potential to enhance streetscapes, increase the overall urban forest canopy, improve air quality, attenuate noise, reduce the urban heat island effect, and provide wildlife habitat.

Potential Constraints and Considerations

- Tree species shall be chosen based on:
  - Hardiness zone;
  - Allowable growth area for both canopy and root structure;
  - Frequency and degree of maintenance; and
  - Typical life expectancy and disease resistance.
- Interface between trees and utilities, both above and below ground.
- Volume of soil required to achieve treatment capacity and support mature tree growth.
- In subsurface flow designs, non-compacted soil media shall be provided within the limits of the open surface area of the tree trench only. Structural soil shall be extended within the remaining bounds of the tree trench to provide adequate bearing capacity to support sidewalks and other pedestrian amenities.

Figure 8.4 Tree Trench installed in Hudson Falls, NY

- In surface flow designs, non-compacted soil media shall be provided within the limits of the open surface area of the tree trench.
- Maintenance required may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.
- Tree trenches shall be located and designed to allow maintenance workers and equipment to safely navigate around the practice.

Interaction with Vehicles, Bicycles and Pedestrians

- Tree trenches do not impede bicycle traffic.
- A break in the tree trench shall be provided every 40 ft, minimum, where sidewalks are not present between parking stalls and tree trenches.
- Trees provide the benefit of shade and a physical separation between pedestrians and vehicle traffic.
- Tree trenches must consider accessibility requirements:
  - The pedestrian zone shall meet accessible minimum width requirements.
  - The pedestrian zone shall meet the accessible changes in level requirements.
  - In subsurface flow designs, tree trenches may protrude into the pedestrian zone when the surface of the trench (tree grate, flexible porous pavement, etc.) meets accessibility requirements.
  - In surface flow designs, a protective barrier, such as curb or railings, shall be provided at the perimeter of the trench to restrict pedestrian access.

Urban Design Integration

- Tree trenches are best suited for source control treatment of directly adjacent impervious surfaces. Typical applications include pedestrian hardscapes, road rights-of-way, and medians. Refer to **Figure 8.5** for application examples.
- Runoff from adjacent building roofs can be captured and directed into right-of-way tree trenches. Roof drains shall discharge at the surface of the tree trench or connect to a storm sewer structure for flow dissipation, prior to entering the tree trench. Direct connections to the subsurface infiltration pipe are not permitted.

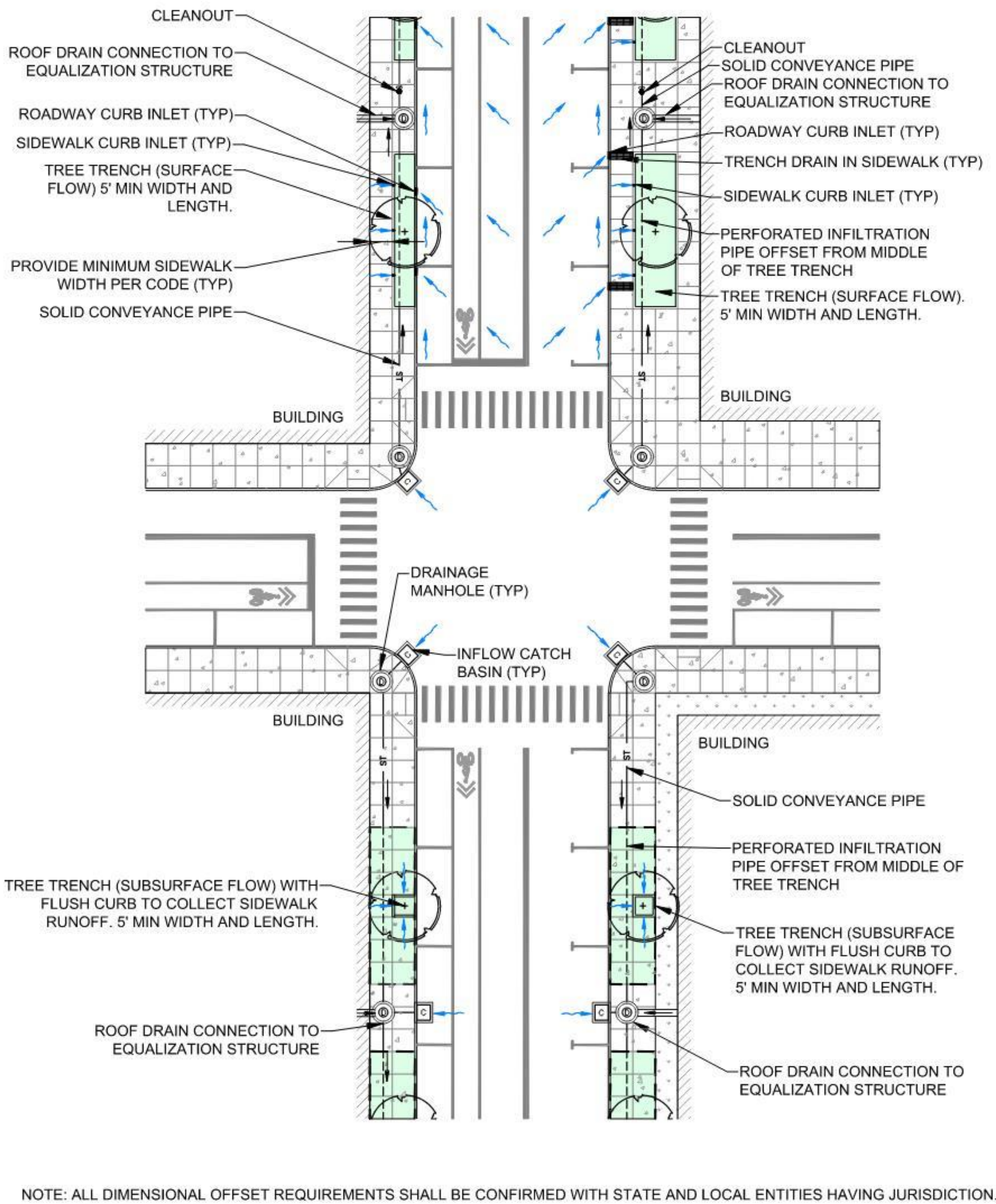


Figure 8.5 Tree Trench Configuration at Urban Intersection

Rain Garden

Rain gardens may be applied as filtration or infiltration practices, depending on site conditions, to provide volume reduction for urban stormwater management. This practice is designed to capture, temporarily store and treat stormwater runoff from adjacent impervious surfaces. In addition, rain gardens have the potential to reduce urban heat island effect and provide wildlife and pollinator habitat through dense, native vegetation.

Potential Constraints and Considerations

Figure 8.6 Rain Garden installed in Lake George, NY

- Contributing drainage area is limited.
- May be installed in the building use zone or the buffer zone.
- Requires adequate space for pedestrian circulation around the rain garden.
- Surface area may need to be increased to limit the depth of ponding and ensure that ponding does not extend into pedestrian zones.
- Grading and landscaping placement must establish an appropriate transition zone from the elevation of the pedestrian zone to the elevation of the rain garden bottom area.
- Volume of soil required to achieve treatment capacity.
- Interface between the rain garden section and below ground utilities.
- Plant species shall be chosen based on:
  - Hardiness zone;
  - Frequency and degree of maintenance; and
  - Typical life expectancy and disease resistance.
- Require maintenance which may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.
- Rain gardens shall be located and designed to allow maintenance workers and equipment to safely navigate around the practice.

Interaction with Vehicles, Bicycles and Pedestrians

Figure 8.7 Rain Gardens installed in Manhattan, NY

- Rain gardens may be used as a divide between the pedestrian zone and any recreational site areas or amenities (i.e. playgrounds, multi-use trails, seating areas, etc.)
- Rain gardens must consider accessibility requirements:
  - The pedestrian zone shall meet accessible minimum width requirements.

Urban Design Integration

- Rain gardens are best suited for source control treatment of directly adjacent impervious surfaces. Typical applications include pedestrian plazas, pedestrian medians, pocket parks, and multi-use trails.

Stormwater Planter

Stormwater planters may be applied as filtration or infiltration practices, depending on site conditions, to provide volume reduction for urban stormwater management. This practice allows designers to capture, temporarily store and treat rooftop runoff. In addition, stormwater planters have the potential to enhance streetscapes, reduce urban heat island effect, and provide wildlife habitat.

Potential Constraints and Considerations

Figure 8.8 Stormwater Planter installed in Tarrytown, NY

- Stormwater planters shall be placed in the building use zone against building faces and used to capture and treat rooftop runoff only.
- Volume of soil required to achieve treatment capacity.
- Interface between the stormwater planter section and below ground utilities.
- Plant species shall be chosen based on:
  - Hardiness zone;
  - Frequency and degree of maintenance; and
  - Typical life expectancy and disease resistance.
- Require maintenance which may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.
- Stormwater planters shall be located and designed to allow maintenance workers and equipment to safely navigate around the practice.

Interaction with Vehicles, Bicycles and Pedestrians

- Stormwater planters must consider accessibility requirements:
  - The pedestrian zone shall meet accessible minimum width requirements.
  - Stormwater planters may protrude into the pedestrian zone; however, the pedestrian zone shall meet accessible width requirements.
  - Recessed stormwater planters shall be designed with a protective barrier, such as curb or railings, at the perimeter of the planter to restrict pedestrian access.

Urban Design Integration

- Stormwater planters are best suited for source control treatment of directly adjacent impervious surfaces. Typical applications include treatment of rooftop runoff.

Porous Pavement

Porous pavement may be applied as a volume reduction practice for urban stormwater management. This practice has the potential to reduce local flooding, minimize ice conditions, reduce the burden on closed storm or combined sewer networks, and promote groundwater recharge.

Figure 8.9 Porous Asphalt parking stalls installed in Cohoes, NY

Potential Constraints and Considerations

- Highly compacted impervious subbase under existing roadways or hardscapes may need to be removed.
- Porous pavement designs shall consider traffic loading and volume conditions.
- Interface between the porous pavement section and below ground utilities.
- Requires maintenance (semiannually) which may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.
    - Porous pavement gutters require more regular maintenance (minimum 4 times per year).

Interaction with Vehicles, Bicycles and Pedestrians

- Porous pavement may be applied in the building use zone, pedestrian zone, buffer zone and roadways.
- Porous pavement within the pedestrian zone must consider accessibility requirements:
    - The pedestrian zone shall meet accessible minimum width requirements.
    - The pedestrian zone shall meet the accessible changes in level requirements.
    - Porous pavements used within the pedestrian zone shall be a stable, firm, walkable surface.
- Porous pavements may be implemented in bike lanes to reduce the period of time required for pavement to dry.

Urban Design Integration

- Porous pavements can be used in new and retrofit scenarios.
    - Porous concrete may be a suitable replacement for conventional concrete in sidewalk applications.
    - Porous asphalt may be a suitable alternative to conventional asphalt and can be used in a variety of applications such as low traffic roadways, bicycle lanes, shoulders, parking stalls, and multi-use trails.
    - Porous pavers can be used in a variety of applications such as low traffic roadways, bicycle lanes, streetscapes, recreation areas, plazas and parking stalls.
    - Flexible porous paving may be applied in areas such as the buffer zone, around street trees, playground or sporting surfaces, and lower impact multi-use trail surface.
- Alternating porous pavement types may be used to differentiate surfaces by modal use.
- Alternating porous pavement textures, colors or patterns may enhance overall street aesthetic.

Bioretention Bumpout

Bioretention bumpouts may be applied as filtration or infiltration practices, depending on site conditions, to provide volume reduction for urban stormwater management. This practice can be applied as a curb extension (bumpout), within the buffer zone, to capture, temporarily store and treat stormwater runoff from roadways and adjacent impervious surfaces. In addition, bumpouts reduce the burden on closed storm or combined sewer networks, promote groundwater recharge, enhance streetscapes, provide traffic calming by visually and physically narrowing the roadway, and create safer and shorter pedestrian crossings at intersections.

Potential Constraints and Considerations

Figure 8.10 Bioretention Bumpout (Millburn Environmental Commission)

- Designers shall consider existing on-street parking conditions, road width, and vehicle turning radii.
- Alteration of existing curb line may directly impact existing road drainage patterns and shall consider longitudinal and cross slope to bumpout inflow points.
- In a retrofit design, placement of bumpouts shall consider location of existing catch basins and potential removal of catch basins to maximize the interception of stormwater runoff from roadways.
- Surface area may need to be increased to limit the depth of ponding and ensure that ponding does not extend into roadways or pedestrian zones.
- Volume of soil required to achieve treatment capacity.
- Vegetation shall accommodate adequate sight distance at intersections.
- Plant species shall be chosen based on:
  - Hardiness zone;
  - Frequency and degree of maintenance; and
  - Typical life expectancy and disease resistance.
- Considerations shall be taken for below grade utilities that may be present in the bioretention section.
- Pretreatment is required for bumpouts. Due to spatial constraints and runoff required to enter at the surface, pretreatment shall be provided in the form of gabion baskets or stone and curb check dams Refer to **Figure 8.11**.
- Bumpout design shall consider maneuverability of snow removal equipment.
- Maintenance may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.
- Bumpouts shall be located and designed to allow maintenance workers and equipment to safely navigate around the practice.

Interaction with Vehicles, Bicycles and Pedestrians

- Where a designated bicycle lane is present, bumpout placement shall provide adequate space between the edges of curb extension and travel lane for bicycle movement.
- If placed near an intersection, bumpouts shall accommodate pedestrian passage through the curb extension.
- Mid-block bump outs shall not encourage undesired or unsafe mid-block pedestrian crossings.
- Allows for separation between pedestrian zones and travel lanes creating a safer and more walkable environment.
- Recessed bumpouts shall be designed with a protective barrier on the edge of the pedestrian zone, such as curb or railings, to restrict pedestrian access. As an alternative, grading and landscaping placement can be used to establish an appropriate transition zone from the elevation of the pedestrian zone to the elevation of the bioretention bottom area.

Urban Design Integration

- Bumpouts are best suited for source control treatment of directly adjacent impervious surfaces. Typical applications include intersections and road rights-of-way. Refer to **Figure 8.15** for application examples.

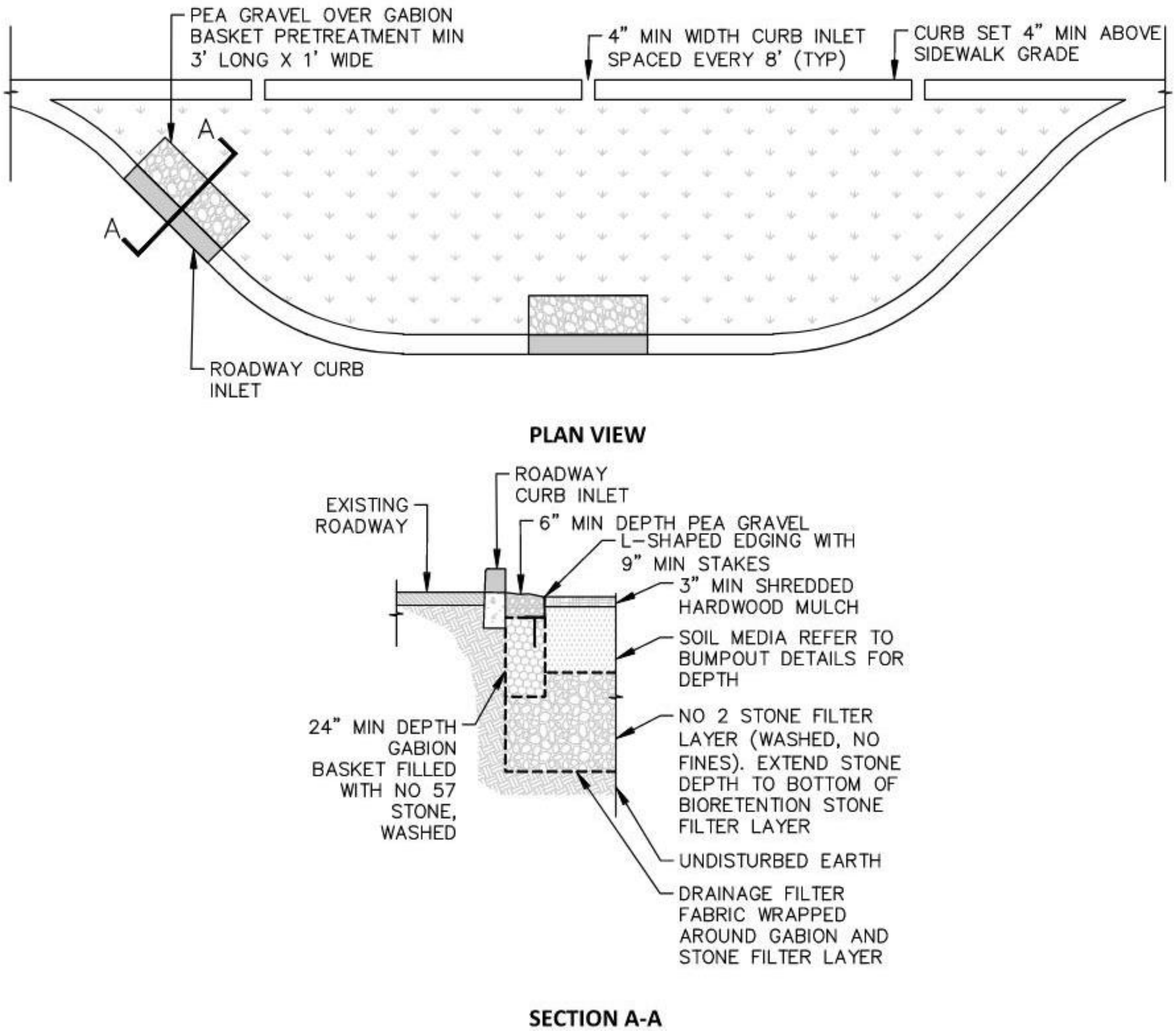


Figure 8.11 Pretreatment for Bioretention Bumpouts – Gabion Basket

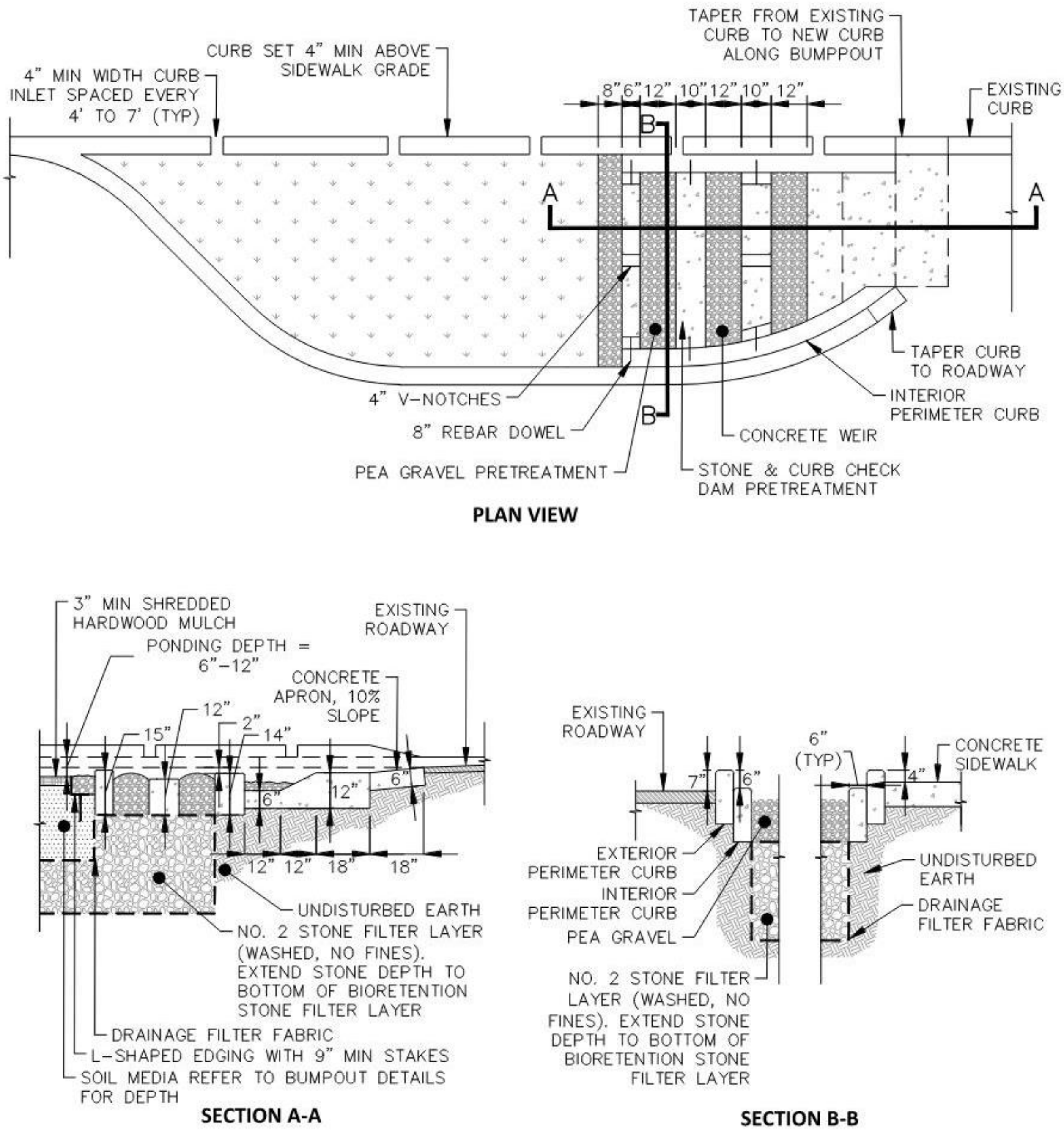


Figure 8.12 Pretreatment for Bioretention Bumpouts – Stone and Curb Check Dam

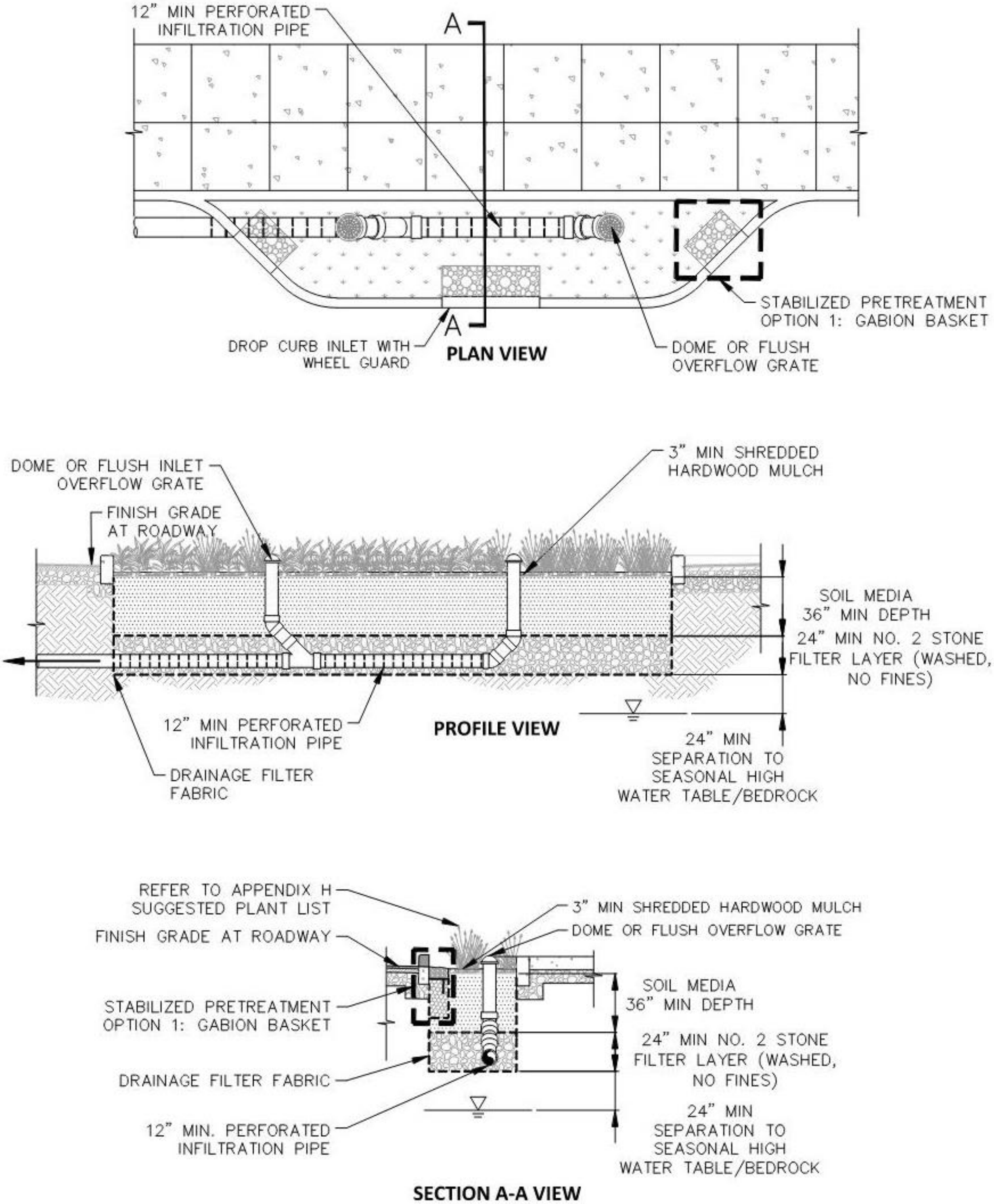


Figure 8.13 Bioretention Filter Island Bumpout

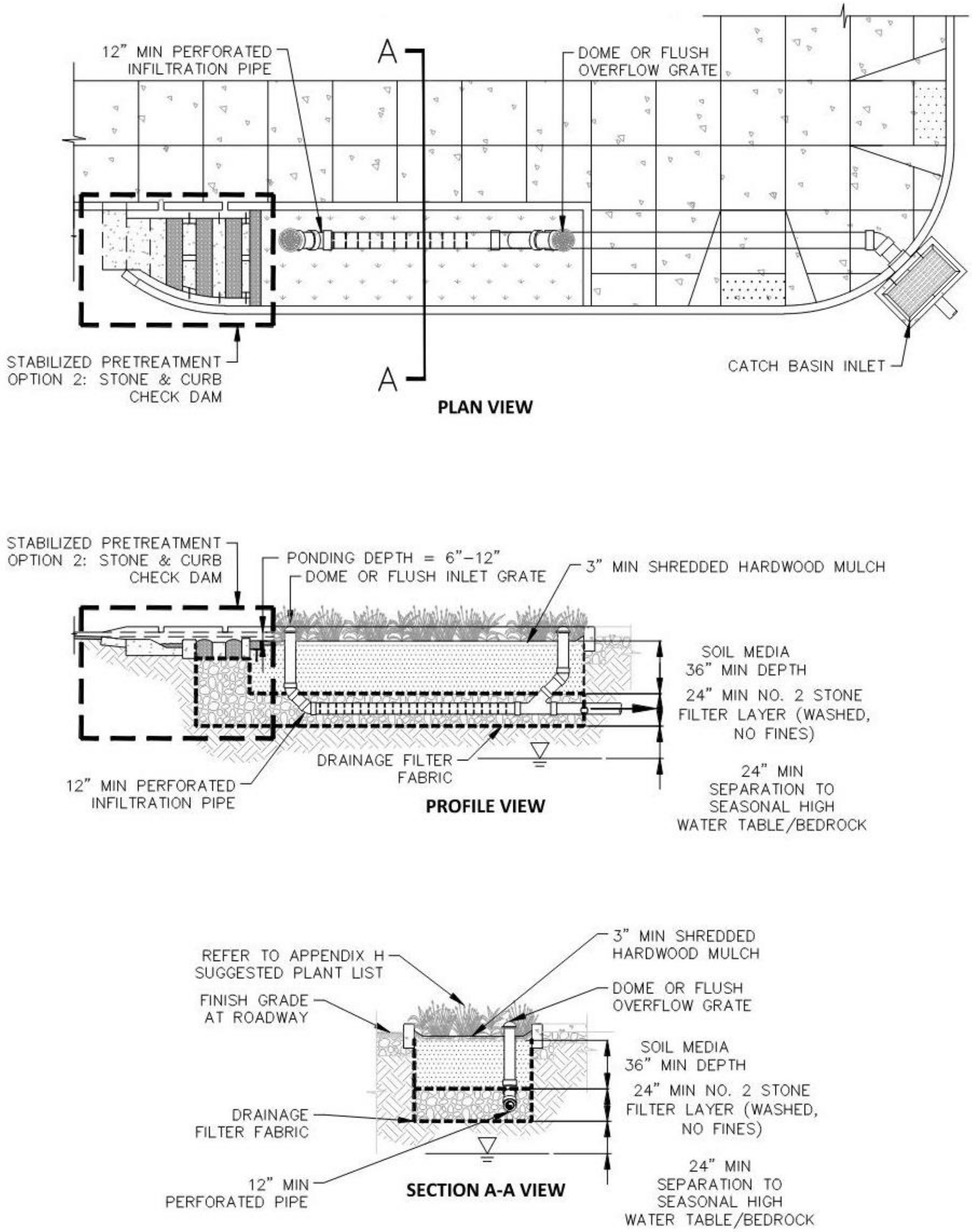
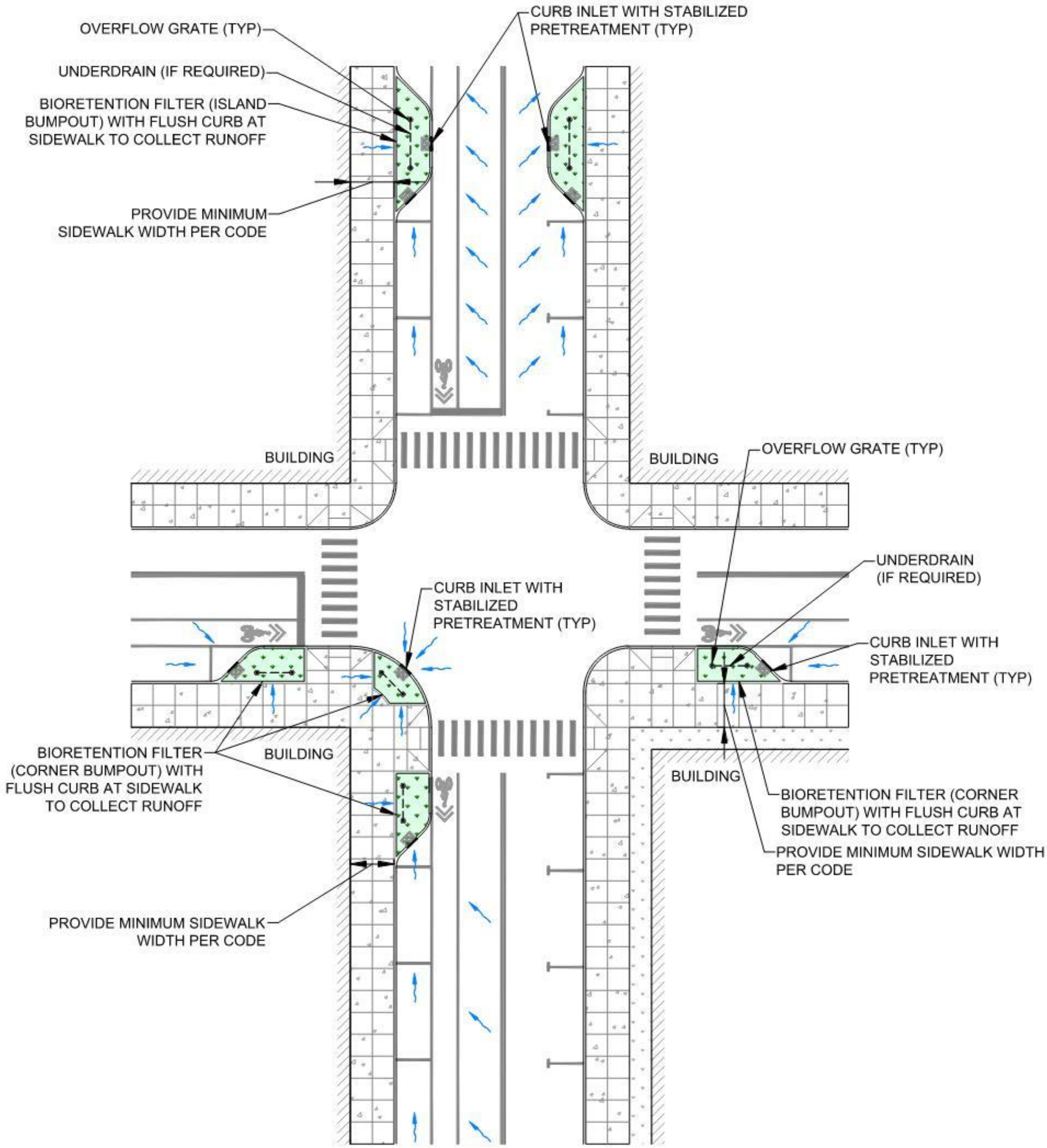


Figure 8.14 Bioretention Corner Bumpout



NOTE: ALL DIMENSIONAL OFFSET REQUIREMENTS SHALL BE CONFIRMED WITH STATE AND LOCAL ENTITIES HAVING JURISDICTION.

Figure 8.15 Bioretention Bumpout Configuration at Urban Intersection

Bioslope

Bioslopes can be applied as a volume reduction practice for urban stormwater management. This practice is best suited for linear applications to treat stormwater along impervious areas, such as medium to high volume roadways with minimal pedestrian interaction, linear utility projects, low volume access drives, and multi-use trails.

Potential Constraints and Considerations

- Limited to sheet flow applications only.
- Adequate space must exist to provide all components of the bioslope, including pretreatment.
- Require maintenance which may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.

Figure 8.16 Bioslope Application
(Georgia Stormwater Management Manual, 2016 Edition)

Interaction with Vehicles, Bicycles and Pedestrians

- Applicable where curb and gutters are not utilized.
- Roadway must provide adequate space for vehicle stopping, such that the vehicle does not interact with the pretreatment and treatment zones.
- Bicycle travel and pedestrian zone, if applicable, must be provided with adequate space outside of the pretreatment and treatment zones.

Urban Design Integration

- Require a relatively small amount of space to function effectively and can be applied in rights-of-way where availability is limited.

Underground Infiltration

Underground Infiltration can be applied as a volume reduction practice for urban stormwater management. This practice can be used to capture, temporarily store and treat stormwater runoff, reduce the burden on closed storm or combined sewer networks, and promote groundwater recharge in areas where space is constrained.

Figure 8.17 Underground infiltration system installed in Mahopac, NY

Potential Constraints and Considerations

- Adequate cover shall be provided, based on manufacturer's recommendations, to protect the structural integrity of the system.
- Urban fill soils shall not be used in areas of underground infiltration practices. Urban fill in considered soil that includes unsuitable materials such as brick, cement, asphalt, demolition debris, etc.
- Maintenance required may be outside the regular scope of municipal public works staff. Identifying a suitable maintenance plan and appropriate staff to manage is recommended.

Interaction with Vehicles, Bicycles and Pedestrians

- Proposed grates, covers and inspection ports associated with the system shall be selected and placed with the anticipated traffic above the system in mind to avoid interfering with traffic.
- Proposed grates, covers and inspection ports associated with the system, within the pedestrian zone, shall not impede pedestrian movements and shall meet the accessible changes in level requirements.
- Inlet grates within the pedestrian zone shall meet accessibility requirement.
- Inlet grates within the bicycle travel lane shall meet bicycle safety requirements.

Urban Design Integration

- Ideal for highly urbanized areas where soil permeability is high and space is constrained.
- Systems have little to no surface footprint and can be integrated within the building use zone, pedestrian zone, or buffer zone.

Chapter 9: Redevelopment Activity

This Chapter outlines alternative approaches for addressing stormwater management at projects that include the disturbance and reconstruction of existing impervious surfaces (i.e. redevelopment activity). The approaches set forth in this Chapter comply with the Department's technical standards.

Section 9.1 Introduction

Redevelopment of previously developed sites is encouraged from a watershed protection standpoint because it often provides an opportunity to conserve natural resources in less impacted areas by targeting development to areas with existing services and infrastructure. At the same time, redevelopment provides an opportunity to correct existing problems and reduce pollutant discharges from older developed areas that were constructed without effective stormwater pollution controls.

Redevelopment activities can range from large-scale redevelopment (e.g. reconstruction of a box store, mall, etc.), to much smaller building, parking lot or road reconstruction projects. The proposed density of the large-scale projects can be high, resulting in space constraints to implement on-site stormwater controls. Added to this basic space constraint is the need to tie into the existing drainage infrastructure, which may be at an elevation that does not provide enough head for certain stormwater management practices (SMPs). Other problems encountered in redevelopment include the presence of underground utilities, incompatible surrounding land uses, highly compacted soils that are not suitable for infiltration, and contaminated soils that require mitigation and can drive up project costs.

Because the technical standards contained elsewhere in this Manual were primarily intended for new development projects, compliance with the sizing criteria in full may present a challenge on projects that include redevelopment activities. Therefore, this Chapter sets forth alternative sizing criteria for redevelopment activities. Implementation of this alternative sizing criteria will result in pollutant reductions over existing conditions where no practices are currently in place, particularly when considering the cumulative effect of multiple projects.

For redevelopment activities located in critical environmental areas (see http://www.dec.ny.gov/permits/6184.html) and other sensitive environmental or regulated areas, all attempts should be made to seek compliance with the sizing criteria set elsewhere in this manual.

Section 9.2 Scope and Applicability

The provision of stormwater management practices during redevelopment activities should follow an approach to balance between 1) maximizing improvements in site design that can reduce the impacts of stormwater runoff, and 2) providing a maximum level of on-site treatment that is feasible given the site constraints present where the redevelopment activities are occurring.

Under conditions where onsite treatment is not practicable, an appropriate off-site watershed improvement to offset the required level of control may be applied, in the presence of a regulated/permitted municipal stormwater management program. The off-site stormwater management approach is subject to applicable local agency approval for banking and trading of credits. This approach may not be an acceptable option in all cases. In addition, a SWPPP that incorporates this approach is considered to be not in conformance with the State's technical standards.

Requirements for installation of post construction controls set forth in current stormwater regulations do apply to construction projects that include redevelopment activities.

The sizing criteria described in this Chapter apply to redevelopment activities only. If a construction project includes both new development and redevelopment activities, the stormwater management practices for the new development portion of the project must be designed in accordance with the sizing criteria in **Chapter 4**, and the redevelopment activities portion of the project is subject to the sizing criteria in **Section 9.2.1**.

If runoff from the reconstructed impervious area (i.e. redevelopment activity) was being treated by an existing stormwater management practice that generally meets the criteria of one of the practices included in this manual, the final design must include WQ_v treatment equal to the treatment that was provided by the existing practice or the treatment options defined in **Section 9.2.1** of this Chapter, whichever treatment volume is greater.

9.2.1 Sizing Criteria

Note: The following sizing criteria apply to redevelopment activities only.

A. **Water Quality** treatment objective shall be achieved using the following options. If there is an existing stormwater management practice located on the site that captures and treats runoff from the impervious area that is being disturbed, the water quality volume treatment option selected must, at a minimum, provide treatment equal to the treatment that was being provided by the existing practice(s) if that treatment is greater than the treatment required by options I - V:

   I. The plan proposes a reduction of existing impervious cover by a minimum of 25% of the total disturbed, impervious area. A reduction in site imperviousness will reduce the volume of stormwater runoff, thereby achieving, at least in part, stormwater criteria for both water quality and quantity. The final grading of the site should be planned to minimize runoff contribution from new pervious area onto the impervious cover. Effective implementation of this option requires restoration of soil properties in the newly created pervious areas. Soil restoration is achieved by practices such as soil amendment, deep-ripping, and de-compaction (See **Section 5.1.6** Soil Restoration).

   II. The plan proposes that 100% WQv is captured and treated, for a minimum of 25% of the disturbed, redevelopment impervious area, by implementation of standard SMP or reduced by application of runoff reduction techniques (see **Chapter 5** of this Manual). The SWPPP must clearly document the 25% redevelopment area that is being treated. The remaining 75% can flow to the design point untreated so long as the water quantity control requirements are met. For all sites that utilize structural SMPs, these practices should be targeted to treat areas with the greatest pollutant generation potential (e.g. parking areas, service stations, etc.). If the construction project includes both new development and redevelopment activities, 100% WQv treatment is required for, at minimum, 25% of the existing disturbed impervious area; however, in accordance with **Chapter 4**, 100% of the WQ_v must be provided for any increases in impervious cover to a given design point. In cases where treatment of the redeveloped area is infeasible, due to site constraints, designers may choose to treat an equivalent or greater existing impervious area that is tributary to the same design point as the redeveloped area. As with design of any practice, sizing of structures shall be based on all contributing areas to the SMP. Construction projects that involve the redevelopment of a portion of the site, may choose diversion or flow splitters to be able to size the control structures for the reconstructed area only. For all sites that utilize runoff reduction techniques (See **Table 3.1**), a proposed plan is effective when runoff is controlled near the source and managed by infiltration, reuse, and evapotranspiration.

   III. The plan proposes that 100% WQv is captured and treated, for a minimum of 75% of the disturbed, redevelopment impervious area, by implementation of a volume-based alternative SMP, as defined in **Section 9.4**. However, in accordance with **Chapter 4**, 100% of the WQ_v must be provided for any increases in impervious cover to a given design point using runoff reduction techniques and/or standard SMPs. If an alternative SMP is proposed for the new development portion of a project, then that practice must be approved by the Department for conformance with the new development design criteria. As with design of any practice, sizing of practices should be based on all areas contributing to the SMP.

   IV. The plan proposes that 100% WQv is captured and treated, for a minimum of 75% of the disturbed, redevelopment impervious area, by implementation of a flow-through alternative SMP sized to treat the peak rate of runoff from the WQ_v design storm, as defined in **Chapters 4** and **10**. As with design of any practice, sizing of practices should be based on all areas contributing to the SMP. For guidance, the Water Quality Peak Flow Calculation is provided in **Section 9.3**. The flow capacity identified in the verification process for the specific alternative practice must be greater than or equal to the calculated peak runoff rate from the WQ_v design storm. For off-line practices, the installation must include flow diversion that protects the practice from exceeding the design criteria. However, in accordance with **Chapter 4**, 100% of the WQ_v must be provided for any increases in impervious cover to a given design point using runoff reduction techniques and/or standard SMPs. If an alternative SMP is proposed for the new development portion of a project, then that practice must be approved by the Department for conformance with the new development design criteria.

V. The plan proposes a combination of techniques, such as impervious cover reduction (IC_{RED}), standard SMPs, runoff reduction or alternative SMPs that provide a weighted average of at least two of the above methods. The plan may provide a combination of the above options using the following calculation. In accordance with Chapter 4, 100% of the WQv must be provided for any increase in impervious cover to a given design point. If an alternative SMP is proposed for the new development portion of a project, then that practice must be approved by the Department for conformance with the new development design criteria.

$$\%ALT = \left(25 - (\%IC_{RED} + \%SMP + \%RR)\right) x\ 3$$

Where:

%ALT = Percent of redevelopment impervious area treated by alternative SMP(s)
$\%IC_{RED}$ = Percent reduction in existing disturbed impervious area
%SMP = Percent of redevelopment impervious area treated by standard SMP(s)
%RR = Percent of redevelopment impervious area treated by runoff reduction technique(s)

For example, water quality volume for the alternative practice for the following scenarios shall be computed as follows:

Example 1: Combination of impervious area reduction and standard SMP

$$0\%ALT = \left(25 - (5\%IC_{RED} + 20\%SMP + 0\%RR)\right) x\ 3$$

Example 2: Combination of impervious area reduction and alternative practice

$$60\%ALT = \left(25 - (5\%IC_{RED} + 0\%SMP + 0\%RR)\right) x\ 3$$

Example 3: Combination of standard SMP, runoff reduction and alternative practice

$$45\%ALT = \left(25 - (0\%IC_{RED} + 5\%SMP + 5\%RR)\right) x\ 3$$

Example 4: Combination of impervious area reduction, standard SMP, runoff reduction and alternative Practice

$$30\%ALT = \left(25 - (5\%IC_{RED} + 5\%SMP + 5\%RR)\right) x\ 3$$

B. Runoff Reduction Volume, although encouraged, meeting the RRv sizing criteria is not required for the redevelopment activity portion of a project. The need to provide RRv shall be considered separately for each design point. For design points with a net increase in impervious area, RRv is required for the increase in impervious area only. For urban redevelopment projects requiring RRv refer to **Chapter 8** for urban design considerations. For design points with a net decrease in impervious area, RRv is not required for that design point.

C. Water Quantity controls shall be sized using the following options:

VI. Channel Protection for redevelopment activities is not required if there is 0% change to hydrology that increases the discharge rate from the project site. Evaluation of the change to hydrology shall include the redevelopment activity portion of a project, and if applicable any new development tributary to the same design point as the redevelopment, in the analysis. This criterion, as defined in **Chapter 4** of this Manual, is not based on a pre- versus post-development comparison. However, for redevelopment activities this requirement is relaxed. If the hydrology and hydraulic analysis for the project site shows that the post-construction 1-year 24-hour discharge rate and volume are less than or equal to the pre-construction discharge rate and volume, providing 24-hour detention of the 1-year storm to meet the channel protection criteria is not required.

VII. Overbank Flood and Extreme Flood Control for redevelopment activities is not required if there is 0% change to hydrology that increases the discharge rate from the project site. Evaluation of the change to hydrology shall include the redevelopment activity portion of a project, and if applicable, any new development that is tributary to the same design point as the redevelopment in the analysis. This is true because the calculated discharge of pre-development versus post-development flows results in zero net increase. This consideration does not mean that existing quantity controls may be neglected in planned designs. Existing quantity controls must be maintained for post-development flow discharge control. Any new, replacement quantity controls shall be designed to provide equivalent control as the existing.

9.2.2 Performance Criteria

The performance criteria of selected SMPs for redevelopment activities fall under three categories:

1. Performance criteria for standard stormwater management practices as defined in **Chapter 6** of this Manual must be applied in the design of the practices.
2. Performance criteria for runoff reduction techniques as defined in **Chapter 5** of this Manual must be applied to the design of the practices, and;
3. The alternative SMPs discussed in this Chapter are to be used for redevelopment activities only, unless approved for use on new development activities. The performance criteria for alternative SMPs are based on the testing protocols and procedure set for verification of manufactured system by regulatory agencies.

Section 9.3 Water Quality Peak Flow Calculation

The peak rate of discharge for the water quality design storm is needed for the sizing of diversion structures for off-line practices, such as flow-through Alternative SMPs. An arbitrary storm would need to be chosen using the Rational Method, and conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2 inches. This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff bypasses the filtering treatment practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels.

The procedure outlined in **Appendix B** shall be used to estimate peak discharges for small storm events.

Section 9.4 Alternative Stormwater Management Practices Proprietary Practices

Proprietary practices encompass a broad range of manufactured structural control systems available from commercial vendors designed to treat stormwater runoff and/or provide water quantity control. Manufactured treatment systems are often attractive during redevelopment activities because they tend to take up less space, often installed underground, and can usually be retrofitted to existing infrastructure. The NYSDEC provides criteria for *Proprietary Practices for Stormwater Management* that can be applied for new development, redevelopment, and pretreatment: (https://www.dec.ny.gov/chemical/29089.html).

Table 9.1 Common Proprietary Practice Categories

Category	Description	Treatment Type
Hydrodynamic Separators	Devices that move water in a circular, centrifugal manner to accelerate the separation and deposition of primarily sediment from the water.	Flow Based
Wet Vaults	Water-tight structures that include a permanent pool and promote settling of particulates through detention and use of internal baffles and other proprietary modifications.	Volume Based
Media Filters	Surface or subsurface practices that contain filter beds containing absorptive filtering media that promotes settling of particulates as well as adsorption and absorption of other pollutants attracted to the characteristics of the proprietary filter media.	Flow Based

9.4.1 Evaluation of Alternative Practices

As a group, the performance of manufactured stormwater management practices (SMPs) have been verified thus far only to a limited extent, with a majority of the verification studies limited to laboratory testing. Where verification data does exist, they generally indicate that these practices do not meet both the 80% total suspended solids (TSS) and 40% total phosphorus (TP) removal efficiency target that is specified in **Chapter 3** of this Manual. However, proprietary practices that have been certified by specific verification sources and demonstrate that they provide some level of water quality treatment, are allowed for redevelopment activities in New York State. This allowance is conditioned upon the system being operated at the specific tested design flow rate, defined based on the verified performance of each specific system. Based on the conclusions of the verification sources, it is believed that these treatment systems have the capability of achieving an acceptable TSS removal efficiency in field applications.

NYSDEC's evaluation of proprietary practices for demonstration of minimum removal efficiency for redevelopment activities shall be based on one of the following stormwater management practice evaluation systems:

- New Jersey Corporation for Advanced Technology (NJCAT) verified and New Jersey Department of Environmental Protection (NJDEP) certified, for inclusion in NJCAT Verification Database or NJDEP list of approved Manufactured Treatment Devices (MTD's). The NJCAT "Archived List" shall not be referenced for device approvals.
- Washington State Technology Assessment Protocol - Ecology (TAPE), list of "Approved Technologies." Practice must be approved at the "General Use Level" use designation for "Basic", "Enhanced," and/or "Phosphorus" treatment types.

The proposed manufactured treatment systems that are verified or certified through the above systems and meet the criteria stated above are allowed for redevelopment activities in New York State. Proposed manufactured treatment systems that are not verified yet may be considered for acceptance in New York State if verified at any time through one of these verification sources.

All the manufactured treatment systems must be sized appropriately to provide treatment for the water quality volume or the runoff from the entire contributing area. Due to the proprietary nature of the practices, designers are responsible to ensure that manufacturer's recommendations are followed for all design details, such as structural integrity, configuration, assembly, installation, operation, and maintenance of the units. Designers are also responsible to address, at minimum, all the relevant requirements set by New York State standards such as pretreatment, bypass, quantity controls, overflow, head configuration, inflow/outflow rates, maintenance, separation distance, accessibility, and safety issues concerning the selected practice.

9.4.2 Recommended Application of Practice

Many proprietary practices are useful on small sites and space-limited areas where there is not enough land or room for other structural control alternatives. Proprietary practices can also be reasonable alternatives where there is a need to tie into the existing drainage infrastructure, where site elevations limit the head for certain stormwater management practices (SMPs). Hydrodynamic separators are generally more effective on sites with potential loading of coarse particulates. Specific media filters may be suitable in most conditions.

9.4.3 Benefits

The benefits of using proprietary practices will vary depending on the type of practice, but may include:

- Reduced space requirements for practices located below grade.
- Reduced engineering and design due to prefabricated nature of systems and design support and tools provided by manufacturer.
- Spill containment and control capabilities

9.4.4 Feasibility/Limitations

Depending on the proprietary practice, the following factors may be considered as a limitation:

- Limited performance data. Data that does exist suggest these practices don't perform at the same level as the suite of standard practices in **Chapters 3** and **6** of this Manual, particularly with regard to nutrient load reduction.
- Application constraints such as limits to area draining to a practice, due to pre-manufactured nature of products.
- High maintenance requirements (e.g., need for specialized equipment, confined space entry training, frequency of recommended maintenance, and cost of replacement components) that often are ignored or forgotten because many practices are underground and out of sight.
- Higher costs per treated area than other structural control alternatives, but this can be offset by value of land not needed due to subsurface nature of many proprietary practices.
- Concern over mosquito breeding habitat being provided by practices that have wet sumps as design components.

9.4.5 Sizing and Design Guidance

Sizing and design guidance will vary based on the product being used. Since sizing criteria is integral to the verified performance of manufactured practices, designers should refer to the capacities and flow rates associated with the models (sizes) of the manufactured SMPs identified by the verification source.

The New York State design standards calls for small storm hydrology and the use of Simple Method for hydrology calculation. For practices with volume-based sizing approaches, sizing shall be performed to meet the water quality volume as defined in **Section 4.2** of this Manual. For rate or flow-based sizing approaches, sizing shall be performed based on the peak rate of discharge for the water quality design storm, as described in **Section 9.3**.

Proprietary practices are designed as on-line or off-line practices. On-line practices typically have built-in bypass capabilities. Flow through systems, that do not have built-in bypass must be designed as off-line systems

It is important for designers to specify proprietary practices based on their treatment capacities (CASQA, 2003). Since hydraulic capacity can be as much as ten times that of the treatment capacity, designer must ensure that hydraulic load does not exceed the performance rate defined in the verification process. The above applies to all design elements that affect the performance rate. Some examples of such design elements are head, orifice sizing, oil storage or sediment storage capacities, baffle configuration, or screen size.

Practices with a volume-based sizing approach must be sized to capture and treat 75 % of the WQ_v as defined in **Chapter 4** of the Manual. Flow through practices must be sized to the peak rate of runoff from the WQ_v design storm, as defined in **Chapter 4** and **Chapter 10**, and **Section 9.3**. For off-line practices, the installation must include flow diversion that protects the practice from exceeding design criteria.

9.4.6 Environmental/Landscape Elements

There are few or no environmental or landscaping elements that designers can consider with most proprietary treatment practices. They are frequently absent or predetermined by the manufacturer. The use of land area above the facility needs to be selective and manufacturer design specifications must be strictly followed.

9.4.7 Maintenance

Maintenance is a critical component to ensure proper functioning of proprietary practices. Most manufacturers provide maintenance recommendations. When these schedules are not followed, proprietary practices can be expected to fail. Most proprietary practices require a minimum of quarterly inspections and cleanouts. In addition, specialized equipment (e.g., vacuum excavator trucks and boom trucks) may be required for maintaining certain proprietary practices. Refer to maintenance requirements defined in **Section 3.5** of this Design Manual.

Links

New Jersey Corporation for Advanced Technology, Technology Verification Database, http://www.njcat.org/verification-process/technology-verification-database.html

New Jersey Department of Environmental Protection (NJDEP) – Stormwater Manufactured Treatment Devices, https://www.nj.gov/dep/stormwater/treatment.html

Washington State Department of Ecology – Emerging Stormwater Treatment Technologies (TAPE), http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html

Chapter 10: Addressing Stormwater Pollutants of Concern

Section 10.1 Introduction and Overview

The chapter presents a discussion of five categories of common pollutants of concern that are found in stormwater runoff. The following sections provide common pollutant sources, environmental fate and transport characteristics, an overview of SMP pollutant removal capabilities, and recommended SMP design modifications to further reduce specific pollutants of concern. Common sources of origin for pollutants of concern are listed in **Table 10.1.**

Table 10.1 Common Sources for Pollutants of Concern

Pollutant of Concern	Common Sources
Solids (TSS)	Road and vehicle wear, soil erosion, dust, litter, organic debris.
Phosphorus	Fertilizers, farm-animal waste, detergents, flame-retardants in many applications (including lubricants), corrosion inhibitors, and plasticizers.
Nitrogen	Fertilizers, farm-animal waste, and faulty septic systems. Naturally occurring from vegetation decomposition.
Metals (typically include copper, lead, zinc, and cadmium)	Industrial and domestic waste, mining, mineral leaching, automobile parts and fluids, roof runoff, paints. Can occur naturally in soil.
Pathogens (including bacteria such as fecal coliform and E. coli)	Domestic sewage, animal waste, combined sewer overflows (CSOs), biofilms. Naturally occurring in plant or soil material.

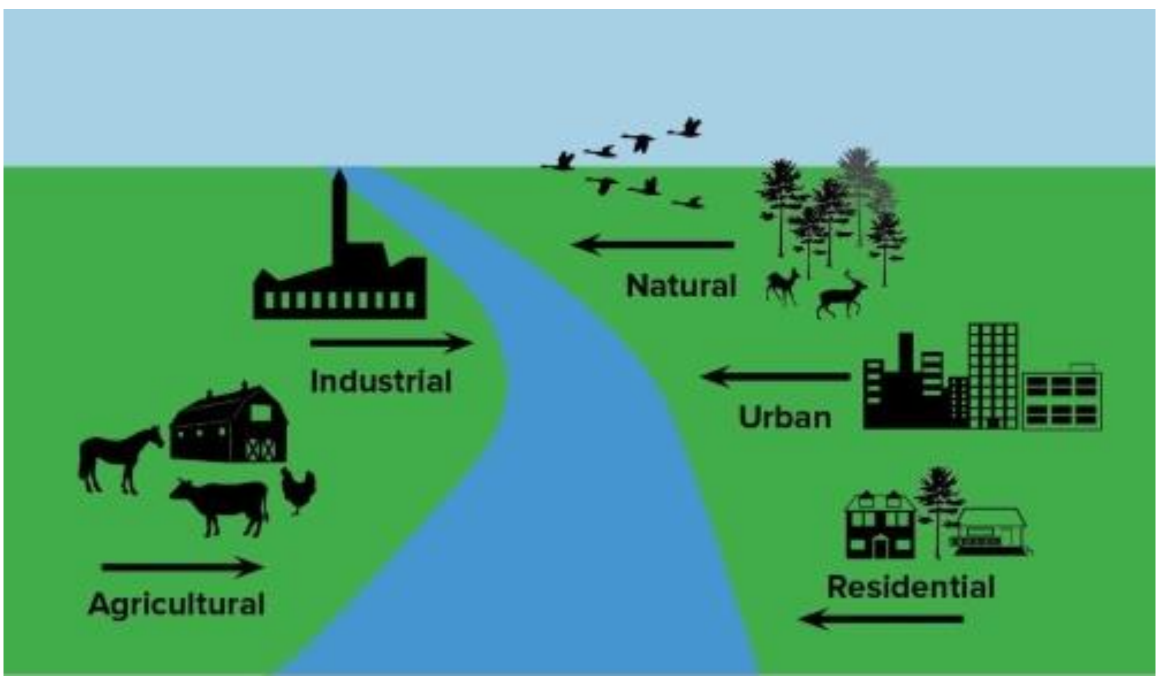


Figure 10.1 Common Sources of Pollutants of Concern in a Watershed

10.1.1 Description and Properties of Pollutants of Concern

Solids (TSS)

Solids in stormwater can consist of sediment, trash, and other forms of organic materials and debris. Total suspended solids (TSS) is the measure used to commonly describe the particulates of various origin that are suspended in a body of water. Sediment is naturally present to varying degrees in receiving waters and runoff; however, both urban and agricultural human activities can increase sediment loads to levels that impact aquatic life and other beneficial uses of waterbodies. Solids contribute to many water quality, habitat and aesthetic problems in urban waterways. Elevated levels of solids increase turbidity, thereby reducing the penetration of light at depth within the water column and limiting the growth of desirable aquatic plants. Solids that settle out as bottom deposits contribute to sedimentation and can alter and eventually destroy habitat for fish and bottom-dwelling organisms.

Solids also provide a medium for the accumulation, transport, and storage of other pollutants such as nutrients and metals. In the context of stormwater, the primary concern has traditionally been the fine solids fraction. As particles decrease in size, they have a higher ratio of surface area to mass, so smaller particles generally have a higher capacity for carrying heavy metals and nonpolar organics. Pollutants such as phosphorus, pesticides, non-polar organics, and metals such as copper, zinc, cadmium, and lead, may adsorb onto the surface of sediment, especially to clay and organic particles in runoff.

Phosphorus

Phosphorus in stormwater occurs in dissolved and particulate forms. Dissolved forms typically are more than 90% bioavailable, while particulate forms are typically less than 25% bioavailable. Orthophosphate is the most readily bioavailable form of phosphorus and can move from sediment into the water column by diffusive processes, and can also bind to metals, such as iron and aluminum to form solid complexes. Due to its tendency to sorb to soil particles and organic matter, phosphorus is primarily transported in surface runoff with eroded sediments. In areas with high phosphorus content in soils, deposition of sediment due to construction or other land disturbance activities can represent a significant source.

Phosphorus is typically the limiting nutrient in most freshwater systems, resulting in stormwater discharge of phosphorus having the potential to cause significant water quality impairment to receiving waters. Dissolved phosphorus has the greatest impact on receiving waters and minimizing or treating for dissolved phosphorus in runoff should be a priority for protecting receiving waters. While phosphorus is an essential nutrient for all life forms, increased amounts of bioavailable phosphorus in surface waters can stimulate excessive algae growth and result in numerous water quality problems (WERF, 2005).

Nitrogen

Nitrogen predominantly exists in stormwater as nitrogenous organic solids, nitrate, and ammonia. Nitrogen generally does not sorb strongly to soil particles and can be transported in surface runoff in both particulate and dissolved phases. Most forms of nitrogen can transform into nitrate in the nitrogen cycle. Nitrate is totally soluble in water, readily available for biological uptake, and moves freely through most soils. As a result, nitrate is the primary form of nitrogen that is leached into groundwater and can commonly cause surface water degradation that leads to eutrophication. Ammonium nitrogen sorbs to surfaces of clays and finer-grained soils or organic soil matter, making it less likely to enter groundwater. However, under the right soil conditions, ammonium can readily transform into the more mobile form of nitrate.

Movement of nitrogen into surface water can take several pathways. It can enter water directly through direct discharges from municipal and industrial waste sources or can be dissolved in runoff water or attached to soil particles. Nitrogen can also be emitted into the atmosphere and then deposited to surface waters and land through precipitation and dry deposition.

Metals

Metals typically have low solubility and are not mobile in soil. Metals of primary concern in stormwater include cadmium, copper, lead, and zinc. Most are readily adsorbed within typical pH ranges found in soil. Leaching of metals may also increase under certain environmental conditions as mobility typically increases for most metals as pH decreases. Metals may also form complexes with organic matter, which may increase their mobility as well.

Metals are found in either a dissolved state or bound to suspended solids in stormwater, with most of the metal mass bound to suspended solids. As such, metals can be easily filtered out in soil and engineered media. However, metals are not easily biodegraded, which results in their ability to accumulate and persist for long periods of time, until they are disposed of (Weiss et al., 2008). At trace concentrations, several of these metals are essential to human life; at higher concentrations they can be toxic.

Pathogens

Pathogens, or disease-causing organisms, can be broken down into three categories: bacteria, protozoa, and viruses. Many of these pathogens are commonly found in runoff and may pose a threat to human health. Fecal coliform and *Escherichia coli* (E. coli) bacteria are the most commonly used indicators of pathogen presence. Fecal indicator bacteria in urban stormwater originate from feces of warm-blooded animals deposited on pervious and impervious surfaces. Pet waste, leaking septic systems, and urban wildlife are primary sources. These bacteria may be directly deposited into the receiving water or transported in stormwater flows. Additionally, bacteria may persist for extended periods of time in sediments, biofilms, and organic litter within stormwater facilities, pipes, and media.

Bacteria are living organisms and their primary effect on stormwater quality results from their life status rather than their simple presence. Bacteria can be controlled (i.e. inactivated) without being removed, but concentrations can also increase without further bacterial loading when conditions are conducive to natural population growth within stormwater conveyances, treatment facilities, and receiving waters. While sediment and organic litter represents a sink for most pollutants, bacteria may survive longer in sediments/organic litter than in the water column. Therefore, sediment or organic litter, if mobilized, could actually be a significant source of bacteria, and removal of water column particulate-bound or free bacteria may not constitute a reliable permanent removal mechanism in some cases.

10.1.2 Summary of Pollutant Characteristics

Table 10.2 summarizes the typical fate and transport characteristics and behavior of pollutants within the environment.

Table 10.2 Pollutant Characteristics

Characteristic	Solids (TSS)	Phosphorus	Nitrogen	Metals	Pathogens
Mobility	Moderate	Moderate	High	Very low/ Moderate	Moderate/High
Solubility	Low	Low/ High for dissolved forms	High	Low	Low
Abundance in stormwater	High	Moderate/ High	Low/ Moderate	Low/ High	Likely present
Toxicity	Variable	Low	Low. Primary concern is for infants less than 6 months in age	Variable	Variable
Degradation Potential	Low	High for particulate form	High in anaerobic environments; low in aerobic environments	Low	Low
Adsorption/ Absorption	High	High for dissolved form	Low	High	High
Plant uptake	Low	High for dissolved form	High	Low	Low
Potential risk to groundwater	Low	Low/ Moderate	Low/ Moderate based on high mobility but relatively low concentrations in urban stormwater	Low, except possibly for zinc	Low/Moderate

Section 10.2 Pollutant Removals in Stormwater Management Practices

Pollutant removals highly vary among stormwater management practices. Generally, practices that utilize filtration and sedimentation as their primary removal mechanism are effective at decreasing the presence of solids, metals, and pathogens. Infiltration practices are preferred for phosphorus removal, and practices that promote settling, filtration, and biological activity are recommended for nitrogen removal. The matrices shown in **Table 10.3** and **Table 10.4** examine the pollutant removal capabilities of standard stormwater management practices (SMP) and runoff reduction techniques.

<table>
<tr><th colspan="7">Table 10.3 Standard SMP Pollutant Removal Capability Matrix[1]</th></tr>
<tr><th rowspan="2">SMP Group</th><th rowspan="2">SMP Design</th><th colspan="5">Pollutant of Concern</th></tr>
<tr><th>Solids (TSS)</th><th>Phosphorus (TP)</th><th>Nitrogen (TN)</th><th>Metals</th><th>Pathogens</th></tr>
<tr><td rowspan="4">Pond</td><td>Micropool ED Pond</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Fair</td><td rowspan="4">Fair</td></tr>
<tr><td>Wet Pond</td></tr>
<tr><td>Wet ED Pond</td></tr>
<tr><td>Multiple Pond</td></tr>
<tr><td rowspan="5">Wetland</td><td>Shallow Wetland</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Fair</td><td rowspan="4">Fair</td></tr>
<tr><td>ED Shallow Wetland</td></tr>
<tr><td>Pond/Wetland System</td></tr>
<tr><td>Pocket Wetland</td></tr>
<tr><td>Gravel Wetland</td><td>Good</td><td>Good</td><td>Fair</td><td>Fair</td><td>Fair</td></tr>
<tr><td rowspan="4">Infiltration</td><td>Infiltration Trench</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Good</td><td rowspan="4">Good</td></tr>
<tr><td>Infiltration Basin</td></tr>
<tr><td>Dry Well</td></tr>
<tr><td>Underground Infiltration</td></tr>
<tr><td rowspan="6">Filters</td><td>Surface Sand Filter</td><td rowspan="3">Good</td><td rowspan="3">Good</td><td rowspan="3">Good</td><td rowspan="3">Good</td><td rowspan="3">Fair</td></tr>
<tr><td>Underground Sand Filter</td></tr>
<tr><td>Perimeter Sand Filter</td></tr>
<tr><td>Infiltration Bioretention</td><td>Good</td><td>Good</td><td>Good</td><td>Good</td><td>Good</td></tr>
<tr><td>Filtration Bioretention</td><td>Good</td><td>Good</td><td>Fair</td><td>Good</td><td>Good</td></tr>
<tr><td>Bioslope</td><td>Good</td><td>Good</td><td>Fair</td><td>Good</td><td>Fair</td></tr>
<tr><td rowspan="2">Open Channels</td><td>Dry Swale</td><td>Good</td><td>Good</td><td>Fair</td><td>Fair</td><td>Poor</td></tr>
<tr><td>Wet Swale</td><td>Good</td><td>Good</td><td>Fair</td><td>Fair</td><td>Poor</td></tr>
</table>

[1] Ratings based on pollutant removal efficiencies:

Good pollutant removal (>80% TSS, >40% TP, >30% TN, >60% Metals, >70% Pathogens)

Fair pollutant removal (30-80% TSS, 15-40% TP, 15-30% TN, 30-60% Metals, 35-70% Pathogens)

Poor pollutant removal (<30% TSS, <15% TP, <15% TN, <30% Metals, <35% Pathogens)

Table 10.4 Runoff Reduction Technique Pollutant Removal Capability Matrix[1]

	GI Design	Pollutant of Concern				
		Solids (TSS)	Phosphorus (TP)	Nitrogen (TN)	Metals	Pathogens
Runoff Reduction Technique	Sheet Flow to Riparian Buffers or Filter Strips	Good	Good	Fair	Poor	Poor
	Vegetated Swale	Fair	Fair	Fair	Fair	Poor
	Tree Planting/Tree Pit/Tree Trench	Good	Good	Fair	Good	Good
	Disconnection of Rooftop Runoff	Good	N/A[2]	N/A	N/A	N/A
	Infiltration Rain Garden	Good	Good	Good	Good	Good
	Filtration Rain Garden	Good	Good	Fair	Good	Good
	Green Roof	Good	Poor[3]	Fair	Good	Good
	Infiltration Stormwater Planter	Good	Good	Good	N/A	N/A
	Filtration Stormwater Planter	Good	Good	Fair	N/A	N/A
	Rain Barrels & Cisterns	Good	N/A	N/A	N/A	N/A
	Porous Pavement	Good	Fair	Fair[4]	Good	Good

[1] Ratings based on pollutant removal efficiencies.

Good pollutant removal (>80% TSS, >40% TP, >30% TN, >60% Metals, >70% Pathogens)

Fair pollutant removal (30-80% TSS, 15-40% TP, 15-30% TN, 30-60% Metals, 35-70% Pathogens)

Poor pollutant removal (<30% TSS, <15% TP <15% TN, <30% Metals, <35% Pathogens)

[2] Not enough data available. More research needs to be performed. May provide partial benefits.

[3] Typically leach phosphorous in first years after construction if built with media having high organic content.

[4] Pervious concrete or permeable interlocking concrete pavement have highest nitrogen removal capabilities.

Section 10.3 Recommended SMP Design Modifications to Enhance Pollutant Removal

Generally, all pollutants experience enhanced removal rates when SMPs are implemented within a treatment train and are maintained appropriately and consistently. Proper maintenance involving removing sediments and harvesting vegetation is crucial to avoid clogging and reduced practice efficiency. However, certain design aspects of practices can be modified to improve pollutant reductions. Performance enhancing mechanisms include selecting appropriate plant species for a specific pollutant and application of iron-enhanced check dams.

10.3.1 Plant Species Selection

A combination of plants is necessary for optimal water quality and hydraulic performance. Plants with thick roots create macropores and help prevent clogging of filter media, while finer root systems prove to be best for nutrient removal performance. Plant traits that benefit pollutant removal efficiency and decrease nutrient effluent concentration include:

- High plant biomass
- Rapid growth rate of >10mg/g/day
- Long roots and a large total root length of a root system (~1000 m)
- Large total root mass and dense fine root patterns (>40% dense roots)

Table 10.5 presents specific plants that have been tested to be effective at reducing pollutant levels in stormwater effluent.

Table 10.5 Recommended Plant Species to Maximize Pollutant Removal

Pollutant	Plant Species
Nitrogen	Alfalfa (Medicago sativa), Big Muhly Grass (*Muhlenbergia lindheimeri*), Blue Grama (*Bouteloua gracilis*), Buffalo Grass (*Buchloe dactyloides),* Curl-Leaf Mountain Mahogany (*Cercocarpus ledifolius*), Indian Grass (*Sorghastrum nutansv*), Little Bluestem (*Schizachyrium scoparium*), Silver Sagebrush (Artemisia cana), Swamp Sunflower *(Helianthus angustfolius*), Utah Serviceberry (Amelanchier utahensis)
Phosphorus	Big Muhly Grass (*Muhlenbergia lindheimeri*), Buffalo Grass (*Buchloe dactyloides),* Evergreen Azalea (*Rhododendron indicum),* Purple Joe-Pye Weed (*Eutrochium purpureum*), River Birch (*Betula nigra*), Swamp Sunflower *(Helianthus angustfolius*), Tall Sedge (*Carex appressa*)
Metals	Clustered Field Sedge (*Carex praegracilils*), Creeping Juniper (*Juniperus horizontalis*), Kentucky-31 (*Poa pratensis*), Smallwing sedge (*Carex microptera*), Switch Grass (*Pancium virgatum*), Tall Sedge (*Carex appressa*), Yellow Marsh Marigold (*Caltha palustris*)
Pathogens	Palmetto Buffalo *(Bouteloua dactyloides),* Scarlet Honey Myrtle (*Melaleuca fulgens*), Wooly Tea-Tree (*Leptospermum lanigerum*)

10.3.2 Iron-Enhanced Check Dams

Research being performed by the Minnesota Department of Transportation indicates that implementing an iron-enhanced check dam within swales can help enhance the removal of dissolved phosphorus and metals from stormwater. Iron-enhanced check dams, as shown in **Figure 10.2**, are low permeable mounds consisting of sand and iron filings installed horizontally across a swale.

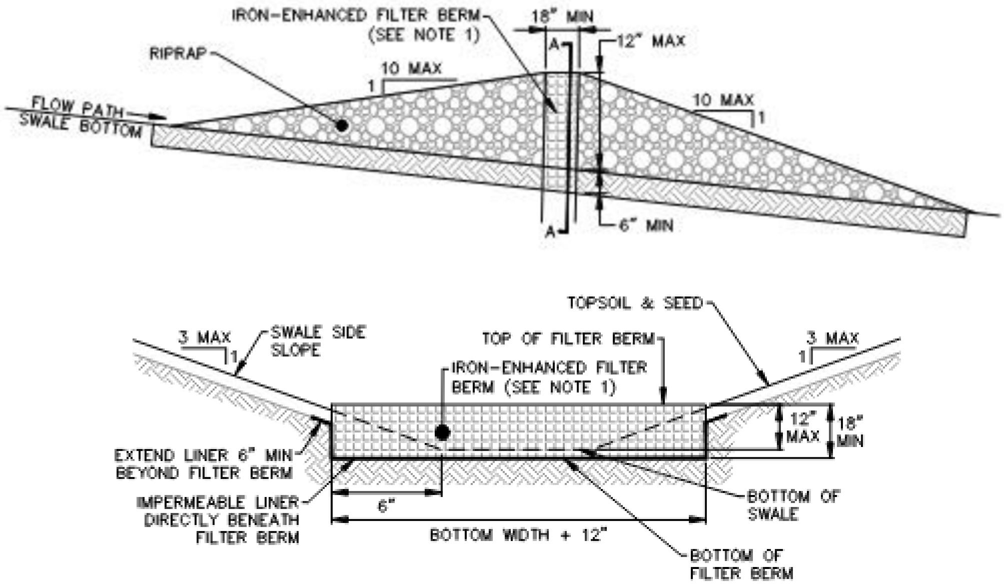


Figure 10.2 Profile view and cross-sectional view of an Iron-Enhanced Swale Check Dam

Design considerations for employing iron-enhanced check dams in swales include the following:

- Filter berm shall consist of a metal cage to meet dimensional requirements.
- Cage shall be tightly packed with filter media that is encapsulated within a single woven geotextile enclosure (i.e. filter log or filter sock).
- Filter media shall consist of 95% sand (coarser than ASTM C-33) and 5% iron shavings (by weight).
- The filter berm must be buried into the ground at least 6 inches below the normal swale bottom to prevent flow-bypass underneath the filter media.
- An impermeable liner shall be placed directly beneath the filter log. Acceptable impermeable liner options include:
  - 12 to 24 inches of clay soil (min. 50% passing the #200 sieve and max. permeability of 1×10^{-5} cm/sec); or
  - 40 mil HDPE geomembrane.
- Riprap, selected in accordance with NYSDOT gradation requirements, shall be placed, extending to the top of bank, of the filter log to form the check dam.

Since the bottom of the filter is subject to receiving stormwater more frequently, it is highly recommended to mix the iron filings every other year to redistribute the filter media to the bottom, restore sorption capacity, and eliminate macropores. Replacing the entire filter media approximately every six years is also recommended (Minnesota Department of Transportation, 2019).

10.3.3 Enhanced Bioretention Media

Refer to **Chapter 6 Section 6.4.4.1**.

Chapter 11: Planting Guidance for Stormwater Management Practices

Section 11.1 Introduction

This Chapter serves as guidance for selection of plants for stormwater management practices, in order to maximize the runoff reduction and water quality benefits. Plants serve imperative roles in the environment, such as:

- Producing oxygen through photosynthesis;
- Creating food energy for the ecosystem;
- Providing shelter for a wide range of organisms;
- Improve aesthetics and property values;
- Providing soil stabilization;
- Supporting biological uptake through root systems;
- Promoting evapotranspiration;
- Filter both water and air;
- Soil nutrient management;
- Reducing heat island effect; and
- Benefit to human health and wellbeing.

This Chapter outlines several general considerations when incorporating plantings into SMPs including:

- Site constraints;
- Confined sites;
- Snow storage;
- Water availability;
- Plant origin;
- Planting location;
- Plant growth patterns;
- Plant installation; and
- Material availability.

In addition, this Chapter outlines several practice specific considerations when incorporating plantings into SMPs including:

- Plant form;
- Plant installation categories;
- Plant scale;
- Rooting depth;
- Rooting volume;
- Inundation tolerance; and
- Maintenance requirements.

Section 11.2 Landscape Planning

Plantings are considered an integral part of the function and success of most stormwater management practices. It is highly recommended to engage a registered landscape architect, with specific experience in stormwater management planning early in the process and throughout the design and installation phases. Stormwater management plantings consist of interactions between hydrology, plants, and soils. These plantings should collectively create a high-performing system that meets multiple goals and objectives for function and aesthetics. As such, landscape architects should be brought in as early as possible, no later than Step 3 of the Six Step Process for Stormwater Site Planning and Practice Selection, refer to **Section 3.6**. The following figure outlines the landscape architect's role in the Six Step Process.

Step 1: Site Planning

↓

Consult Landscape Architect for recommendations to preserve natural resources and reduce impervious cover

↓

Step 2: Determine Water Quality Volume (WQv)

↓

Step 3: Runoff Reduction by Applying Runoff Reduction Techniques and SMPs with RRv Capacity (**Refer to Chapters 5 & 6**)

↓

Consult Landscape Architect on practice selection and planting schematic for Green Infrastructure Techniques and SMPs with RRv Capacity being applied

↓

Step 4: Determine minimum RRv required

↓

Step 5: Apply SMPs to address remaining WQv (**Refer to Chapter 6**)

↓

Consult Landscape Architect on practice selection and planting schematic for Standard SMPs being applied

↓

Refine stormwater management cross section, layout and plant selection

↓

Step 6: Apply volume and peak rate control practices

↓

Finalize plant selection and complete plan

Figure 11.1 Incorporating Landscape Planning in the Six Step Process

During the SMP selection in Steps 3 and 5, it is important to review the functional role plants can play in meeting runoff reduction and water quality requirements, as follows:

- Water uptake:
  - Stormwater is immediately slowed through contact with plant stems.
  - Stormwater management and volume control are provided through plant uptake and used by the plant (depending on the species and the climatic conditions this can be a significant amount of water).
  - Ponded stormwater filters through the practice filter media (where applicable)
  - Plant roots help maintain soil integrity and porosity to facilitate stormwater flow through the media.
- Processing of pollutants:
  - Filtering of particulates and pollutants through the leaf canopy, filter media (where applicable), and root structure
  - Plants provide mechanical filtration and aid in sediment removal by slowing water and allowing sediment to drop out of flowing water.
  - Pollutant remediation through phytoremediation.
- Habitat development and support:
  - Increased biodiversity.
  - Support pollinators and other species through food sources, nesting, and reproductive sites. Habitat goals can be matched with plant species selections.
  - Create microclimates for flora and fauna in mixed planting or buffer areas.
- Local effects:
  - Evapotranspiration, the process of water vapor being released through plant leaves; conditions the air.
  - Energy expenditure reduction from shading, reduction of heat island effect, and wind exposure mitigation.
  - Glare reduction from reflections off sidewalks, buildings, and other surfaces.
  - Provide visual interest thereby softening architecture and infrastructure.
- Regional effects:
  - Many small SMPs in proximity to one another when viewed collectively, can become important ecological links between larger regional environmental conservation areas (e.g., parks, recreation areas, and protected lands) by providing supporting and linking habitats between systems.

Section 11.3 General Plant Considerations

11.3.1 Site Constraints

Prior to plant selection, a thorough site assessment should be performed to determine the site's physically capacity. Additionally, the vision for the project, regulatory requirements, and the project's specific goals, should be considered. The following table provides a series of physical criteria for analysis prior to plant selection.

Table 11.1 Site Assessment

Physical capabilities	Existing soil conditions
	Localized hydrologic patterns
Surface spatial constraints	Property lines and easements
	Existing structures that cannot be moved
	Limits of hard and softscapes, overhead utilities
Underground constraints	Depth of bedrock
	Depth to seasonal high water table
	Proximity to foundations
	Extents of existing tree roots
	Underground utility routing
Location / User	Urban
	Suburban
	Rural
	Projected user group (memory care, children, pets)
Climatic considerations	Solar exposure
	Wind exposure
	Temperatures and microclimates
Seasonal care practices	Snow removal
	Deicing practices
	Salt runoff patterns
Owner participation	Owner capacity and capability to maintain
	Programmatic agreement
	Commitment to planting establishment

Figure 11.2 Parking Lot Bioretention (Photo Source: NYSEFC)

11.3.2 Confined Sites

Development in urban areas or those with limited space for SMPs may consider several options including tree pits, tree trenches, rain gardens, stormwater planters, green roofs and bioretention. Due to the limited space available for these practices, plant selection should be focused on their ability to mature and thrive within a limited filter media footprint, while the practice is still sized appropriately for the contributing area (refer to **Chapter 5 and 6**). In urban environments, the planting selection should also account for heavy vehicle and/or pedestrian traffic as well as the potential for higher pollutant concentrations.

In areas with concern of compaction of underlying soils, modular proprietary practices may be used to protect and maintain uncompacted filter media and allow for additional space for root growth. However, the modular proprietary practice shall still meet the criteria outlined in **Chapters 5 and 6**.

11.3.3 Snow Storage

It is recommended that SMPs not be used for snow storage. Where unavoidable, practices used for snow storage need to consider the structure of plants and their ability to handle snow load. In these situations, herbaceous plants may work best. In addition, the practice is likely to receive a higher concentration of salt or sand laden snow which can be problematic for many species and overall practice performance.

11.3.4 Water Availability

It is important that the designer understands the intent of the project to utilize irrigation and that there be water available during establishment, or first three plant growing seasons. At a minimum, temporary tanks, water trucks or hose access points should be available to allow for necessary watering during establishment. A temporary irrigation system may be utilized during the establishment period and then removed or abandoned afterward. The decision to use irrigation will significantly impact the plant selection.

11.3.5 Plant Origin

Consideration should be given to using native plants, as they are typically well suited to local environments (e.g., climate, soils, rainfall, etc.). For example, in coastal settings, where conditions are hot, dry, and occasionally salty due to winter deicing, pair plants from a list of naturally occurring exposed, dry, and high salinity habitat where conditions may be similar. Reference documents for plant selection include:

- DEC's New York Natural Heritage Program guide "Ecological Communities of New York State";
- The New York Natural Heritage Program's website; or
- New York Flora Atlas website.

When selecting plants (native or non-native) it is necessary to ensure plants are well suited to the climate and microclimate conditions of the site, as well as being ecologically suited for the location.

Plants that show continued and robust growth without extended care and do not take over the plant bed should be prioritized over plants that are considered less vigorous and/or maintenance heavy. Plants with vigorous tendencies should be used with caution. Vigorous tendencies can be advantageous to a project in that they can quickly establish themselves, especially in monoculture settings, but can be ruinous if they allowed to overrun an intented mixed planting.

Care should also be taken when working in sensitive habitat areas with neighboring rare or endangered species. On these sites, consultation with a biologist regarding species selection and plant provenance issues (genetic source and lineage) is recommended.

11.3.5.1 Native

Native plants can include those growing in local settings or specific plant communities within a county, state, or region. When the project goals broaden the native definition to include plants native to the Northeast, the plant palette widens considerably, and can include species native to several growing conditions (e.g., coastal plant communities tolerant of sandy soils, exposed conditions, and saline spray).

The nursery industry continues to expand access to natives. It is important to check plant availability to confirm that they are available for purchase. Some resources include:

- Finger Lakes Native Plant Society;
- Long Island Native Plant Initiative;
- NYS Adirondack Park Agency Native Plant List; or
- PlantNative.org.

11.3.5.2 Non-native

In addition to natives, the micro-climates of New York State have long supported many non-native and non-invasive plant varieties. A non-native plant is introduced, with human help (intentionally or accidentally), to a new place or new type of habitat where it was not previously found. Not all non-native plants are invasive. Many non-native, non-invasive species are also suitable and complementary to stormwater practices and may function better than native plants under certain conditions.

11.3.5.3 Invasive

New York State has made significant strides and efforts to eliminate the use of invasive species. When selecting stormwater plantings, it is important that invasive species, both native and non-native, are not chosen. Consultation with the NYSDEC Invasive Species Regulation (6 NYCRR Part 575) is critical and must be evaluated for applicable information.

11.3.6 Planting Location

11.3.6.1 Plant Hardiness Zones

A hardiness zone is the standard that determines which plants are most likely to thrive at a location. USDA has an interactive Plant Hardiness Zone Map available to designers for use. The map is based on the average annual minimum winter temperature, divided into 10-degree Fahrenheit zones. New York includes a wide range of growing conditions that are represented by USDA plant hardiness zones, which generally range from Zone 3b to Zone 7b. The temperatures established by the hardiness zones are affected by topography, elevation, and hydrology, which create varied moisture regimes, solar access, and wind exposure.

11.3.6.2 Macroclimate and Microclimate

Macroclimate refers to the general climate of the overall region. The four climate conditions include temperature, humidity, wind, and precipitation, which are affected by site latitude, site elevation, prevailing winds, proximity to water, proximity to mountains, and topography. Microclimate refers to the specific local conditions of a site which are affected by vegetation, elevation, slope, built structures, as well as water, wind, and sun exposure. As such, plantings should be selected according to the macroclimate and microclimate constraints of the site location.

Strategic plant selections and placement can help control climatic conditions in several ways:

- Grass areas have low albedo and high conductivity;
- Trees and vegetation can be used to screen or direct wind;
- Trees and vegetation absorb sunlight and add humidity to the air;
- Planted areas typically are cooler during hot days and have less heat loss during the night;
- Trees can be used to shade the south and west facing portions of the site; and
- Deciduous trees filter direct sunlight in the summer while allowing it to pass through in the winter.

11.3.7 Plant Growth Patterns

11.3.7.1 Growth Rate

Most plants undergo a shock period when initially planted and may remain at their planted size for up to 2 years before springing forth new growth. Overall growth rate can be impacted by available growing medium, nutrients and water availability and maintenance practices such as pruning.

11.3.7.2 Longevity

In nature and cultivated environments some plants germinate quickly, grow fast, and provide a community for other plants to establish. This may be partially due to their tolerance for outside factors, like air pollution or compacted soils. These are sometimes known as pioneer plants. Plants are impacted by many outside factors, some have a natural shortened life expectancy while others are affected by insects or pathogens that shorten their life expectancy. It is important for designers to stay current on trends in plant diseases.

11.3.7.3 Sunlight Tolerance

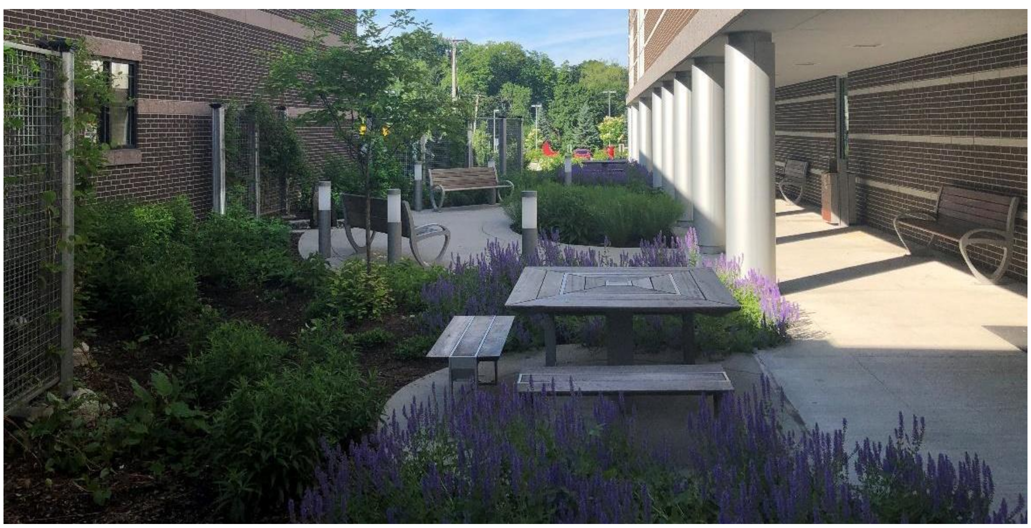


Figure 11.3 Hudson Headwaters Healing Rain Garden (Photo Source: HHHN)

11.3.8 Plant Installation Considerations

11.3.8.1 Planting season

Stormwater planting generally occurs throughout the construction season, however given construction sequencing and timing there may be constraints. Some species of plants may be unavailable or held at a nursery during fall due to digging season limitations and provisions for procurement.

In addition, some evergreen species, as well as those with thin bark, abundant small twigs, or coarse roots may have difficulty establishing new roots during fall planting and the trees may desiccate over winter due to lack of moisture. For fall planting it is recommended that trees be watered for a period prior to being removed from the nursery as well as additional watering after they are installed on site, generally through to heavy frost. Temperatures and rainfall should be monitored throughout the project construction schedule, as the late spring and early fall months can see less precipitation and temperature spikes or drops requiring additional watering for new plantings.

11.3.8.2 Diversity

The variety of plants selected for a design should be considered from both an ecological and aesthetic perspective. Ecologically designs that utilize only one plant species, also known as a monoculture, may face struggles with insects, disease, and extremes in weather conditions. A planting palette with greater diversity mimics more natural systems, and has inherent resilience against environmental changes, pests, and diseases, as not all species will be impacted equally.

When a uniform aesthetic is the project goal, a selection of 4-7 plants that have similar structure, form, height, bloom color, etc. may be used to create the impression that the practice is comprised of a singular species, while offering plant diversity to avoid the issues created by monoculture.

11.3.8.3 Predation Protection

New plantings, particularly those in stormwater wetlands, are often targets for predation by deer, muskrats, rabbits, mice, birds, and other wildlife. To prevent this and assist in establishment, fencing around plantings and netting over top may be necessary. Style, type, and duration of these enclosures varies with the predatory animal. As such, consulting with an ecologist may be helpful in determining which measures will be most effective.

Figure 11.4 Mattituck-Southhold Wildlife Screen (Photo Source: Nanci Bateman, RLA, NYSDEC)

11.3.8.4 Mulch

Mulch is useful as a surface layer to help minimize weed growth, moderate soil temperatures and moisture, and provide an aesthetic finish. Organic mulches help with silt and sediment capture, as well as absorbing hydrocarbons, to help reduce pollution. However, when used in SMPs with filter media, organic mulch may result in contributing organic matter to upper layers of the system, which has the potential to reduce infiltration if the mulch layer is too thick. In addition, organic mulches may also float when the system ponds, resulting in clogged overflow structures and covering plants.

In lieu of organic mulches, inorganic mulches may be used, such as stone mulch. If organic mulches are preferred, it is recommended that shredded mulch be used, and typically installed only at initial planting. Over time the need for mulch should be reduced as the groundcover and shrub layers cover the planting areas.

Consideration should be given to erosion and sediment control measures throughout the design and construction phase, as well as post installation of stormwater plantings. Erosion and sediment control measures should be maintained around the system until the entire drainage area has stabilized to keep sedimentation out of stormwater systems.

11.3.8.5 Staking

Staking is not universally recommended as studies have shown that trees develop better trunk taper, and therefore stronger trunk support, when not staked at planting. Staking is recommended only in spaces where trees are subject to high winds, trees are of significant size, or when planted in loose soils and only for the first year. Staking should be removed after the first growing season.

11.3.8. Material Availability

Plants should be readily available, and sources confirmed during the design process, to the greatest extent practical. In addition to the standard nursery wholesalers, several quality niche nurseries exist for native species, as well national and state sponsored nurseries. Contract growing; where a nursery is engaged during design to grow specific quantities and varieties may be possible. This method typically requires extended lead time of a year or more.

When considering appropriateness of plant substitutions, it is important to discern if the change will achieve the overall goals of both the SMP, as well as the larger project goals. The substitutions should be reviewed to determine if the substitution will meet all specifications of the originally selected plants.

Section 11.4 Practice Specific Plant Considerations

11.4.1 Plant form

It is useful in the early stages of planting design to consider plant form rather than plant species. Several plant forms are more conducive to application in specific SMPs. The following table lists key strengths and limitations of each plant form.

Table 11.2 Key Strengths and Limitations by Plant Form

Plant Form	Strengths	Limitations
Trees	Provide shade Large water uptake Disperse rain	Require larger planting area Heavy or difficult to move Often hard to establish Broad root structure
Shrubs	Varied size and shape Defines stormwater area Provide four season interest	Vigorous Dwarf is relative Subject to breakage due to snow loading
Herbaceous	Diverse scale and texture Varied bloom times Can be planted small More economical than shrubs	Winter die back Requires more regular maintenance
Turf grass	Generally tolerant of some standing water Generally quick to establish Good for erosion control	Heavier maintenance Fertilizer, pesticides may be required

11.4.2 Plant Installation Categories

Plant materials can be professionally grown, or field collected. At professional nurseries, plant propagation is typically divided into several categories as follows:

Table 11.3 Plant Installation Categories

Plant Installation Categories	Category Description
In ground – ball and burlap	Most large trees and some shrubs are commercially grown in the ground at the nursery are typically harvested in the spring prior to leaf-out. Keeping the root ball intact is key for plant survival. The harvesting can be done mechanically with a tree spade or the plant can be dug by hand. The root ball is typically wrapped in burlap and can be either placed in a wire basket or hand tied with jute rope for delivery.
Containerized	Containers are used for larger perennials, ornamental grasses, shrubs, and small trees.. Containers should utilize a potting mix closely matching the filter media (refer to **Chapter 5** and **Chapter 6**) as containers utilizing mineral soils may not support healthy plant growth. In addition, larger containerized plants may require more frequent watering and physical support if root bound prior to becoming established.
Plugs	Plugs are small plants, such as sedums, perennials, and ornamental grasses, often arriving to the site in trays. These plants have initial root systems with a small amount of growing media and can typically adapt quickly. They must be manually placed directly in the soil media. Utilizing plugs allows for more control in terms of plant placement. However, given their relative size, many plants are usually needed to complete the project. The scale of the plant and root makes plugs a good option for semi-intensive or intensive roofs, or areas where a diverse meadow or herbaceous wetland is desired.
Cuttings	Cuttings are taken from a "parent" plant capable of rooting from their stems . They are typically broadcast over the soil media and lightly tamped or raked into the soil media, or pushed into the ground (woody stem cuttings). The cuttings method is particularly effective with sedum varieties, as the plant can root easily when in direct contact with the soil media. However, the types of plants available in cutting form is limited and with cast cuttings it is difficult to be exact with spacing or location of plants. Often the design effect is "meadowlike" if several species are mixed or a monoculture effect if only one species is selected.
Mats, Carpets and Trays	Vegetated mats or carpets are pre-grown plantings containing the plant, root and soil media surrounding the root. The mat is rolled out over the surface and pinned in place, similar to sod. This method is effective with sedum varieties and is less labor intensive than container or plug planting. However, the variety of plants is minimal, with limited offering of pre-planted mat selections available. The layout and installation can be a monoculture for ease of installation, or a more intricate design can be developed where the mat is cut and placed in specific patterns.

11.4.3 Plant Scale

The scale of plants should correlate to the scale of the stormwater practice and its surrounding context. Plant species should be selected, such that they will not outgrow their available space. Additionally, line of sight should be considered near vehicular intersections and pedestrian walkways.

11.4.4 Rooting Depth

The typical rooting depth of each plant form should be consistent with the depth of the filter media or planting soil provided within the practice. Stormwater management practice filter media or planting soil depth shall meet the design criteria outlined in **Chapters 5 and 6.** The following table shows minimum depths of filter media or planting soil that can support each plant form in typical growing conditions.

Table 11.4 Minimum Recommended Filter Media Depth for Plant Forms

Minimum Recommended Filter Media Depth	Plant Forms
6 inches	Drought tolerant herbaceous perennials, groundcovers, and turf Drought tolerant small ornamental grasses
8 inches	Groundcovers, herbaceous perennials, and small ornamental grasses tolerant of dry conditions, turfgrass
12 inches	Herbaceous perennials Small to medium ornamental grasses, Drought tolerant small shrubs
18 inches	Small to medium woody shrubs, Larger ornamental grasses
24 inches	Larger woody shrubs
30 inches	Small trees
36 inches	Medium to Large Trees

11.4.5 Rooting Volume

Available volume for rooting should be matched to plant needs, particularly for large trees. The following table shows recommended rooting volumes, given the ultimate diameter at breast height (DBH) and soil volume required. This volume can be within the stormwater practice itself or in combination with soil rooting areas outside the practice, so long as roots can grow out of the stormwater practice.

Table 11.5 Recommended rooting volumes per tree diameter (Adopted from Urban, 2008)

DBH at Maturity	Recommended Rooting Volume
4”	200 cu. ft.
8”	450 cu. ft.
12”	750 cu. ft.
16”	1,000 cu. ft.
20”	1,250 cu. Ft.
24”	1,500 cu. Ft.

Particularly in urban contexts linking planting areas and drainage media for long runs below grade allows plants and trees to have substantial rooting volumes, without the construction complexities of starting and stopping the materials, and additional holding capacity.

11.4.6 Inundation Tolerance

Inundation or flooding impacts plant selection because excess water can deprive them of certain basic needs, notably oxygen carbon dioxide exchange . As a majority of runoff reduction techniques, and some standard practices, result in temporary inundation or permanent ponding of areas of the stormwater practice (i.e. plunge pool = permanent ponding) the proper selection of plant material is key to a successful system. Plants should be selected based on their ability to survive standing or fluctuating water levels as well as drought conditions.

11.4.7 Maintenance Requirements

Plants' growth needs (e.g., water levels, nutrients, pH, etc.) should be matched to the characteristics of the filter media or natural soil, in which they are planted, in order to reduce the level of additional maintenance beyond what is normally required for the practice. To reduce energy, resources, and pollution, selecting plant materials that do not require long term irrigation, fertilization, etc. should be considered.

11.4.8 Plant Considerations – Practice Specific Summaries

Urban, suburban, and rural sites have widely differing needs and options for stormwater management landscaping and plantings. Therefore, it is important to consider how the selected landscaping and plantings will impact the practice, existing environment, hydrology, outflow or infiltration opportunities, as well as the construction of adjacent surfaces and features. It is important to select plant types and scales that are appropriate for the given practice and the adjacent site conditions. A large tree may quickly outgrow a small urban stormwater planter. As such, planting choices should consider the future maturity that will match the scale of the area in which the practice is placed.

With the varying climates and environments across New York State, there is no singular plant palette for a stormwater design. The following sections provide a series of criteria that should be considered during stormwater management plant selection.

11.4.8.1 Tree Plantings/ Tree Pits/ Tree Trenches

Table 11.6 Plant Considerations for Tree Plantings/Tree Pits/Tree Trenches

Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive trees, with other suitable plant materials layered into the practice depending on size and location.
Plant Installation Categories	In-ground ball and burlap: Applicable. Containerized: Applicable. Shrubs : Applicable. Plugs and Cuttings: Not applicable: Mats, Carpets and Trays: Not applicable.
Plant Scale	Scale of tree(s) should be correlated to the available space and surrounding context, including overhead and underground utilities. Tree species should be selected such that it will not outgrow its space. Additionally, line of sight and branching height should be considered near intersections and pedestrian walkways.
Rooting Depth	The recommended rooting depth of each plant form should match the filter media depth provided. Where the recommended depth is greater than the requirement outlined in **Chapter 5**, the larger of the two should be applied.
Rooting Volume	Available volume for rooting should be matched to plant needs, given the ultimate diameter at breast height (DBH) and soil volume required. This volume can be within the stormwater practice itself or in combination with soil rooting areas outside the practice, so long as roots can grow out of the stormwater practice.
Inundation Tolerance	Species should be selected based on the practice specific ponding depth outlined in **Chapter 5** and the plant tolerance for drought and/or temporary flooding.
Maintenance	Refer to **Chapter 12**.

Figure 11.5 Locust Street/ Paris Park Tree Trench (Photo Source: Village of Hudson Falls/NYSEFC)

11.4.8.2 Vegetated Swales

Table 11.7 Plant Considerations for Vegetated Swales

Plant Considerations	**Practice Specific Considerations**
Plant Form	Turf grass: Choose the appropriate mix for the soil, soil exposure, velocity factors and temperature of the project site. Example Mixes Include: • Mix A: o Perennial ryegrass: 30 lbs. per acre or 0.68 lbs. per 1,000 sf o Tall fescue or smooth bromegrass: 20 lbs. per acre or 0.45 lbs. per 1,000 sf o Redtop: 2 lbs. per acre or 0.05 lbs. per 1,000 sf • Mix B[1]: o Kentucky bluegrass: 25 lbs. per acre or 0.60 lbs. per 1,000 sf o Creeping red fescue: 20 lbs. per acre or 0.50 lbs. per 1,000 sf o Perennial ryegrass: 10 lbs. per acre or 0.20 lbs. per 1,000 sf *[1]This mixture should be used in areas that are mowed frequently. Common white clover may be added at a rate of 8 lbs. per acre or 0.2 lbs. per 1,000 sf.*
Plant Installation Categories	In-ground ball and burlap trees or shrubs: Not applicable. Containerized Perennials: Applicable. Plugs: Applicable. Cuttings: Not applicable: Mats, Carpets and Trays: Not applicable.
Plant Scale	Capable of being mowed to 6" height
Rooting Depth	Not applicable.
Rooting Volume	Not applicable.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 5** and tolerance for both drought and temporary flood conditions.
Maintenance	Mow as required during the growing season to maintain grass heights of 4 to 6 inches. Refer to **Chapter 12**.

11.4.8.3 Rain Gardens

Table 11.8 Plant Considerations for Rain Gardens	
Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive trees, shrubs and/or herbaceous plants with other suitable plant materials positioned within the practice depending on size and location.
Plant Installation Categories	In-ground ball and burlap: Applicable. Containerized: Applicable. Plugs: Applicable Cuttings: Not applicable: Mats, Carpets and Trays: Not applicable.
Plant Scale	Scale of tree(s) should be correlated to the available space and surrounding context, including overhead and underground utilities. Tree species should be selected such that it will not outgrow its space. Additionally, line of sight and branching height should be considered near intersections and pedestrian walkways.
Rooting Depth	The recommended rooting depth of each plant form should match the filter media depth provided.
Rooting Volume	Available volume for rooting should be matched to plant needs, given the ultimate diameter at breast height (DBH), location and depth of geotextile fabric within the practice cross section, and soil volume required. This volume can be within the stormwater practice itself or in combination with soil rooting areas outside the practice, so long as roots can grow out of the stormwater practice.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 5** and tolerance for both drought and temporary flood conditions.
Maintenance	Refer to **Chapter 12**.

Figure 11.6 Canal Square Park Rain Garden (Photo Source: City of Cohoes/NYSEFC)

11.4.8.4 Stormwater Planters

Table 11.9 Plant Considerations for Stormwater Planters

Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive trees, shrubs and/or herbaceous plants with other suitable plant materials layered into the practice depending on size and location.
Plant Installation Categories	In-ground ball and burlap: Applicable. Containerized: Applicable. Plugs: Applicable Cuttings: Not applicable: Mats, Carpets and Trays: Not applicable.
Plant Scale	Scale of tree(s) should be correlated to the available space and surrounding context, including overhead and underground utilities. Tree species should be selected such that it will not outgrow its space. Additionally, line of sight and branching height should be considered near intersections and pedestrian walkways.
Rooting Depth	The recommended rooting depth of each plant form should match the filter media depth provided.
Rooting Volume	Available volume for rooting should be matched to plant needs, given the ultimate diameter at breast height (DBH), location and depth of geotextile fabric within the practice cross section, and soil volume required. This volume can be within the stormwater practice itself or in combination with soil rooting areas outside the practice, so long as roots can grow out of the stormwater practice.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 5** and tolerance for both drought and temporary flood conditions.
Maintenance	Refer to **Chapter 12**.

11.4.8.5 Green Roofs

Table 11.10 Plant Considerations for Green Roofs		
Plant Considerations	**Practice Specific Considerations**	
	Extensive	**Intensive**
Plant Form	Non-invasive small herbaceous plants, bulbs, turf, and groundcover with other suitable plant materials layered into the practice depending on size and location.	Non-invasive small trees, shrubs, herbaceous plants, bulbs, turf, and groundcover with other suitable plant materials layered into the practice depending on size and location.
Plant Installation Categories	In-ground ball and burlap: Not applicable. Containerized: Applicable. Plugs: Applicable Cuttings: Applicable Mats, Carpets and Trays: Applicable	Small In-ground ball and burlap: Applicable Containerized: Applicable. Plugs: Applicable Cuttings: Applicable Mats, Carpets and Trays: Applicable
Plant Scale	Layout and massing of plants should always consider views to and from the green roof, as well as views from adjacent buildings. In addition, the layout should consider if the green roof is meant to remain static, or if the natural dynamics of the plants will be allowed.	
Rooting Depth	The recommended rooting depth of each plant form should match the filter media depth provided.	
Rooting Volume	Available volume for rooting should be matched to plant needs and soil volume required. The rooting volume is within the filter media of the stormwater practice itself.	Available volume for rooting should be matched to plant needs, given the ultimate diameter at breast height (DBH) where applicable and soil volume required. This volume is within the filter media of the stormwater practice itself.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 5** and tolerance for both drought and temporary flood conditions.	
Maintenance	Plant patterning is important to facilitate maintenance and inspections. Larger blocks of plants in clear arrangements will help highlight weed species and facilitate their removal by maintenance crews. Dried stalks and leaves should be removed in the spring. Refer to **Chapter 12**.	

Figure 11.7 SUNY ESF Gateway Center Green Roof (Photo Source: Tim Toland)

11.4.8.6 Stormwater Ponds/Wetlands

Stormwater ponds and wetlands have specific hydrological regimes. Ponds and wetlands are designed with a permanent pool that will be wet year-round, as well as storage above the permanent pool that will be wet periodically from storm events. In addition, they typically have varying topography and therefore varying soil moisture levels.

Figure 11.8 Wet Pond at Westbrook Conservation Initiative (Photo Source: Lake George Association)

Pond and Wetland Hydrologic Zones and Plants

For stormwater pond and wetland plantings it is necessary to determine which of the hydrologic zones will be established within the practice. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation, although a practice may not include all hydrologic zones. Each zone has its own set of plant selection criteria based on the hydrology of the zone, the stormwater functions required of the plant and the desired landscape effect. These zones create a distinctive form within the practice and the plant communities grow in patterns that respond to these zones. The following table outlines the six possible hydrologic zones.

Table 11.11 Hydrologic Zones

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep Water Pool	Permanent pool deeper than 18 inches
Zone 2	Shallow Water Bench	6 to 18 inches deep
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Zone 1: Deep Water Area (Permanent Pool Deeper than 18 inches)

Ponds and wetlands have deep pool areas that comprise Zone 1, which are best colonized by submergent plants. This zone is not routinely planted for several reasons. The availability of plant materials that can survive and grow in this zone is limited, and plants may clog the stormwater facility outlet structure. In many cases, these plants will gradually become established through natural recolonization. If submerged plant material becomes more commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat. The following should be considered when plantings are proposed within Zone 1:

- Should be able to withstand constant inundation deeper than 18 inches.
- Should be able to enhance pollutant uptake.
- May provide food and cover for waterfowl, insects, and other aquatic life.

Zone 2: Shallow Water Bench (6 to 18 inches deep)

Zone 2 includes all areas (i.e., aquatic bench, low marsh, high marsh) that are inundated below the permanent pool, to a depth of 18 inches, and is best colonized by emergent species. Plants will stabilize the edges of the permanent pool, absorb wave impacts and reduce erosion, when water level fluctuates. Plants also slow water velocities, increase sediment deposition rates and reduce resuspension of sediments caused by wind. Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. The following should be considered when plantings are proposed within Zone 2:

- Should be able to withstand constant inundation to depths between six and 18 inches.
- Should be able to enhance pollutant uptake.
- May provide food and cover for waterfowl, insects, and other aquatic life.

Zone 3: Shoreline Fringe (Regularly inundated)

Zone 3 encompasses the shoreline of a pond or wetland and extends vertically from the top of permanent pool to the peak water surface elevation of the water quality extended detention volume. This zone may include the safety bench of the practice and may be regularly inundated by the water quality storm event. This zone can be the most difficult to establish since plants must be able to withstand inundation during storms or drought during the summer. The following should be considered when plantings are proposed within Zone 3:

- Should have vigorous cover to stabilize the soil and minimize erosion caused by waves and wind action or water fluctuation.
- Should be able to withstand occasional inundation of water.
- Should shade the permanent pool, especially the southern exposure, to reduce the water temperature.
- Should be able to enhance pollutant uptake.
- May provide food and cover for waterfowl, songbirds, and wildlife.
- Should be selected and located to control overpopulation of waterfowl.
- Should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- Should have very low maintenance requirements since they may be difficult or impossible to reach.
- Should be resistant to disease and other problems which require chemical applications.

Zone 4: Riparian Fringe (Periodically Inundated)

Zone 4 extends vertically from the peak water surface elevation of the water quality extended detention volume to the peak water surface elevation of the channel protection volume. Plants in this zone are subject to periodic inundation after storms and may experience saturated or partly saturated soil conditions. The following should be considered when plantings are proposed within Zone 4:

- Should be able to withstand periodic inundation after storms, as well as occasional drought during the summer months.
- Should stabilize the ground from erosion caused by runoff.
- Should shade the permanent pool, especially the southern exposure, to reduce the water temperature.
- Should be able to enhance pollutant uptake.
- Should have very low maintenance since they may be difficult or impossible to access.
- May provide food and cover for waterfowl, songbirds, and wildlife.
- Should be selected and located to control overpopulation of waterfowl.
- Should be located to reduce pedestrian access to the permanent pool.

Zone 5: Floodplain Terrace (Infrequently Inundated)

Zone 5 is infrequently inundated by flood waters that quickly recede in a day or less. Operationally, Zone 5 extends from the peak water surface elevation of the channel protection volume up to the extreme flood water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone, and establish a low maintenance, natural vegetation. The following should be considered when plantings are proposed within Zone 5:

- Should be able to withstand infrequent but brief inundation during storms. However, should be tolerant of varied moisture conditions during dry weather periods.
- Should stabilize the practice side slopes from erosion.
- Ground cover should be very low maintenance, as they may be difficult to access on steep slopes or if frequency of mowing is limited.
- May provide food and cover for waterfowl, songbirds, and wildlife.
- Placement should provide structure and shade to accommodate a greater variety of plants.

Zone 6: Upland Slopes (Seldom or Never Inundated)

The last zone extends above the extreme flood water surface elevation and includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. The following should be considered when plantings are proposed within Zone 6:

- Care should be taken to locate plants so they will not overgrow pedestrian/vehicle routes or limit visibility.
- Capable of surviving the site specific constraints, including soil condition, light, and function within the landscape.
- Ground covers should emphasize infrequent mowing to minimize maintenance.
- In pedestrian related areas, placement should be aesthetically pleasing, serve as a buffer and provide shade to accommodate a greater variety of plants. Particular attention should be paid to seasonal color and texture.

Wetland Indicator Status

Wetland plant species are given a wetland indicator status that indicates the probability of their occurrence within specific zones of the wetlands. Indicator categories are used to indicate a plant's likelihood for occurrence in wetlands versus non-wetlands. Wetland biologists typically use wetland indicator status to categorize and understand a plant's location on the gradient from permanent pool to upland condition.

Table 11.12 Wetland Plant Indicator Status Categories

Indicator Code	Indicator Status	Comment
UPL	Upland	Almost never occur in wetlands
FACU (FAC-)	Facultative Upland	Usually occur in non-wetlands, but may occur in wetlands
FAC	Facultative	Occur in wetlands and non-wetlands
FACW (FAC+)	Facultative Wetland	Usually occur in wetlands, but may occur in non-wetlands
OBL	Obligate Wetland	Almost always occur in wetlands

Pond/Wetland Plant Installation

Site preparation, accurate grading, and specification of appropriate soils will help ensure successful establishment of the plants. Planting schedules may be grouped by hydrologic zones that consider minimum/maximum inundation tolerance. Select native plants suitable to the region from nurseries that specialize in wetland species, from regional plant catalogs, or from native seed distributors.

Table 11.13 Pond/Wetland Plantings

Plant Type	Description	Plant Example
Submergent	Roots and plant below the permanent pool	Pondweeds, eelgrass
Emergent	Plants with leaves that grow through the permanent pool	Cattails, sedges, and rushes
Floating	May root on practice bottom, leaf floats on the permanent pool	Water lilies, duckweed

Wetland Filter Media Installation

Proper installation of wetland filter media is critical to ensuring that the vegetation will benefit from the air, water, nutrients, and physical support provided by the media. The following table outlines installation considerations for wetland filter media.

Table 11.14 Wetland Filter Media Installation Considerations

Protect Soils from Over Compaction	Sequencing excavation
	Use floatation of low ground pressure equipment
Heavy Equipment Considerations	Decompaction of the soils may be required prior to planting
	Disking, ripping, plowing, or tilling
	Final soil bed planting areas should be finished by hand

Pond/Wetland Planting Maintenance

The maintenance plan should include detailed monitoring protocols for wetland plantings that align with permit requirements, to include plant establishment and removal of invasive species. Where plants are slow to establish, biodegradable erosion control mats and blankets may be used to secure soils. The maintenance plan should also include annual mowing of the pond buffer along maintenance rights-of-way and the embankment with the remaining buffer should be managed as a meadow (mowing every other year). Refer to **Chapter 12**.

11.4.8.8 Surface Sand Filter

Table 11.15 Plant Considerations for Surface Sand Filters

Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive grass species selected based on specific site and soil conditions present within the practice.
Plant Installation Categories	In-ground ball and burlap: Not applicable. Containerized: Not applicable. Plugs: Applicable. Cuttings: Applicable. Mats, Carpets and Trays: Applicable.
Plant Scale	Not applicable.
Rooting Depth	Not applicable.
Rooting Volume	Not applicable.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 6** and tolerance for both drought and temporary flood conditions.
Maintenance	Mowing during the growing season to maintain grass heights of 4 to 6 inches. Refer to **Chapter 12**.

11.4.8.9 Bioretention

Table 11.16 Plant Considerations for Bioretention	
Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive trees, shrubs and/or herbaceous plants with other suitable plant materials layered into the practice depending on size and location. Woody non-herbaceous shrubs and trees shall not be specified at inflow locations. Trees shall be planted primarily along the perimeter of the facility.
Plant Installation Categories	In-ground ball and burlap: Applicable. Containerized: Applicable. Plugs: Applicable Cuttings: Applicable Mats, Carpets and Trays: Not applicable.
Plant Scale	Scale of tree(s) should be correlated to the available space and surrounding context, including overhead and underground utilities. Tree species should be selected such that it will not outgrow its space. Additionally, line of sight and branching height should be considered near intersections and pedestrian walkways.
Rooting Depth	The recommended rooting depth of each plant form should match the filter media depth provided.
Rooting Volume	Available volume for rooting should be matched to plant needs, given the ultimate diameter at breast height (DBH), location and depth of geotextile fabric within the practice cross section, and soil volume required. This volume can be within the stormwater practice itself or in combination with soil rooting areas outside the practice, so long as roots can grow out of the stormwater practice.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 6** and tolerance for both drought and temporary flood conditions.
Maintenance	Refer to **Chapter 12**.

Figure 11.9 Albany Housing Authority Development Bioretention Filter (Photo Source: AHA/NYSEFC)

11.4.8.10 Bioslope

Table 11.17 Plant Considerations for Bioslopes

Plant Considerations	**Practice Specific Considerations**
Plant Form	Plantings are not required. However, if surface stabilization is necessary, then non-invasive grass species or sod can be selected based on specific site and soil conditions present along the slope. Surface stabilization must be selected to preserve the infiltration rate of the filter media.
Plant Installation Categories	In-ground ball and burlap: Not applicable. Containerized: Applicable. Plugs: Applicable. Cuttings: Not applicable. Mats, Carpets and Trays: Not applicable.
Plant Scale	Ground cover, grass, short perennial
Rooting Depth	Not applicable.
Rooting Volume	Not applicable.
Inundation Tolerance	Not applicable.
Maintenance	Mowing during the growing season to maintain grass heights of 6 to 15 inches. Refer to **Chapter 12**.

11.4.8.11 Dry Swales

Table 11.18 Plant Considerations for Dry Swales

Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive grass species selected based on specific site and soil conditions present along the channel. Refer to **Appendix G** for non-erosive velocities of vegetated channels.
Plant Installation Categories	In-ground ball and burlap: Not applicable. Containerized: Applicable. Plugs: Applicable Cuttings: Not applicable Mats, Carpets and Trays: Not applicable.
Plant Scale	ground cover or grass.
Rooting Depth	Not applicable.
Rooting Volume	Not applicable.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 6** and tolerance for both drought and temporary flood conditions.
Maintenance	Mowing during the growing season to maintain grass heights of 4 to 6 inches. Refer to **Chapter 12**.

11.4.8.12 Wet Swales

Table 11.19 Plant Considerations for Wet Swales

Plant Considerations	**Practice Specific Considerations**
Plant Form	Non-invasive grass species and wetland plants selected based on specific site, soil and hydric conditions present along the channel. Refer to **Appendix G** for non-erosive velocities of vegetated channels.
Plant Installation Categories	In-ground ball and burlap: Not applicable. Containerized: Not applicable. Plugs: Applicable Cuttings: Applicable Mats, Carpets and Trays: Not applicable.
Plant Scale	Wetland plants should be installed below the WQv maximum ponding depth.
Rooting Depth	Not applicable.
Rooting Volume	Not applicable.
Inundation Tolerance	Species should be selected based on the ponding depth outlined in **Chapter 6** and tolerance for both drought and temporary flood conditions.
Maintenance	Regular observation for invasive species. Refer to **Chapter 12**.

Section 11.5 Plant Maintenance

A critical component of plant selection is understanding the installation process, duration of plant establishment, and necessary maintenance to ensure longevity of plantings and function of the practice. Plantings should be designed with the understanding that they will change over time and that their maintenance and care will change as well. It is recommended for all stormwater management projects to have a long-term maintenance plan with a specific focus on the first three years. This should indicate which elements are imperative to inspect seasonally, watering suggestions, pruning, weeding, fertilizing, replenishment of mulch, maintenance of protective fencing, and policy regarding replacement of plantings.

Owners or the entity responsible for implementing the maintenance program should be collaborative partners during the design and understand the importance of having a quality maintenance component. Plants should be chosen that match the maintenance capabilities of the project owner. Horticulturally intensive plants (e.g., those requiring require regular dividing, pruning, winterization, annual fertilizing, etc.) should generally be avoided unless the owner provides commitments for their care. Plants that require regular dividing, pruning, or other intensive maintenance practices should also be avoided. Refer to **Chapter 12** for Maintenance Guidance.

11.5.1 First Year Maintenance

A regular maintenance plan shall be put in place following installation. Traditionally, this is performed by the Contractor until the site is turned over to the Owner. Primarily in the first-year watering is the key care required. Watering rates should be established and are contingent on the species and on the rainfall, planting media. The watering regime should be designed to transition toward natural rainfall patterns and make plants less reliant on supplemental watering. A specified level of water should be provided either via supplemental irrigation or natural rainfall. Other care includes observing for invasive species, and general observation of plant growth (e.g., evaluating vigor, color, dieback, etc.)

11.5.2 Second Year Maintenance

Maintenance performed by the site owner shall include:

- occasional watering as needed due to climatic conditions,
- periodic weeding,
- and leaf cleanup from fall/winter season.

A visual inspection of planting is important to determine if plant loss has occurred between the first and second growing season. If plant loss has occurred replacement is recommended. If the practice is mulched an additional thin top dressing can be applied to exposed bed areas (Note: mulch should not be placed at the base (trunk flare) of any tree or shrub.

It is important to determine the causes of erosion, if observed, and remedy the issue. Special consideration should be given to the type and size of any maintenance equipment that is utilized within a green infrastructure practice to reduce the threat of over compaction.

11.5.3 Third Year Maintenance

The third year of planting maintenance should require less supplemental watering as plants should be established. Maintenance should include periodic weeding and leaf removal. Caution must be exercised to ensure that mulch layers do not become too thick. Preferred mulch depth is 3” to 4”.

11.5.4 Long Term Maintenance

Beginning in the third-year plantings should be well established (cannot be pulled by hand from the ground) and pushing new growth in their respective growth season. At this time supplemental water can be reduced to extended dry periods or removed. The on-going maintenance should include weeding of undesirable plants, replacement of dead, dying, or non-established plants, pruning of broken branches, leaf litter removal and inspection for signs of decay, disease, or insect damage. Plants should be replaced in kind or with suitable substitutes that meet the original objective of the planting. Planting bed areas should be edged and re-mulched annually to reduce weed growth and support moisture retention. Caution must be exercised to ensure that mulch layers do not become too thick or crowd against the root flair. The preferred mulch depth is 3" to 4"

11.5.5 Invasive Control

During all phases of maintenance invasive species monitoring is important. Eradication of invasive or other undesirable plant species is essential and should be conducted as early as possible. Site selection and sizing of practices should be mindful of nearby areas (including those outside of project limits) where invasives may exist, as these may provide sources that can establish within new stormwater areas. Coordination with NYS Invasive Species staff (Bureau of Invasive Species and Ecosystem Health) throughout the project is recommended. A wide range of methods for their elimination exists, falling generally into three categories:

- Chemical: a pre-emergent or a foliar herbicide for emergent plants.
- Biological: a biocontrol species, host-specific to the non-native exotic plant.
- Mechanical: using tools to remove the plant including the root.

Disposal of removed invasive materials requires specific treatment. Consult the DEC Invasive Species staff (Bureau of Invasive Species and Ecosystem Health) for proper disposal protocol.

Chapter 12: Maintenance Guidance

SMPs will not function to protect water resources without proper attention to operation and maintenance (O&M). In order to ensure long-term performance, it's critical that O&M tasks and responsibilities are identified, clearly outlined in an inspection and maintenance plan, and assigned to various stakeholders. This Chapter was developed to address the need for maintenance guidance, and is structured in the following sections:

- **Section 12.1** introduces the 10 SMP groups used in this Chapter, establishes the 3 level hierarchy for inspection and maintenance responsibilities and procedures, and provides an overview of planning and budgeting for maintenance.
- **Section 12.2** outlines the key components to be inspected, the Level 1 inspection and maintenance procedures, and common triggers for Level 2 and Level 3 inspections, for each of the 10 SMP groups.
- **Section 12.3** includes diagnostic measures for specific problems, as well as guidance for performing repair activities.

Section 12.1 Introduction

12.1.1 Stormwater Management Practice (SMP) Groups

For the purpose of this Chapter, the standard SMPs and Runoff Reduction Techniques have been clustered into ten SMP groups (**Table 12.1**), containing practices that share common inspection components and maintenance concerns. This grouping has been applied to the detailed inspection guidance provided in **Section** 12.2, as well as the fillable **Level 1 and Level 2 Inspection Checklists** that are available for download on the NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov). The checklists identify common problems with key components of the SMPs, recommend follow-up actions to correct them, and outline triggers for Level 2 and Level 3 inspections. These checklists have been developed as a guideline to assist responsible parties with efficient and thorough O&M.

Table 12.1 Practices Discussed in this Chapter, by Group

SMP Group	Practices Included	
1. Sheet Flow and Disconnection	• Sheet Flow to Filter Strip • Rooftop Disconnection	• Sheet Flow to Riparian Buffers
2. Tree Planting	• Tree Planting	
3. Swales	• Vegetated Swale	• Wet Swale
4. Bioretention	• Tree Pit • Tree Trench • Rain Garden • Stormwater Planter	• Infiltration Bioretention • Filtration Bioretention • Bioslope • Dry Swale
5. Rainwater Harvesting	• Rain Barrel	• Cistern
6. Porous Pavements	• Porous Asphalt • Porous Paver	• Porous Concrete • Stabilized Grid/Cell
7. Green Roofs	• Extensive Green Roof	• Intensive Green Roof
8. Ponds and Wetlands	• Stormwater Ponds	• Stormwater Wetlands
9. Infiltration	• Infiltration Trench • Infiltration Basin	• Dry Well • Underground Infiltration
10. Sand Filters	• Surface Sand Filters • Perimeter Sand Filters	• Underground Sand Filters

12.1.2 Maintenance Hierarchy

This Chapter is structured around a hierarchy concept, where the severity of the problem directly correlates to the level of experience needed to perform the inspection and identify corrective maintenance measures.

Many SMP maintenance problems start out as minor, and can be easily identified by individuals with limited experience (**Level 1**). As long as these issues are detected early, through regular inspections, they can typically be addressed in an expedient and cost-effective manner.

However, in some cases, issues may arise that require additional technical knowledge or capabilities to diagnose the problem and identify the appropriate remedy (**Level 2**). At this point, assistance from an individual with training in SMP inspection, operation and maintenance, may be necessary.

Similarly, some problems escalate to the point where a Qualified Professional or specialized expert is needed to return the SMP to proper functioning condition (**Level 3**).

The step-wise approach of the Maintenance Hierarchy (**Figure 12.1**) was developed to ensure long-term performance of SMPS, through cost-effective implementation of inspection and maintenance.

Figure 12.1 The SMP Maintenance Hierarchy

Level 1: Individuals with Limited or No Training

Level 1 includes routine inspection and maintenance activities conducted by:

- Property owners, property managers, or HOA representatives, for privately owned SMPs
- Municipal maintenance staff/interns or volunteers, for municipally owned SMPS.

These individuals typically have very limited training in stormwater operation, inspection, and maintenance, but can use available guidance to quickly identify and rectify common or minor issues with SMP performance. For most SMPs, the majority of inspection and maintenance activities can be conducted at this skill level, thus Level 1 forms the base of the Maintenance Hierarchy pyramid. Many well-functioning SMPs can be adequately maintained for long periods of time using Level 1 capabilities.

Some issues may arise that require a higher level of resources and expertise. Such issues are referred to in this Chapter and the Inspection Checklists as “kick-outs to Level 2.”

Level 2: Trained Individuals

Level 2 includes inspection and maintenance activities conducted by municipal employees or landscape contractors who have completed training on SMP operation, inspection, and maintenance. Level 2 inspections can occur in response to two circumstances:

1. As part of an ongoing, municipal inspection program whereby SMPs are visited on a rotating basis at a frequency of once every five years, or a frequency established by the local program; or
2. In response to a “kick-out” from a Level 1 Inspector.

Circumstance #2 requires coordination and communication between the Level 1 and Level 2 Inspectors, with documentation and background provided by the Level 1 Inspector. This is essential to make the hierarchy approach successful.

As with kick-outs from Level 1 to Level 2, the same can exist from Level 2 to Level 3. If the Level 2 Inspector encounters a problem where a Qualified Professional is needed to re-design certain components of the SMP, and/or a Qualified Contractor is needed to undertake a more serious repair, then Level 3 is activated.

Level 3: Qualified Professionals

Level 3 includes inspection and maintenance conducted by Qualified professionals, including professional engineers and landscape architects, that can revisit design issues associated with chronic or serious problems. For repair and maintenance of the SMPs at this level, individuals with specific skills and certifications, such as a certified plumber with experience working with rainwater harvesting systems or a horticulturalist with knowledge on proper plantings, may need to be called in by the Qualified Professional.

Table 12.2 describes how SMP inspection and maintenance activities differ at each level of the Maintenance Hierarchy.

Table 12.2 SMP Inspection and Maintenance Hierarchy Levels

	Level 1: Individuals with Limited or No Training	**Level 2: Trained Individuals**	**Level 3: Qualified Professionals**
Qualifications/ Training of Inspectors	No special training, but person is provided educational materials	On-the-job training and/or workshops	Professional License, such as a PE or RLA
Frequency of Inspection	At least annually	Routine as determined by the local program OR as kick-out from Level 1 inspection	Only as needed from Level 2 inspection
Inspection Guidance	Inspection guidance is included in **Section** 12.2**.** Refer to the NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov) for **Level 1 Inspection Checklists**.	Refer to the NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov) for **Level 2 Inspection Checklists**.	Guidance on diagnosing common problems is included in **Section 12.3.** Refer to the NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov) for a **Level 3 Inspection Form**.
Typical Maintenance Activities	Routine mowing. Trash removal. Plant care and upkeep. Mulching as needed. Removal of small amounts of sediment from pretreatment areas of the practice.	Removal of larger amounts of sediment. Structural damage repair. Minor regrading and scarification of soil surface to restore permeability.	Redesign an improperly functioning practice, to include: regrading the contributing drainage area, replacing filter media or plantings, modifying conveyance structures, etc.
Triggers for Inspection or Maintenance by this Level	Regular inspection (no trigger)	Common triggers for Level 2 inspection are included in **Section** 12.2**.**	Common triggers for Level 3 inspection are included in **Section** 12.2**.**

12.1.3 Level 1, 2 and 3 Inspections

12.1.3.1 General Guidance for Level 1 Inspections

Read through this guidance before performing an inspection and use the specific guidance in **Section** 12.2 for the SMP Group that includes the practice being inspected. Refer to **Chapter 11** for guidance on plant maintenance, as well as control of invasive species.

When to Conduct a Level 1 Inspection

Level 1 Inspections are the most common and are intended to identify minor maintenance issues early and keep up with routine maintenance tasks. They should be conducted *at least annually* for all practices and supplemented with additional visits after large storms, winter salting and sanding, or other seasonal changes. In addition, it is recommended that inspections take place more frequently during the first few years after installation of an SMP. Many issues can be identified and corrected during this early period, so that they do not lead to larger problems in subsequent years. Once the SMP is stable and seems to be functioning properly, the inspections can become less frequent.

What to Take into the Field

The Level 1 Inspection is simple, and it is assumed that very little measurement is needed. However, the Inspector should take pictures to document findings and keep a record of all inspections. The following items may be needed during a Level 1 Inspection:

1. Letter of permission to access property if the Inspector is from an outside agency
2. Clipboard and pencils (if using paper forms), or Tablet or smartphone (if using digital forms)
3. Level 1 Inspection Checklists (paper or digital copies)
4. Notes or records from past inspections
5. Approved Site Plan, Planting Plan (includes planting/seed mixes), and/or details for SMP's
6. Digital camera or smartphone
7. Engineer's scale
8. Flagging/stakes and waterproof marker (to mark problem areas that need to be revisited)
9. 25-ft Measuring Tape (optional, to measure pipe sizes and SMP dimensions)
10. Safety equipment: safety vest, steel-toe shoes, traffic cones, etc. (if SMP is located near traffic)
11. Bug spray (if needed)
12. Sun block (if needed)

Level 1 Checklists

The **Level 1 Inspection Checklists** are available for download on the NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov). These checklists outline common problems with key components of the SMPs and describe follow-up actions for each observed condition. Refer to **Figure 12.2**, for an example checklist.

The Checklists are intended to be used as follows:

- Check the box in the LEFT column if the problem is present at the site.
- Check the appropriate follow-up action(s) in the RIGHT column, or add an action as needed to fix the problem.
- Record all your actions. Keep copies of the Level 1 Inspection Checklists, plus notes, photos, or other documentation of corrective measures to fix problems. Record dates of actions and any follow-up inspections. This will be important for communicating with Level 2 Inspectors and/or the local maintenance program.
- Activate a Level 2 Inspection using the blue cells to identify conditions when a more detailed inspection is necessary to further diagnose a problem. Refer to **Section** 12.2 for common triggers of Level 2 Inspection for each of the SMP Groups. Consult the local stormwater program authority for the most appropriate Level 2 inspection option.

Porous Pavement 1. Drainage Area	
Problem (Check if Present)	**Follow-Up Actions**
 ☐ Bare soil, erosion of the ground (rills washing out the dirt)	☐ Seed and mulch areas of bare soil to get vegetation established. ☐ Fill in erosion areas with soil, compact, and seed straw to get vegetation established. ☐ If a rill or small channel is forming, try to redirect water flowing to this area by creating a small bern or adding topsoil to area by creating a small berm or adding topsoil to areas that are heavily compacted. ☐ Kick-Out to Level 2 Inspection: Large areas of soil have been eroded, or larger channels are forming. May require rerouting of flow paths.

Figure 12.2 Example Level 1 Inspection Checklist, with Follow-Up Actions. *Note "Kick-Out to Level 2" highlighted in light blue*.

12.1.3.2 General Guidance for Level 2 and 3 Inspections

Read through this guidance before performing an inspection, and use the specific guidance in **Section** 12.2 for the SMP Group that includes the practice being inspected, or **Section 12.3** for the specific problem encountered.

When to Conduct a Level 2 Inspection

Level 2 Inspections occur as routine inspections for compliance with local stormwater regulations or when triggered by a Level 1 Inspector to address or diagnose specific problems. In this situation, the Level 2 Inspector should confer with the Level 1 Inspector about problems they have identified and then conduct a follow-up inspection that focuses on diagnosing the causes of the problems and possible solutions.

The frequency of Level 2 Inspections is typically defined by the municipality, but shall occur at least once every five years. As with Level 1 inspections, the frequency may change with the age of the SMP, with higher inspection frequency the first couple of years after installation.

Notifying the Owner/Operator

Consult the project files and maintenance agreement to ascertain the Owner/Operator. Confirm that there is right of access through the local code, signed maintenance agreement, or other means. Contact the Owner/Operator at least three business days in advance of the proposed inspection. If the Owner/Operator cannot be found or contacted, make a reasonable effort through file research to contact a property representative, and document those efforts in writing. If the inspection is in response to a Level 1 inspection and referral to your agency, speak with the person who conducted the Level 1 inspection and get any documentation they may have. For publicly owned and managed SMPs, the municipality or other regulated MS4 is responsible for long-term operation and maintenance.

What to Take in the Field

Level 2 inspections may require authorized access to private property. Therefore, additional identification shall be provided for these inspections. It is recommended that the following items be taken into the field during a Level 2 Inspection:

1. Letter on municipal letterhead granting access to property and/or agency photo badge
2. Clipboard and pencils (if using paper forms), or Tablet or smartphone (if using digital forms)
3. Level 2 Inspection Checklists (paper or digital copies)
4. Dry erase board and marker (optional) to include in photos to keep track of SMP tracking # in municipal database (see **Figure 12.3** as example)
5. Notes or records from past inspections
6. Approved Site Plan, Planting Plan (includes planting/seed mixes), and/or details for SMP's
7. SMP As-Built Plan (if available)
8. Digital camera or smartphone
9. Engineer's scale
10. Flagging/stakes and waterproof marker (to mark problem areas that need to be revisited)
11. 100-ft Measuring Tape
12. Hand level and pocket rod (if needed to measure relative elevations)
13. Pipe wrench (to open underdrain clean-out caps)
14. Flashlight (to look into underdrain cleanouts and/or manholes)
15. Manhole cover puller
16. Soil probe, auger, and/or shovel
17. Safety equipment: safety vest, steel-toe shoes, traffic cones, etc. (if SMP is located near traffic)
18. Bug spray (if needed)
19. Sun block (if needed)

Level 2 Checklists

The **Level 2 Inspection Checklists** are available for download on the NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov). These checklists outline recommended repairs for common problems with key SMP components, and common triggers for Level 3 Inspection.

Conducting the Inspection

In general, the inspection should follow a consistent, logical approach, such as outlined below.

- Conduct a quick tour of the practice to identify any obvious issues and important components: inlets (number, location), surface area, outlet structures, berms or impoundments, outfalls, downstream conveyance channels or receiving waters. Check these components against the approved design plan or as-built drawing (if available).
- Starting at the upland area, use the Level 2 Checklist to evaluate the practice. The inspection will proceed from the upland drainage area to inlets, side slopes, berms, treatment area, and outlets/outfalls. Make sure to fill in key information on the inspection form, such as SMP identifier number, site name, Inspector name, date, and weather conditions.

Figure 12.3 Use a white board and digital camera to note SMP tracking #, date of inspection, and other forms of documentation. Alternatively, tag photographs using a smartphone

- Take photos of key practice components or maintenance concerns. Mark photo locations and orientation on a sketch Site Plan.
- Review the Inspection Checklists before leaving the site to make sure that all necessary information has been collected.

Follow-Up Actions

Upon completion of an inspection, complete these follow-up actions as soon as possible:

- Enter the inspection information in the appropriate database or hard copy file
- Download and label photos
- Communicate problems and corrective measures to the Owner/Operator (private or public). This may involve the Level 2 Inspector making a judgement call as to whether observed problems warrant a Level 3 investigation, providing a timeframe for correcting simpler issues, and coordinating with the Owner/Operator to pursue such an investigation, if required. Many local programs have existing protocols for sending letters, activating a compliance procedure, or verifying that repairs and corrections are completed by the Owner/Operator.

The **Level 2 Inspection Checklists** summarize follow-up actions and recommended repairs associated with various observations of SMP condition (blue cells) and highlight specific conditions that would trigger Level 3 Inspection (grey cells).

Level 3 Inspection Guidance

Level 3 Inspections are conducted in response to more complex issues identified during a Level 2 inspection, with the goal of developing specific repairs to resolve the issues. Therefore, the inspection primarily focuses on the problematic components of the SMP, but it is good practice to perform a cursory review of all system components. **Section 12.3** identifies twelve problems that are typically addressed in Level 3 inspections and discusses how to diagnose the cause of each problem, as well as repairs needed to address them. It should be noted that the problems addressed in each subsection can occur in a variety of SMPs. As a result, each subsection identifies the SMPs where the problem most commonly occurs and, in some cases, an SMP-specific diagnosis procedure.

12.1.4 Planning for Stormwater Maintenance

This section outlines key elements of stormwater maintenance planning, including:

1. Program models for stormwater maintenance
2. Inspection and maintenance checklists
3. Planning for the costs of stormwater maintenance
4. Identifying the need for infrequent maintenance items

12.1.4.1 Program Models for Stormwater Maintenance

The Maintenance Hierarchy concept (See **Section 12.1.2**) is discussed throughout this Chapter, but the individuals who will conduct the Level 1, Level 2 and Level 3 inspections and maintenance will vary depending on how the local program is administered. While this Chapter does not focus on program elements, it is important to note that the local program requirements will influence who performs ongoing maintenance. A legally binding and enforceable maintenance agreement shall be established between the property owner and local reviewing authorities to assign maintenance responsibilities to the responsible parties. This will play an important role in how to develop a comprehensive maintenance plan. All required maintenance elements shall be included in the maintenance plan.

Stormwater maintenance plans can generally be designated in three categories: 1) Private; 2) Local Government; and 3) Hybrid Approach. Understanding the program and regulations in the local community will influence the best techniques for developing the maintenance plan (**Table 12.3**).

Option 1: Private Maintenance

In this option, maintenance is the responsibility of the private landowner. In regulated MS4s, however, the landowner will periodically report to the local government. In this model, it is important to ensure that the maintenance plan is very easy to understand.

Option 2: Local Government Maintenance

In this option, the local government takes over maintenance responsibility for all stormwater practices. While it is still important to develop a clear and simple plan, the designer can assume some level of training or supervision for the individuals conducting inspections and maintenance. Maintenance access should be made available to local government staff through official easements.

Option 3: Hybrid Approach

In the hybrid approach to stormwater maintenance, larger practices or practices on public land are maintained by the local government, and smaller practices on private property are maintained by the landowner. Alternatively, the local government may take responsibility for inspections, but leave the landowner responsible for maintenance items identified during the inspection.

Table 12.3 Maintenance Considerations for Three Program Options

Program Option	Inspection/Maintenance Performed By:	Key Considerations for the Designer
Option 1: Private	Level 1: Property owner or HOA Level 2: Private Contractor Level 3: Certified Contractor	Make the plan very simple and graphic intensive. Include a list of contractors if applicable. Provide links to educational materials.
Option 2: Local Government Program	Level 1: Interns or Untrained Staff Level 2: Trained Local Staff Level 3: City/Town/Village Engineer or other individual hired by the municipality	Learn about the resources the local program has at its disposal. If government staff are being trained, develop a maintenance plan that is consistent with their knowledge and understanding. Be aware of equipment and materials on hand in this community.
Option 3: Hybrid Approach	Inspection and maintenance responsibilities are divided between the local government and private landowner.	Understand how the responsibilities are divided and develop a plan that is consistent with this arrangement.

12.1.4.2 Inspection and Maintenance Checklists and Documentation

The NYSDEC Construction Stormwater Toolbox website (www.dec.ny.gov) includes inspection checklists specific to each level of the maintenance hierarchy. The maintenance plan should include the inspection checklists for each level for the SMP Group(s) being constructed. The checklists include blank sections under each of the practice key components, to input project specific information. All materials developed as a part of the maintenance plan should be provided to the practice owner and local government. (See **Table 12.4**)

Table 12.4 Customizing Checklists and Guidance		
Hierarchy	**Checklist Guidance**	**Tips for Customizing**
Level 1	**Section** 12.2 includes guidance.	Attach photographs of the practice (once installed), and a simple aerial photograph of the site to locate the practice. Include key local government contacts and contractors along with the checklist. Modify to add other problems, as they are identified during inspections. Attach site specific photographs of each problem identified.
Level 2	**Section** 12.2 includes triggers for Level 2 and Level 3 Inspection.	Modify to add other observed conditions and recommended repairs, as they are identified during inspections. Attach site specific photographs of each observed condition identified.
Level 3	**Section** 12.2 and **Section 12.3** include guidance.	Attach site specific photographs of each observed condition identified. Develop plans, details, and/or written narrative of recommended

12.1.4.3 Budgeting for Maintenance

A maintenance plan should include a budget for annual maintenance. In the Local Government Maintenance model, a single entity (the local government) will be responsible for maintenance of many practices, so the cost of maintenance for an individual practice may not be as important as estimating the average cost of maintenance across all practices. For privately maintained practices, on the other hand, it is very helpful to develop a cost estimate that is as accurate as possible for the specific location. As a result, two options for estimating costs are presented here, including:

- **Option 1**: Average or Unit Costs
  Generalized cost data are used to estimate an annual cost. This option may be used for a municipality or other institution that manages a large number of practices.
- **Option 2:** Detailed Individual Practice Budget
  Annual costs are estimated using more detailed practice information, as well as more detailed estimates of labor and material costs.

Option 1: Average or Unit Costs

In this option, annual maintenance costs are estimated on a per-acre basis or as a percentage of the total construction costs. These prices typically range from about 1% to 4% of the construction costs (King and Hagan, 2011; **Table 12.5** Typical Maintenance Costs**)**.

Table 12.5 Typical Maintenance Costs (Source: King and Hagan, 2011; Adjusted to 2015 Costs)		
Practice	**Annual Maintenance Cost (% of Construction)**	**Annual Maintenance Cost ($/cf of water quality volume treated)**
Buffers	4%	$0.25 - $0.35
Tree Planting	4%	$0.35
Ponds and Wetlands	4%	$0.22 - $0.35
Infiltration Trench/ Basin	2%	$0.25
Filtering Practices	4%	$0.41 - $0.47
Bioretention	4%	$0.44
Swales	3%	$0.18 - $0.26
Porous Pavement	1%	$0.64 - $0.89

While the costs in **Table 12.5** may be a reasonable starting point, it is important to note that the actual data will vary greatly, depending on labor rates and material costs. For example, the hourly "Open Shop" labor rate for rough grading is approximately $27/hour in Elmira and $38/hour in New York City (Means, 2015). In addition, costs for labor, materials and equipment will vary depending on the maintenance arrangement (**Table 12.6**).

Table 12.6 Variability in Maintenance Costs Based on Maintenance Arrangement

Maintenance Arrangement	Labor	Materials	Equipment
Public Maintenance (Municipality)	Level 1: Intern Wage Level 2: Staff Salary Level 3: Professional Staff or Contractor	Low: Materials bought in bulk.	Low: Typically owned by Public Works or similar department.
Private Maintenance (Homeowner)	Level 1: Homeowner (Free) or Contractor Level 2: Private Landscaper or Contractor Level 3: Professional Contractor	High: Materials purchased in small quantities.	High: Specialized equipment needs to be rented if needed.
Private Maintenance (Commercial or HOA)	Level 1: Free (with HOA volunteers) or Contracted Labor Rate Level 2: Private Landscaper or Contractor Level 3: Professional Contractor	Varies: Materials may be bought in bulk or on a small scale, depending on the size of the private entity.	High: Specialized equipment needs to be rented if needed.

Option 2: Site-Based Costs

Because the unit costs of labor and materials, and the average annual costs of maintenance can be highly variable, more detailed data will be needed to estimate costs at a particular site. One approach for estimating costs is to generate a list of routine maintenance items, along with associated unit costs for labor, materials, and equipment. This approach requires the user to enter basic design data for the practice, as well as information regarding local labor rates and other general costs. In the bioretention example below, unit costs are used to estimate routine maintenance costs, including regular inspections and maintenance.

Example Annual Cost Estimation: Bioretention

An example cost estimation for a bioretention filter follows below, which demonstrates how the unit cost and typical frequency data can be used to estimate average annual maintenance costs. **Table 12.7** summarizes the characteristics of the example bioretention practice, as well as the unit cost assumptions for typical inspection and maintenance activities. **Table 12.8** then summarizes routine inspection and maintenance activities, their frequency and extent, and associated labor costs.

Using the assumptions for this example, the annual costs for routine inspection and maintenance would be $1,828 ($1.15/cfof Water Quality Volume) in the first year, and $1,468 ($0.90/cf WQ_v) in subsequent years. These values are much higher than the $0.44/cf estimated using general cost data (**Table 12.5**). However, significant cost savings could be realized by using volunteer or intern-level labor for Level 1 inspections and routine maintenance.

Table 12.7 Bioretention Example: Assumed Practice Characteristics and Unit Costs

Practice Design		**Unit Costs**	
Water Quality Volume (cf)	1,600	Level 1 Labor ($/hr)	$15
Forebay Volume (cf)	400	Level 2 Labor ($/hr)	$35
Total Practice Area (sf)	2,000	Mulch ($/cy)	$10
Filter Area (sf)	1,000	Plants ($/plant)	$1
Ponding Area (sf)	1,500	Trash Tipping Fee	$25
Slope Area (sf)	500	Seed/Mulch for a small area	$10
Turf Area (sf)	No Turf	Average Cost for a PVC Replacement Part (Planning Level)	$100
Inlets (#)	1		

Table 12.8 Bioretention Example: Routine Inspection and Maintenance Costs										
Task	Frequency (x/year, Decimal)	Typical Extent	Extent	Hours (Unit)	Hours/yr	Level	Materials and Equipment	Annual Costs		
								Labor	Materials and Equipment	Total
Level 1 Inspection - 1 to 5-acre drainage	1	Practice	1	1 per inspection	1	1		$15		$15
Level 2 Inspection - 1 to 5-acre drainage	0.2	Practice	1	2 per inspection	0.4	2		$14		$14
Watering - grass and plants: Year 1	16	Weekly for first growing season, over filter surface area	1,000	0.5 per 400 sf area	24	1	Assume minimal cost for water	$360		$360
Trash and Debris Removal	4	Ponding area	1,500	1 per 400 sf practice surface area	15	1	Assume $25 Tipping Fee for Each Trip	$225	$100	$325
Weeding	2	Assume 50% of practice area	1,000	4 per 400 sf practice surface area	20	1		$300		$300
Mulching	1	Ponding area	1,500	4 per 400 sf area	15	1	Bark mulch; assume 15 cy/application	$225	$150	$375
Sediment Removal (minor, less than 2”)	1	Assume one small area per inlet	1	1 per small area	1	1		$15		$15
Erosion Repair (minor)	1	Inlets; assume 25 sf/practice	25	1 per 25 sf	1	1	Seed, mulch, and topsoil	$15	$10	$25
Erosion Repair (minor)	1	10% of slope area	50	1 per 25 sf	2	1	Seed, mulch, and topsoil	$30	$20	$40
Minor Regrading	0.5	1 spot per 400 sf of practice area	5	1 per repair	2.5	2	Assume done by hand	$88		$88
Planting (plants)	0.2	Assume 50% of practice area	1,000	8 per200 sf	8	1	Assume 500 plants/planting	$120	$100	$220
Minor PVC or Metal Repairs (observation well cap, PVC outlet control, grates)	0.2	1 per practice	1	1 per repair	0.2	2	Assume about a $100 piece of equipment	$7	$20	$27
Sediment Removal (small forebay)	0.2	per forebay	1	2 per forebay	0.4	2	Assume removal by hand	$14		$14
							Total Costs - Year 1	**$1,428**	**$400**	**$1,828**
							Total Costs - Subsequent Years	**$1,068**	**$400**	**$1,468**

12.1.4.4 Planning for "Non-Routine" Maintenance

If the guidance provided in this Chapter is followed and practices are designed properly, the routine maintenance (and budget guidance in **Section 12.1.4.3**) should be sufficient to keep a practice functioning indefinitely. However, planning is needed for infrequent maintenance items. In the initial maintenance plan, identify a few of the most likely infrequent items. If initial routine inspections start to identify a more serious problem, develop a plan and budget for performing the repairs. To be more conservative, another option is to provide a contingency budget to plan for non-routine repairs over the life of the practice.

Note: Maintenance and repairs that rise to a Level 3 inspection may require permits from the NYSDEC and/or US Army Corps of Engineers, if they are undertaken within or adjacent to regulated wetlands or other waters of the U.S.

Section 12.2 Inspections by SMP Group

12.2.1 Sheet Flow and Disconnection

Includes: Sheet Flow to Riparian Buffers/Filter Strips (RR-2) and Disconnection of Rooftop Runoff (RR-4)

Components

The intent of sheet Flow and disconnection is for runoff from small areas of impervious cover to spread out evenly and dissipate in a grassy, vegetated, riparian, or reforestation area. It is a low-technology practice intended to reduce runoff at its source. Key components to inspect for Sheet Flow and Disconnection include the following:

- **S&D-1 Drainage Area:** The drainage area consists of rooftops and/or impervious surfaces such as parking lots, driveways, or sidewalks. Pervious areas such as lawns or forests may also be part of the drainage area.
- **S&D-2 Level Spreader/Energy Dissipator:** Some sheet flow and disconnection practices have a mechanism in place to dissipate concentrated runoff and return it to sheet flow.
- **S&D-3 Treatment Area:** After runoff is dissipated as sheet flow, it enters the treatment area.

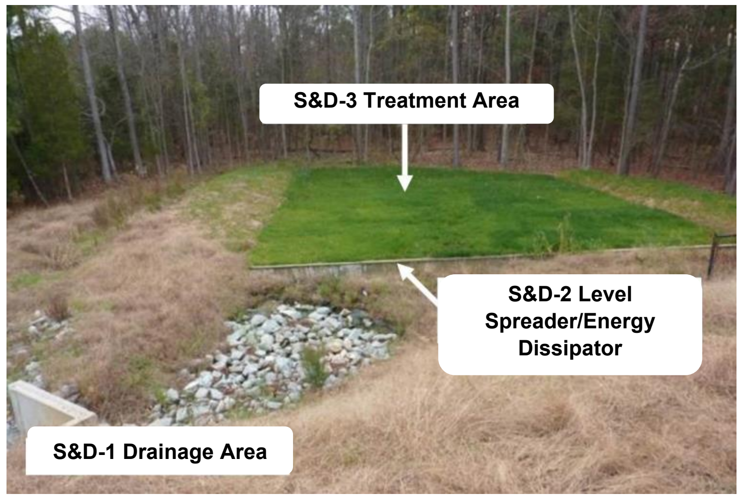


Figure 12.4 Key Areas for Level 1 Inspection of Sheet Flow and Disconnection with filter strip shown. (R. Winston, NCSU)

Level 1 Inspections

Frequency: *2 times per year in early spring and fall. Recommend an additional inspection during a storm to better see any active blockages, bypassing, or other problems.*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of S&D practices are:

- Widespread sediment accumulation in paved tributary area
- Deterioration at pavement edge
- Deterioration of level spreader/energy dissipator
- Erosion in the treatment area

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of S&D practices are:

- Major sediment or erosion caused by uphill issue
- Significant damage to level spreader/energy dissipator

12.2.2 Tree Plantings

Includes: Tree Plantings (RR-3)

Components

Key components to inspect for tree planting include the following:

- **TP-1 Surface Area:** The tree planting surface area is the mulched area where water accumulates and is absorbed during a storm.

- **TP-2 Vegetation:** The vegetation of a tree planting is comprised of the tree itself. The health of the tree is one of the most critical maintenance items for tree plantings.

Note: This is a simple, "non-structural" practice and, as such, maintenance tasks are similar to any landscape maintenance. Tree planting can involve individual trees or multiple trees, such as reforesting a riparian buffer.

Figure 12.5 Key Areas for Level 1 Inspection of Tree Plantings

Level 1 Inspections

Frequency: *Annually in early spring. Recommend every 3 months, within 1 week of ice storms and within 1 week of high wind events (>20 mph) until the trees reach maturity.*

The Level 1 inspection goes hand in hand with active maintenance and includes inspection of the surface area (TP-1) and Vegetation (TP-2) of the tree planting. Watering, mulching, and pruning are common maintenance activities. During the first three years, mulching, watering, and protection of young trees may be necessary, see **Chapter 11** for additional maintenance guidance. Watering should occur during the growing season. Mulching and pruning occurs once a year in the spring and early spring, respectively.

At a minimum, inspections shall include an assessment of tree health and determination of survival rates. Any dead trees shall be replaced, and remaining trees shall be inspected for evidence of insect, disease, or other physical damage.

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of TP practices are:

- Appearance of fungus or pest damage to vegetation

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of TP practices are:

- Uncertainty about how to address the infestation or disease

12.2.3 Swales

Includes: Vegetated Swales (RR-5) and Wet Swales (O-2)

Components

Key components to inspect for swales include the following:

- **SW-1 Drainage Area:** The drainage area sends runoff to and is uphill from the swale. When it rains, water runs off and flows to and along the swale.
- **SW-2 Inlets:** The inlets to a swale are where water flows in. Depending on the design, water can flow in through: a ditch, pipe, or curb opening at top of swale or as sheet flow along the entire length of swale.
- **SW-3 Surface Area:** The swale surface area is the vegetated bottom area and side slopes where water flows during a storm. Depending on the design, the swale may also contain check dams, which are small dams of earth, stone, wood, or other materials that slow down and temporarily pond water as it flows down the swale.
- **SW-4 Vegetation:** The health of vegetation within the swale is perhaps the most critical maintenance item for the property owner or responsible party.
- **SW-5 Outlets:** These are where water leaves the swale when it fills up or where water reaches the downstream end of the swale. There may be a small stone apron or rock dam here or even an outlet grate.

Level 1 Inspections

Frequency: *Annually in early Spring. Recommend an additional inspection during the growing season or in the early fall to assess the health of vegetation.*

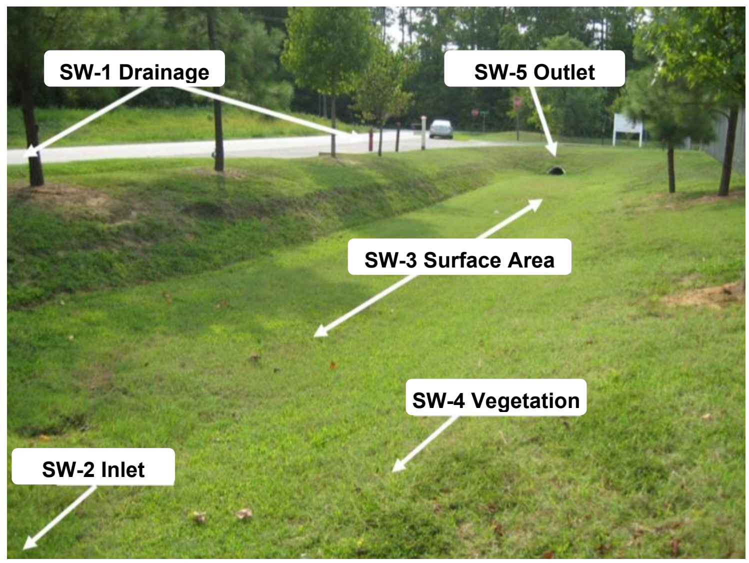


Figure 12.6 Key Areas for Level 1 Inspection of Swales

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of SW practices are:

- Water ponding on the surface for more than 72 hours following a storm event
- Vegetation being replaced by weeds and invasive species
- Erosion of check dams, inlets, swale surface area or side slopes
- Significant sediment accumulation

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of SW practices are:

- Standing water caused by over compacted or clogged soil media
- Severe erosion around or under check dams
- Large area of vegetation overrun with weeds and/or invasive species
- Problem requires practice redesign or modification to solve
- Severe sediment accumulation that appears to be getting worse over time

12.2.4 Bioretention

Includes: Tree Pits (RR-3), Tree Trench (RR-3), Rain Gardens (RR-6), Stormwater Planters (RR-7), Infiltration Bioretention (F-4), Filtration Bioretention (F-5), Bioslope (F-6), Dry Swales (O-1)

Note: For the purposes of this Chapter, the term "Bioretention" will be used to generally describe all of these practices.

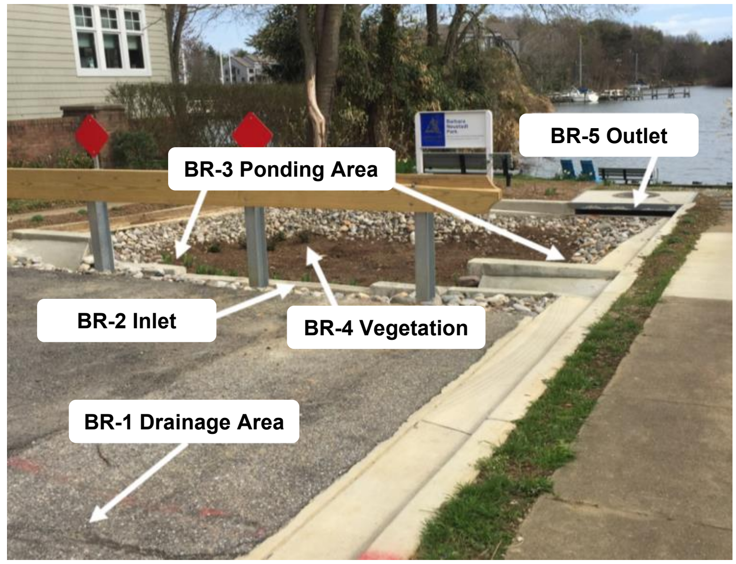


Figure 12.7 Key Areas for Level 1 Inspection of Bioretention

Components

Key components to inspect for Bioretention include the following:

- **BR-1 Drainage Area:** The drainage area sends runoff to and is uphill from the Bioretention. When it rains, water runs off and flows to the Bioretention and ponds within the filter temporarily (usually for no more than 48 hours). Sometimes, the runoff will contain dirt, grit, grass clippings, oil, or other substances that SHOULD NOT be directed to the practice.
- **BR-2 Inlets:** The inlets to a Bioretention are where water flows into the filter. Depending on the design, water can flow in through: curb cuts, pipes, ditches, or sheet flow.
- **BR-3 Ponding Area:** The ponding area fills up with water during a rainstorm. If you picture the Bioretention as a bathtub, there is the *bottom* (usually flat surface), *side slopes* (areas that slope down to the bottom from the surrounding ground), and *berms or structures that control the depth to which water ponds.*
- **BR-4 Vegetation:** The health of vegetation within the Bioretention is perhaps the most critical maintenance item for the Owner/Operator. Many Bioretention become overgrown, and "desirable" vegetation becomes choked out by weeds and invasive plants. Weeding and watering are essential the first year and can be minimized with the use of a weed-free mulch layer. It is important to know what the practice is supposed to look like, and what plants seem to be thriving or doing poorly.
- **BR-5 Outlets:** Outlets are where water leaves the Bioretention when stormwater exceeds the storage capacity.

Level 1 Inspections

Inspection Frequency: *4 times per year during the growing season. During the first 6 months of operation, it is recommended that bioretention practices be inspected at least twice, and after each storm event greater than 0.5".*

Maintenance Frequency: *At least 4 times during the growing season, bioretention should be pruned, weeded, and mowed around; have sediment, trash, and debris removed; and have dead and damaged plants replaced, as needed. In the spring and fall, the practices should have rills, gullies, dead or diseased trees and shrubs repaired or replaced; have bare areas reseeded if applicable; and have mulch replenished to required depth. In the winter months, planting material should be trimmed, and the practice should be inspected for snow accumulation. Once per year, soils should be tested for appropriate pH levels. Finally, every 2 to 3 years, damaged or compromised structures within the practice should be replaced, perennials should be trimmed and divided, and infiltration rates should be checked to ensure proper drainage.*

Maintenance Frequency (Design F-6): In addition to the above, Bioslopes should be inspected after snow events to ensure that the added weight from accumulated snow did not compact the filter media. On a monthly basis, stabilize eroded areas, ensure that flow is not bypassing the facility, and mow the slope using a retractable arm mower to a height of 6 to 15 inches. Recommend performing a flow test on the cleanouts annually to check for clogging, and to remove accumulated sediment that exceeds three inches in depth.

Curb Inlet #1: flow enters through curb channel.

Curb Inlet #2: flow enters through drop curb.

Pea Gravel Diaphragm: sheet flow enters and is evenly distributed along the practice length.

Grass filter strip: sheet flow enters and is evenly distributed along the practice length.

Figure 12.8 Bioretention Filter Inlets

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of BR practices are:

- Water ponding on surface of practice for more than 72 hours after a storm event
- Bioslope does not drain properly
- Sparse or out of control vegetation
- Practice deviates from original design
- Erosion of inlets, filter bed or outlets
- Significant sediment accumulation

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of BR practices are:

- Standing water caused by clogged or over compacted media
- Vegetation management needed
- Bioretention does not conform to original design plan in surface area or storage.
- Severe erosion especially when caused by subsurface defect
- Widespread significant and persistent sediment accumulation

12.2.5 Rainwater Harvesting

Includes: Rain Barrels and Cisterns (RR-8)

Components

Key components to inspect for Rainwater Harvesting systems include the following:

- **RWH-1 Conveyance System and Filter:** The conveyance system is all the components that collect and convey runoff from the roof toward the storage tank. This typically consists of gutters and downspouts, and sometimes additional drainage pipes. These components must be kept clear of debris in order to avoid blockages and spilling of runoff out of the gutters. The system should also be equipped with one or more ways of filtering water coming in from the conveyance system, such as screens, first-flush diverters, and/or vortex filters.

- **RWH-2 Storage Tank:** Many different types and sizes of tanks can be used for rainwater harvesting. They can be situated underground, above ground, or even partially buried. The tank body has an inlet (and/or cover) and one or more outlet points for water to leave the tank. Advanced rainwater harvesting systems usually also have a pump and a filter inside or outside the tank to further clean the stored water and pump it to the point of use.
- **RWH-3 Outlets:** An above-ground rainwater harvesting tank usually has at least two outlets—one at the top of the tank where water overflows when the tank is full, and one near the bottom of the tank for delivering the stored water by gravity feed. Many filters also have an outlet pipe to divert the first flush of roof runoff away from the tank.

Figure 12.9 Key Areas for Level 1 Inspection of Rainwater Harvesting Systems

Figure 12.10 Inspecting the conveyance system, vortex-style filter.

Figure 12.11 Inspecting the RWH system top access port.

Level 1 Inspections

Frequency: *2 times per year in early spring and fall prior to the tank being taken offline. Recommend two additional intermediate inspections per year, during or immediately following a storm.*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of RWH practices are:

- Tank not filling properly or water level drops quickly
- Tank is sinking, leaking or at risk of collapse
- Severe erosion at outlet

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of RWH practices are:

- Structural or mechanical problems
- Problem requires practice redesign or modification
- Accumulation of debris in the tank that cannot be easily removed by hand
- Severe reoccurring erosion at the outlet or downstream drainage concerns

12.2.6 Porous Pavement

Includes: Porous Pavements (RR-9), which covers porous versions of asphalt, concrete, pavers, concrete block, stabilized grid/cell systems, etc.

Components

Key components to inspect for porous pavement include the following:

- **PP-1 Drainage Area:** The drainage area sends runoff to the Porous pavement area and is uphill from the Porous pavement.
- **PP-2 Surface:** The surface of the porous pavement should be relatively clean (not a lot of dirt and grit on the surface), free of cracks and broken pavement, and should NOT hold water after a rainstorm for more than a few hours.

Figure 12.12 Key Areas for Level 1 Inspection of Porous Pavement

Level 1 Inspections

Frequency: *2 times per year in early spring and fall, to inspect for surface deterioration, spalling, etc. In addition, the surface should be inspected monthly to ensure that it is clear of debris and sediments and that it dewaters between storms (or after storms >0.5 inches).*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of PP practices are:

- Extensive bare soil and erosion in the drainage area
- Sediment accumulating on the surface
- Damage to the pavement surface
- Ponding water following storm events

Figure 12.13 Winter salting, sanding, plowing, and snow storage can cause problems for porous pavement surfaces, which may trigger a Level 3 Inspection.

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of PP practices are:

- Severe erosion in drainage area
- Subsurface water conveyance or soil stabilization issues
- Highly clogged pavement
- Solving the problem would require practice redesign or extensive regrading of the drainage area.

Figure 12.14 A Level 3 Inspection is warranted if more than 25% of the porous pavement surface appears to be clogged, joints are filled in, or vegetation is not growing (as shown in photo).

12.2.7 Green Roof

Includes: Green Roofs (RR-10), which covers extensive and intensive systems.

Note: Green Roofs are unique in that they are often covered by a professional ongoing maintenance contract, and their design is highly variable depending on the system specified.

Components

Key components to inspect for green roofs include the following:

- **GR-1 Vegetation and Surface:** The green roof vegetation usually consists of succulent plants, such as sedums, and should form a dense cover over the course of several growing seasons.

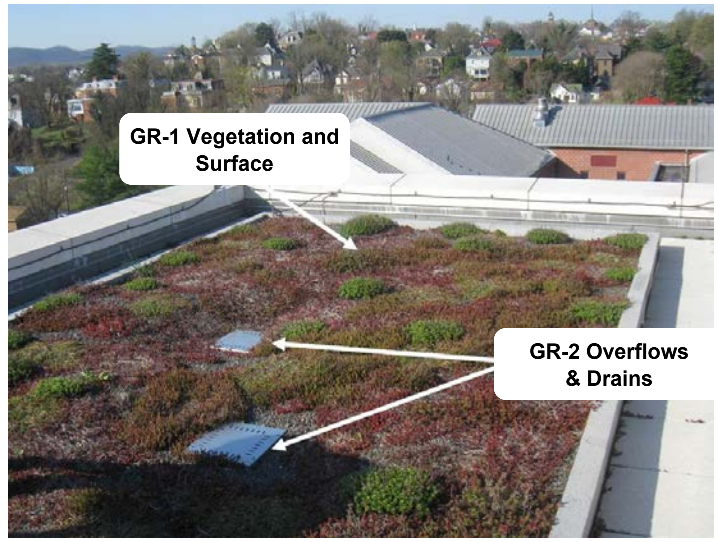


Figure 12.15 Key Areas for Level 1 Inspection of Green Roofs

- **GR-2 Overflows and Drains:** Green roofs typically drain through a network of underdrains to outlet at roof drainage infrastructure. These drainage structures need to be inspected and cleaned periodically to ensure that the media drains properly.

Level 1 Inspections

Inspection Frequency: *2 times per year in early spring and fall.*

Maintenance Frequency: *In the first 2 years of operation, green roofs shall receive routine maintenance on at least a monthly basis, to include watering, fertilizing, and weeding, see* ***Chapter 11*** *for additional maintenance guidance. Once plants have become established, maintenance can be reduced to a frequency necessary to weed, remove invasive species, replace dying vegetation and maintain system components. It is also recommended that inspections occur during periods of drought, to water and ensure that vegetation is surviving.*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of GR practices are:

- Unhealthy or dying vegetation
- Ponding caused by clogged outflow pipes or underdrains
- Minor damage to overflows

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of GR practices are:

- Standing water caused by soil media or underdrain system
- Significant vegetation die-off requiring management
- Severe structural damage
- Roof is leaking

12.2.8 Ponds and Wetlands

Includes: Micropool Extended Detention (P-1), Wet Pond (P-2), Wet Extended Detention Pond (P-3), Multiple Pond Systems (P-4), Shallow Wetland (W-1), Extended Detention Wetland (W-2), Pond/Wetland System (W-3), Pocket Wetland (W-4), Gravel Wetland (W-5)

Note: It is strongly recommended to have as-built drawings and copies of previous inspections at hand, if available. Aerial photos may be needed to help direct the Inspector to the pond or wetland location if it is obscured by vegetation.

Components

Key components to inspect for ponds and wetlands include the following:

- **PW-1 Drainage Area:** The drainage area conveys runoff to and is uphill from the inlet. When it rains, water runs off through roof drains, yard drains, parking lots, roadways, and underdrains to the ponds. Flow is through underground piping systems, overland via swales, or across the ground as sheet flow.
- **PW-2 Inlets:** Free, unobstructed flow from the drainage area to stormwater ponds and wetlands is necessary to prevent shallow flooding and even structural damage from flooding. Inlets can consist of pipes, ditches, swales, or other means to convey stormwater to the pond or wetland.

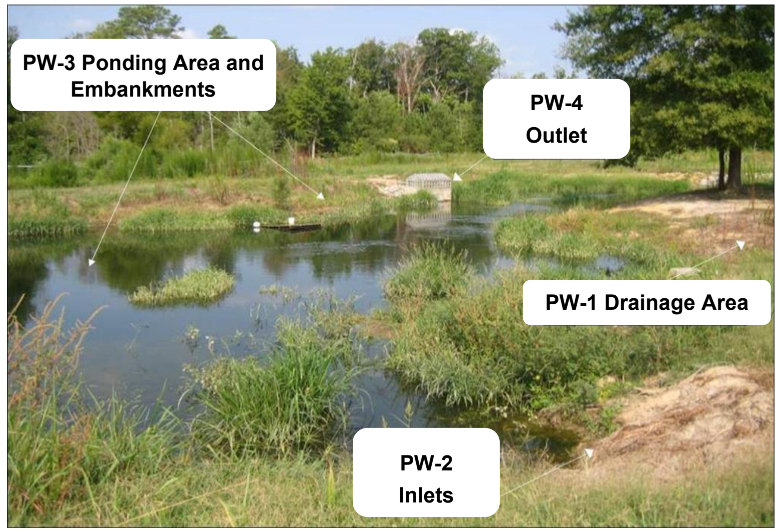


Figure 12.16 Key Areas for Level 1 Inspection of Ponds

- **PW-3 Ponding Area and Embankments:** The ponding area and embankment can consist of the following elements: forebays, safety/aquatic benches, side slopes and permanent pools of water.
- **PW-4 Outlets:** The outlet enables the ponded water to discharge to downstream drainage systems or stream channels. The outlet is often at the base of the dam/embankment on the downstream side.

Level 1 Inspections

Inspection Frequency: *1 time per year in early spring. Recommend additional inspections following major storm events. Inspect the permanent pool and safety elements during every inspection.*

Maintenance Frequency: *At least 2 times per year, the emergency spillway should be mowed and cleared of obstructions. Remove buildup of trash, vegetation, or sediment during every inspection.*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of PW practices are:

- Extensive bare soil and erosion in the drainage area
- Manholes or inlet pipes buried or covered with vegetation
- Excessive sediment buildup or overgrown vegetation

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of PW practices are:

- Severe erosion of the drainage area
- Buried or submerged manholes, pipes or other structures need to be located
- Excessive algae or aquatic plants
- Pipe or headwall settlement, erosion, corrosion, or failure
- Major sediment buildup
- Solving the problem would require practice redesign or extensive regrading of the drainage area

12.2.9 Infiltration

Includes: Infiltration Trench (I-1), Infiltration Basin (I-2), Dry Well (I-3), Underground Infiltration System (I-4)

Components

Key components to inspect for Infiltration include the following:

- **IN-1 Drainage Area:** The drainage area conveys runoff to and is uphill from the infiltration cell. When it rains, water runs off and flows to the infiltration cell and soaks into its underlying layers.
- **IN-2 Inlets:** The inlets are where water flows into the practice. Depending on the design, inlets can include curb cuts, openings in a parking lot or roadway, downspouts, pipes, or ditches. Water can also enter the practice directly as sheet flow.

Figure 12.17 Key Areas for Level 1 Inspection of Infiltration Practices

- **IN-3 Infiltration Area:** The area that collects water and allows it to seep into the underlying soil.
- **IN-4 Outlets:** Outlets are where water exits the surface of the infiltration area during larger storms when the underground infiltration reservoir fills up and the excess water needs somewhere to go. Note that not all infiltration practices will have an identifiable outlet if the design is for all the water to infiltrate into the ground. Outlets may be a berm, stone weir, or pipe.

Level 1 Inspections

Frequency: *At least 2 times a year, especially in early spring, to ensure that the practice has survived the winter. Debris cleanout and dewatering inspection should occur monthly. Inspection of sediment traps, forebays, inlets and outlets should occur at least 1 time per year along with sediment cleanout and aggregate repairs.*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of IN practices are:

- Water stands on the surface for more than 72 hours after a storm event
- Erosion of inlets, infiltration area or outlets
- Excessive sediment buildup

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of IN practices are:

- Standing water caused by clogged media
- Severe erosion of infiltration area, inlets, or around outlets
- Reoccurring significant sediment accumulation that is getting worse with time
- Solving the problem would require practice redesign or modification

12.2.10 Sand Filters

Includes: Surface Sand Filter (F-1), Underground Sand Filter (F-2), Perimeter Sand Filter (F-3)

Components

Key areas to inspect for these types of practices include the following:

- **SF-1 Drainage Area:** The drainage area conveys runoff to and is uphill from the filter.
- **SF-2 Inlets:** Inlets to a filter are where water flows into the filter, such as curb cuts, downspouts, pipes, or ditches that carry water into the filter from the drainage area. Water can enter the practice directly through sheet flow.
- **SF-3 Filter Area:** The Filter Area is the area that collects water and allows it to seep into the filter media.

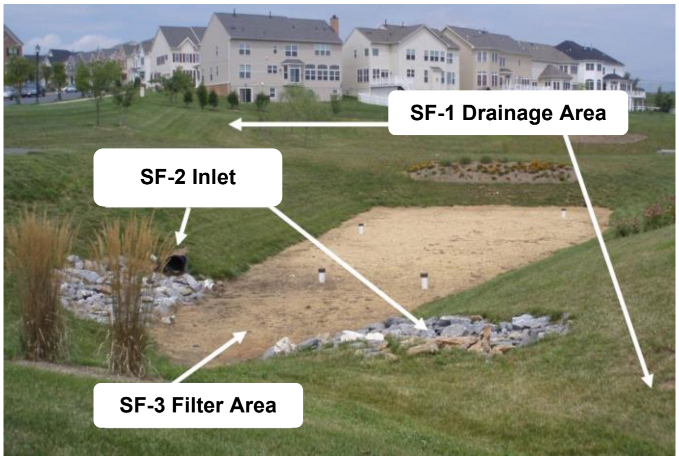


Figure 12.18 Key Areas for Level 1 Inspection of Sand Filters

Figure 12.19 Example Perimeter Sand Filter

Figure 12.20 Example Concrete Perimeter Sand Filter (photo shows the filter with the grate top off as the filter is being maintained. Sedimentation chamber filled with water is on the right, and the sand filter chamber is on the left.

Level 1 Inspections

Inspection Frequency: *All system components shall be inspected at least 1 time per year in early spring. Recommend an additional inspection in the fall to look for debris, vegetation, and water retention.*

Maintenance Frequency: *Any grass cover should be mowed a minimum of 3 times per growing season, to maintain a maximum grass height of 12 inches.*

Triggers for Level 2 Inspection

The most likely triggers for Level 2 Inspection of SF practices are:

- Ponding water more than 72 hours after storm event
- Erosion of inlets, filter bed or outlets
- Excessive sediment buildup

Triggers for Level 3 Inspection

The most likely triggers for Level 3 Inspection of SF practices are:

- Standing water caused by clogged filter media
- Need to pump out sedimentation chamber
- Severe erosion
- Severe sedimentation
- Response to fuel or other spills that make it into the filter
- Subsurface defects with underlying soil
- Solving the problem will require practice redesign or modification

Section 12.3 Diagnostics and Maintenance Measures

This Section summarizes the most common problems found in SMPs, as well as typical maintenance or repair solutions. The guidance provided in this section has some similarities to **Section** 12.2, but differs in the following ways:

1. The primary audience of this Section is the Level 3 Inspector, who is tasked with diagnosing and repairing SMPs that are not working properly. However, this information may also be useful for a Level 2 Inspector seeking to diagnose a particular problem.
2. The maintenance measures described in this Section are more detailed and focus on repairs to specific problems rather than on routine maintenance, such as weeding or minor sediment removal.
3. Because the problems described in this section can be applied to several different practices, this section is organized by the problem type rather than the practice type.

Common problems addressed during Level 3 inspection/maintenance are summarized in **Table 12.9**. This list is not exhaustive but does address SMP issues that require some advanced knowledge and skill to inspect and diagnose solutions. Each problem category is discussed in a separate subsection.

Table 12.9 Common Level 3 Inspection/Maintenance Issues

Subsection/Category	Description
12.3.1 Contributing Drainage Area – Pollutant Sources	Sediment or pollution sources in the Drainage Area
12.3.2 Physical Obstructions	Physical obstructions to maintenance access, overflow, or emergency spillway
12.3.3 Erosion	Erosion on side slopes, practice bottom, at inlet or outlets. Rills and gullies forming where there should be sheet flow
12.3.4 Departure from Design Dimensions	Practice dimensions have been altered, either due to filling with sediment, redesign or filling in, or improper implementation.
12.3.5 Improper Flow Paths	Flow is short-circuiting the practice, or drainage flow paths have been otherwise modified.
12.3.6 Sediment Buildup	Sediment has accumulated in a pool, practice bottom, pretreatment area, or vault.
12.3.7 Clogging	The filter media or other components are clogged, and there may be standing water for longer than intended.
12.3.8 Vegetation	Excessive, inadequate, and/or unhealthy vegetation to support a practice
12.3.9 Embankment and Overflow Condition	Issues with an embankment or overflow weir or channel
12.3.10 Structural Damage	SMP infrastructure, such as concrete or metal elements, have been damaged.
12.3.11 Pool Stability	Permanent pool of water is at the improper elevation.
12.3.12 Pool Quality	Permanent pool of water suffers from poor quality due to algal growth or other issues.

12.3.1 Contributing Drainage Area – Pollutant Sources

Applies Most Commonly To: Sheet Flow/Disconnection, Swales, Bioretention, Porous Pavement, Ponds/Wetlands, Infiltration, and Sand Filters.

Problem #1: Bare soil washing into SMP from drainage area

General Approach for All Practices:

- Identify the specific source(s) of sediment in the drainage area by tracking sediment flow during a rainfall or looking for a track of sediment staining during dry weather.
- For an active sedimentation event, attempt to filter incoming runoff if conditions allow (e.g., enough space upstream of the practice for temporary ponding). Consider installing a silt fence, silt socks (at curb inlets), staked straw bales, or other filtering material at the inlets of the SMP. This will keep at least some of the sediment from getting into the practice.
- Runoff from active construction should not enter the SMP; divert to a temporary and approved sediment control practice.
- For areas of bare soil *not* due to active construction **(bottom photo)**, prep the soil and re-seed/plant with grass species or other thick ground cover appropriate for the region. May also need starter fertilizer, topsoil, and/or compost.
- For steep slopes with bare soil, consider also installing erosion-control matting to hold soil, seed, and straw in place until the vegetation becomes well established.
- For fill and topsoil stockpiles in the drainage area, provide temporary or permanent cover as soon as possible. Alternatively, surround the base of the stockpile with silt fence, or equivalent, to prevent the transport of sediment-laden runoff.

Helpful Skills:

- Erosion and sediment control knowledge and skills
- Landscaping knowledge to understand appropriate ground cover species for re-vegetating bare areas

Equipment Typically Used for Fixing Sediment Sources:

- Silt fencing and other sediment barriers
- Erosion-control matting and/or straw
- Rakes and shovels
- Light excavation or grading equipment for larger jobs
- Equipment to deliver topsoil or compost as needed
- Plants and/or seed mix, plus a way to move and store plant stock without damaging it or drying it out
- Starter fertilizer, topsoil, and/or compost

Problem #2: Other pollution sources in the drainage area

General Approach for All Practices:

- Pollutants may include: road salt, oils, fuels, food grease, wash water, paints and solvents, trash, and many others.
- Identify the source(s) of pollution.
- For pollutants spilled on the ground, remove by hand or use absorbents to soak up wet material. Absorbents and other waste materials shall be disposed of properly.
- For materials stored outside, move them to a covered area or build/add cover over the materials. Provide secondary containment, if possible.
- Make sure all waste containers have lids and fix any leaks (**see improper practice in photo at right**).
- For sites prone to frequent oil leaks and staining (e.g., vehicle maintenance yards), consider installing an oil/water separator to pre-treat runoff that enters the SMP.
- For routine dumping of wash water, grease, paints, or other pollutants, enforce behavior change and explain good housekeeping practices.
- Develop a pollution prevention plan for the site to ensure that hazardous materials and other potential pollutants are not stored where they are exposed to rainfall.
- For areas that receive a heavy salt and/or sand load during the winter, consider diverting upslope runoff, especially for practices such as porous pavement. Some monitoring of winter road or parking lot clearing activities may also be warranted.

Helpful Skills:

- Knowledge of good housekeeping and pollution prevention practices
- Good communication with employees and managers at site (e.g., for correcting bad site operations)

Equipment Typically Used for Correcting Other Pollutant Sources:

- Tarps to cover stockpiles
- Absorbents to soak up spills
- Secondary containment barriers that will hold back any liquids or solids that may leak out of their primary container
- Storage barns, sheds, pole barns and other permanent cover for potential pollutants

12.3.2 Physical Obstructions

Applies Most Commonly To: Sheet Flow/Disconnection, Swales, Bioretention, Rainwater Harvesting, Green Roofs, Ponds/Wetlands, Infiltration, and Sand Filters

Problem #1: Maintenance access is obstructed

Ground-Level SMPs:

- Where a path for vehicles and construction equipment to access the practice was established during construction but is now overgrown, remove woody vegetation and any other tall vegetation. This path should be bush hogged once or twice a year.
- If the SMP needs a large quantity of trash and/or sediment removed in areas where access is limited due to steep grades, overgrown vegetation, etc., it will be necessary to establish safe vehicular access by clearing and possibly re-grading the area. It is advisable to have a maintained, all-weather surface to critical parts of the SMP.
- It is most important to provide access nearest to parts of the practice where sediment and trash tend to accumulate the most: forebay and outlet control structure.
- For an SMP blocked by fences **(photo at right)**, install a gate that is wide enough for vehicles to enter for any current or future maintenance.
- Sometimes access is blocked by unauthorized structures, such as sheds, property fences, retaining walls, etc. Confer with the local stormwater authority on the presence of any maintenance easements and means to gain access to the practice.
- The solutions above should also provide for safe foot access for routine inspection and maintenance.

Rainwater Harvesting:

- Ensure that no structures are covering the filter or the tank's access/inspection port.

Green Roofs

- Ensure that individuals can safely reach the roof with tools in hand (e.g., buckets, pruners, hoses). If the roof cannot be accessed via a walk-through door, this may require installing a wide ladder or fire escape-style stairs on the inside or outside of the building.
- If there is a concern of getting too close to the roof's edge while doing maintenance, install a railing around the edge for safety. Alternatively, for sloped roofs, workers may need to use harnesses during maintenance activities.

Helpful Skills:

- Use of motorized landscaping equipment
- Chainsaw skills
- Use of grading equipment for larger jobs
- *Note*: OSHA safety requirements and certifications may apply to green roof maintenance.

Equipment Typically Used to Regain Proper Access:

- Mower, trimmer
- For very overgrown areas, chainsaw and/or bush hog
- For areas that need to be regraded, excavator, skid steer, or other grading equipment

Problem #2: Flow is obstructed in or out of the practice

General Approach for All Practices:

- Flow can bypass an SMP when there is too much sediment/debris buildup near the inlets or due to grading changes in the drainage area (e.g., repaving of parking lot). If the cause of blockage or bypass is not obvious, inspect the practice during rainfall to watch the flow paths. (See **Section 12.3.5** for additional guidance.)

- Obstruction of overflow or emergency spillway structures is most often due to buildup of debris, such as trees, sticks, trash. It is *very* important to keep these structures clear of such blockages in order to avoid flooding or a dam breach (**avoid conditions caused by beaver activity - top photo**).

- Where debris cannot easily be cleared by hand, special equipment and skills may be needed. An obstructed outlet control structure in a wet pond may need to be accessed by boat **(bottom photo)**. In cases where large sticks, tree branches, trash, or other debris obstruct the overflow or spillway, they may need to be cut up by chainsaw. Large debris will usually need to be hauled away with a truck.

Helpful Skills:

- Chainsaw skills
- Muscle strength to haul large debris
- Boating capabilities

Equipment Typically Used to Clear Obstructions:

- Gloves, shovels, pruners, rakes, and other hand tools
- Waders for wetlands
- Chainsaw for large sticks and branches
- Cable puller (come-along) to remove large branches that cannot be pulled out by hand
- Boat and personal floatation device for outlet control structures in wet ponds
- Truck to haul away debris

12.3.3 Erosion

Applies Most Commonly To: Sheet Flow/Disconnection, Swales, Bioretention, and Ponds/Wetlands

Problem: Erosion on practice surface, inlets, and/or outlets

General Approach for All Practices:

- See **Section 12.3.9** for how to repair erosion on side-slope embankments.
- Rill and gully erosion occur when runoff flow is concentrated. Deep rills and gully erosion on the practice surface **(top photo)** will require the surface to be regraded to make uniform again. Use the lightest equipment possible in order to minimize soil compaction during excavation.
- After excavation, reseed/plant the area with ground cover that is appropriate for the moisture conditions of the practice. Amend or enhance soil as needed according to a soil test; soil may need more organic material to support plants.
- To prevent further erosion on the surface of the practice, ensure that flow from the inlets can spread out adequately and has enhanced energy dissipation features. This may require installing or enhancing a stone apron outlet protection that flares out and down to the level of the practice to slow and spread out the flow. Other options include check dams, energy dissipation devices, or an armored low-flow channel. A stilling basin **(bottom photo)** can also dissipate flow as it comes out of an inlet or outlet pipe. Apply similar treatments to any outlets that are experiencing erosion.
- Any sloped soils that are disturbed during excavation will likely need erosion-control matting to hold it in place while vegetation becomes established.

Helpful Skills:

- Landscaping/Gardening
- Consult with Cooperative Extension Office or independent laboratory for soil testing
- Skills with excavation equipment
- Knowledge of sediment and erosion control practices and resources appropriate for the area

Equipment Typically Used for Fixing Erosion:

- Rakes, shovels, wheelbarrows, and other “landscaping” equipment
- Light excavation or grading equipment for larger jobs
- Equipment to deliver, unload, and move stone and other materials around
- Plants and/or seed mix, plus a way to move and store plant stock without damaging it or drying it out

12.3.4 Departure from Design Dimensions

Applies Most Commonly To: Swales, Bioretention, Ponds/Wetlands, Infiltration, and Sand Filters

Problem: Practice dimensions have been altered

General Approach for All Practices:

- Once constructed, the dimensions of an SMP may become altered from the original design for a variety of reasons. These reasons can include:
- The SMP was not constructed to the proper dimensions at initial installation.
- Sediment accumulation in the SMP reduces the intended storage volume of the practice **(top photo).**
- Redevelopment or regrading of the site encroaches into the footprint of the SMP.
- Dumping of leaves, trash, or other debris into the SMP reduces the intended storage volume of the practice.
- If it appears that the dimensions of an SMP have been altered, proceed as follows:
- Consult the original design or as-built plans and sizing computations for the SMP to identify the intended dimensions and storage volume of the practice. Measure the length, width, and depth of the practice to estimate the current storage volume. Calculate the difference in volume to determine whether it is significant enough to warrant restoring the practice to its original dimensions. If the loss in volume is greater than about 10%, this likely warrants action.
- If the SMP's original storage volume cannot practically be restored because of current site conditions, an additional SMP may need to be built elsewhere on the site in order to regain adequate storage and treatment volume for the site.
- For problems of dumping by individuals on or near the site, install "No Dumping" or similar signage to inform people that this is not an appropriate place to dispose of debris. Any debris that has already been dumped should be removed from the practice either by hand or with equipment.

Helpful Skills:

- Basic surveying
- Understanding stormwater design plans and sizing computations
- Stormwater management design
- Skills with excavation equipment and erosion and sediment control

Equipment Typically Used to Investigate and Fix Dimensions:

- Simple level or survey equipment, tape measure, and other tools to measure SMP dimensions
- Light excavation or grading equipment for larger jobs
- Rakes, shovels, wheelbarrows, and other "landscaping" equipment for small jobs
- Soil stabilization materials

12.3.5 Improper Flow Paths

Applies Most Commonly To: Sheet Flow/Disconnection, Swales, Bioretention, Rainwater Harvesting, Infiltration, and Sand Filters

Problem #1: Flow intended to go into a practice is diverted by debris or grit buildup or capacity issues at inlets

Bioretention, Swales, Infiltration, Sand Filters:

- Grit, sediment, leaves, and other debris builds up at curb inlets or other inlets, sometimes to the point where flow is diverted completely around the practice (photos above). This is a common issue for practices that rely on curb cuts or other small inlet structures to get water into the practice for treatment. A minor amount of debris may be OK and not affect the ability of water to enter the practice. However, be aware of conditions where flow *that is supposed to be treated* is diverted to a downgradient storm drain or other structures in such a way that the stormwater treatment is entirely or partially bypassed.

- In many cases, correcting the problem may simply involve removing debris or unclogging the inlet.
- However, this problem can be chronic if the inlet design is susceptible to clogging. This can occur if the slope from the inlet into the practice is flat and/or there are controllable sources of sediment and debris in the drainage area.
- For chronic problems, consider redesigning inlets to be more clog proof. One solution is to build in a 2 to 3" drop from the curb inlet onto a gravel or stone diaphragm along the edge of the practice (see example in photo are right).
- Inlets that are undersized for the flow coming to them should be enlarged and armored with an appropriate erosion-resistant lining.

Rainwater Harvesting:

- Water intended to be collected in rainwater harvesting systems is sometimes not delivered to the tank or cistern if the system of gutters, downspouts, pipes, etc. is not sized properly or if the first-flush diverter or vortex filter is not functioning correctly and diverting too much water away from the tank.
- As with inlets, this may simply be a matter of routine cleaning of gutters, downspouts, vortex filters, etc.
- It may also be a design or capacity issue, in which case, installing larger gutters or a more robust piping system may be in order.

Source: Rainwater Management Solutions 1
Example of enhancing the gutter and piping system leading to a rainwater harvesting system

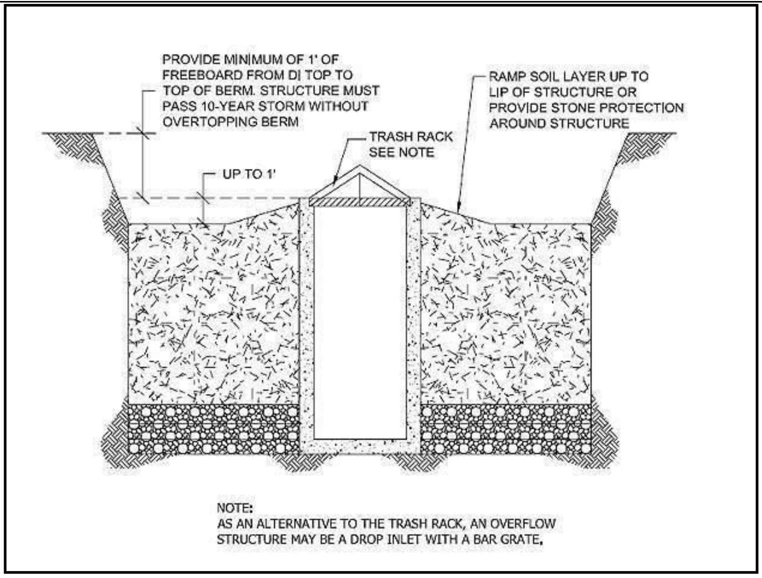
Helpful Skills:

- Basic surveying
- Typical landscaping skills using materials such as soil, rock/stone, edging material, mulch, etc.
- Light construction of gutters, downspouts, piping
- Some knowledge of first-flush diverter and vortex filter products

Problem #2: Flow is not uniformly accessing the entire treatment area

Bioretention, Swales, Infiltration, Sheet Flow and Disconnection, Sand Filters:

Improper flow path issues in this category include:	**These three issues are illustrated below:**
• Water forming channels or rills through the treatment bed of bioretention, swales, infiltration, or surface sand filters, and thus not spreading out across the treatment area surface • Water ponding only at one end of the treatment area because the surface is not level • Water piping through weak spots to an outlet or underdrain, such as where filter media meets a concrete structure • See **Section 12.3.3** for issues of channeling or erosion on the treatment surface. • For uneven treatment area and preferential ponding, assess the severity of the problem. Compare the relative elevations of the "high" part of the treatment area (the area where water does not seem to pond) and any overflow structure or weir where high water flows will leave the practice. If there is still some freeboard (such that the overflow structure is higher than all of the treatment bed surface), then there will still be some ponding for larger rainfall events. Try some minor raking or moving filter media and mulch around to even out the filter bed. • However, the problem is more serious if parts of the treatment area are higher than the overflow structure. These areas will never be valuable for treatment purposes. The treatment area is supposed to fill up like a bathtub, so some regrading is needed to level out the treatment area. • If water is piping or short-circuiting through the soil or filter media, forming sinkholes, or otherwise bypassing the intended treatment mechanism, it will be necessary to repair these spots. Around concrete or metal overflow structures, use soil material right around the structure that can be compacted (bioretention filter media tends to be light, sandy, and fluffy and won't compact very well). Another option is to "ramp up" the soil layer to the lip of the structure so that there won't be a hydraulic jump at this potentially weak point. See the figure below.	 *Water from the inlet at top of photo is channeling through the bioretention area.*  *Water is preferentially ponding only at one end of the bioretention because the surface is not flat.*  *Water is "piping" down to the underdrain at the weak spot where the filter media meets the concrete overflow structure.*

	Ramp up soil layer to the lip of the structure to address this being a weak interface where water can work down and create bypassing. (Source: Virginia 2013 Stormwater BMP Specifications, Specification #9, Bioretention, Figure 9.13.)

Impervious Disconnection:

The most likely flow path issues with Impervious Disconnection are: (1) owners intentionally diverting downspouts away from pervious area and onto impervious area **(left photo below),** and (2) slight grading issues diverting the water away from the intended pervious receiving area **(right photo below).**


Both issues are fairly straightforward to address but involve communicating and working with property owners to explain the purpose of disconnection and how to properly maintain it. The second issue may involve some minor regrading or building low-profile berms to get water to flow to the intended disconnection area.

Helpful Skills:

- Rudimentary surveying
- Typical landscaping skills—using materials such as soil, rock/stone, edging material, mulch, etc.

Equipment Typically Used for Inspecting and Fixing Flow Paths

- Surveying equipment (i.e. Site level or total station) to get relative elevations among different parts of treatment area, inlets, overflow structures, etc.
- Small, simple tools—flat shovels, wheelbarrows, rakes, other common landscape/gardening tools
- Large, more complicated equipment—small excavators to move material around or do regrading. Always work from the side of the practice and NOT within the practice itself.

12.3.6 Sediment Buildup

Applies Most Commonly To: Swales, Bioretention, Porous Pavement, Ponds/Wetlands, Infiltration, and Sand Filters

Problem: Sediment accumulation more than 2" thick covering 25% or more of the practice surface area

Bioretention, Swales:

- Determine the source(s) of sediment. The most likely sources are: (1) premature installation of the practice during the construction process and discharge of construction site sediment loads; (2) erosion in the contributing drainage area *after* construction is complete; and (3) erosion along the practice side slope or within the practice itself. If it is an ongoing source, it must be abated (see **Section 12.3.1**, and **Section 12.3.3).**
- Use a soil auger to auger holes in various places across the Bioretention or Swale surface area, especially in areas where sediment is accumulating. Determine how deep the sediment is penetrating into the filter media layer. Usually, it will be the top 2 to 3" that are most affected. Note that for swales *without* an engineered filter media, the sediment layer will likely be confined to the surface.
- Remove the "fouled" filter media to the affected depth (using flat shovels or small excavators and working from the side) and replace with clean material from an approved vendor (bioretention filter media or equivalent). If no vendors are available in your area, use the filter media specifications from the Design Manual to replicate the right mix of sand, topsoil, and composted organic material.
- Check to ensure that the practice is filtering at the proper rate after the next several storm events.

Infiltration:

- For infiltration practices excavated to a suitable infiltrating soil layer (e.g., not stone reservoir layer), use the same procedures as for Bioretention/Swales above.
- For infiltration trenches and basins that have a stone reservoir layer, use similar procedures, but use a shovel to dig into the stone layer to ascertain how deep the sediment incursion is into the stone. Remove down to this layer and replace with clean material.
- If the infiltration practice is clogged, see **Section 12.3.7.**
- As with Bioretention, check for controllable sources of sediment in the Drainage Area (**Section 12.3.1**).

Porous Pavement:

- NOTE: Routine sweeping with a regenerative air vacuum (max. power 2,500 rpm) is important to avoid more costly repairs that result from deferred maintenance. It is best to sweep the pavement surface in early spring after winter sanding/salting materials or snow piles have led to sediment or winter slag accumulation. If the area is surrounded by tree canopy, fall cleanup is essential, as vegetative debris is broken up by vehicle traffic and ground into the pavement surface.
- Observe the pavement surface during a storm event to see whether the sediment is clogging the pavement (i.e., standing water on the surface after the storm stops). If so, see **Section 12.3.7.**
- Remove several of the paver blocks in different parts of the structure to ascertain how deep the sediment is penetrating into the bedding and reservoir layers. Most of the time, sediment incursion will be limited to the top 1 or 2" of the pavement bedding layer (for porous interlocking concrete pavers and concrete grid pavers).
- Based on the above observations, it may be worthwhile to quantify the infiltration rate using ASTM C-1701/1701M. This is most useful in conducting the test in the *same place within the pavement surface through the course of several years* to document reduction in infiltration rates. Repair or restorative sweeping is warranted when infiltration rates drop below around 10" per hour. NOTE: As stated above, this can likely be avoided if routine annual sweeping is conducted.
- If sediment covers more than 25% of the surface, is deeper than 2", or vegetation is starting to grow where sediment has accumulated, consult a street-sweeping vendor about *restorative* sweeping. In this case, it will be necessary to use a higher RPM sweeper or vacuum sweeper to suck out more of the bedding pea gravel that has been fouled, then replace with clean material.
- Vegetation growing in pavement joints should be removed either manually or with a water-safe herbicide (e.g., glysophate without surfactants). It is important to not let weeds proliferate in the pavement surface because pulling them out by the roots may damage the pavement structure. (Note: The application of herbicides within wetlands or other waters of the U.S. may require an Aquatic Pesticide Permit from the NYSDEC)

Infiltration test using ASTM C-1701

Pulling grass and weeds from the joints can damage parking surface if roots are firmly established in the bedding layer.

- Check the pavement surface after a storm event to ensure that it is draining properly.

The North Carolina State University (NCSU) Stormwater Engineering Group has an informative Urban Waterways publication, *Maintaining Permeable Pavements (2011).*

Routine, air-vacuum sweeping in the early spring and fall is the best approach for porous pavement maintenance (Photo source: Toronto and Region Conservation)

Ponds and Wetlands:

- Sedimentation is an inevitable process in ponds and wetlands. NOTE that upstream erosion, especially along stream channels or ditches leading to the practice will accelerate the sedimentation process and lead to more frequent and costly sediment removal operations. Whenever possible, it is important to mitigate any upstream erosion issues.
- Forebays and/or pre-treatment areas should be cleaned out when they reach 50% of their design capacity. Once cleanout is complete, it will be worthwhile to install a graduated rod into the forebay with a clear marking of future sediment clean-out levels.
- The main body of a pond or wetland may need to be dredged on an infrequent basis or when sediment has replaced 50% of the design capacity. There are many dredging methods available. Excavators with long arms can handle most small or moderate-sized ponds. Other methods may be necessary for larger facilities. Dredging can be a complicated operation involving dewatering, storage of wet sediment, and possibly hauling to on-site or off-site disposal or reuse areas. Consult a qualified contractor to explore available methods and costs for the particular application. Once again, installation of a graduated rod can help mark future clean-out levels. Note: The dredging of accumulated sediment within regulated wetlands, ponds or at outlet structure may require permits from NYS DEC and/or USACE. In addition, removed sediment should be properly disposed of in a regulated solid waste management facility or in an upland area that is at least 100 ft from regulated wetlands or streams. Sediment managed in upland disposal areas shall be graded, seeded, and mulched.

Sand Filters:

- See the section above on Bioretention/Swales as some of the procedures will be similar, especially for above-ground filters. It is important to determine whether the drainage area is generating a controllable source of sediment that can be abated.
- Underground trench or vault filters will require routine maintenance to: (1) remove accumulated sediment, trash, and floatables from the sedimentation chamber, usually with a vac truck; and (2) remove sediment, grit, and sludge from the top layer of the filter media and replace with clean material. NOTE: Depending on the configuration of the underground filter, confined-space procedures may apply. For a normally operating practice, these maintenance tasks should be conducted every two to three years. If the filter is treating a stormwater hotspot or a particularly dirty drainage area (e.g., vehicle maintenance, washing, repair), the frequency may increase to annually or more often, as dictated by Level 2 inspections. Also, in these cases, it may be warranted to test the material to ensure proper disposal.
- Some proprietary filters require replacement of special cartridges or filter material. Consult the vendor or manufacturer for special maintenance procedures.

Routine cleaning of a perimeter or "Delaware" sand filter. This can be done from the surface, but deeper, vault-type filters will require confined-space entry procedures.

Helpful Skills:

- Most common contracting skills
- Excavation, dewatering, and sediment disposal in some cases
- Knowledge of maintenance equipment, such as vac trucks, street sweepers, etc.
- Knowledge of preferred conditions for bioretention filter media
- Soil testing in some cases where sediment is being removed from stormwater hotspots

Equipment Typically Used for Sediment Removal Activities:

- Small, simple tools—flat shovels, wheelbarrows, rakes, other common tools
- Larger jobs—small or large excavators, loaders, dewatering equipment (pumps, dirt bags, etc.), trucks to haul material to on-site or off-site disposal or reuse areas, erosion and sediment-control supplies.

12.3.7 Clogging

Applies Most Commonly To: Bioretention, Porous Pavement, Infiltration, and Sand Filters

Problem: Filter media clogged; water standing on practice surface for 48 to 72 hours or longer after a storm

Bioretention:

Standing water on the bioretention surface 48 to 72 hours after a storm event is a sure indication of clogging (top photo). Clogging of bioretention practices can be tricky to diagnose as there are several probable causes:

a. Clogged underdrain
b. Filter fabric between filter media and underdrain stone
c. Sediment/grit buildup at surface
d. Erosion of contributing drainage area
e. Improper filter media

The following procedure can be used to work through diagnosing the most common causes, beginning with the simplest and easiest to fix and progressing through more complex remedies:

1. Look for a thin, crusty layer of sediment that covers some or all of the filter media. It is often grayish in color. This thin layer can sometimes be enough to cause slow drainage. Scrape this crust off and ascertain sources of sediment in the drainage area (see **Section 12.3.1**). Often, this problem can be caused by the bioretention filter media being installed too early in the construction process, but other chronic sediment sources should also be checked.
2. Open the underdrain cleanout and pour water in to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see whether there is standing water all the way down through the soil. If there is standing water on the surface, *but not in the underdrain*, then there is clogging somewhere in the soil layer. If the underdrain and cleanout have standing water and there is not water coming out the other end (outlet) of the underdrain pipe, then the underdrain is clogged and will need to be rooted out.
3. Use a soil auger to auger several holes down through the filter media to the underdrain layer (if present) or underlying soil. Check to see whether there is a layer of filter fabric at the bottom of the soil layer. The auger will pierce through any filter fabric that is present, and pieces of fabric in the auger bucket should be removed. Notice if the fabric is "blinded" or clogged with sediment. This is a common issue with older bioretention practices. If the practice has a clogged the filter fabric layer, go to step #6, install wick drain.
4. While checking for filter fabric in auger holes, also note whether there is a layer of saturated filter media or bad filter media (e.g., too much clay content) that may be on top of a good media layer. This will be fairly obvious as the top 3 or 4" will be mucky and saturated, with dry and sandy media below. If this is the case, it will be necessary to remove the bad material and replace with good, clean bioretention filter media in accordance with the design specifications. Till or incorporate the good material into the underlying existing filter media to establish a good contact.
5. If the entire profile of filter media is bad, has too much clay content, or does not appear to meet the specifications for filter media, it will be worthwhile to test the soil and compare against the recommended specifications (e.g., clay content, particle sizes, etc.). If the soil does not meet specifications, see steps #6 and #9 below.

6. If the problem appears to be filter fabric or bad filter media (steps #3 or #5 above), there is a critical decision to be made. It is an expensive proposition to dig up the entire facility to either remove the filter fabric or replace the entire soil layer. If the clogging problem is not severe in nature, an intermediate (and much cheaper) option may be to install wick drains. Using a 6" auger bucket, auger numerous vertical holes around the practice surface area, making sure to auger all the way down to the underdrain stone or underlying soil (if there is no underdrain). Hammer 6" perforated PVC or other type of pipe into these holes. Perforations should be about 3/8" diameter. Fill the pipes with clean underdrain gravel (#57 stone) mixed in with coarse construction sand. These drains will serve to wick fines from the surrounding filter media and will provide alternative drainage. Check after the next several storm events to see whether the wick drains improve drainage.
7. Sometimes the cause of saturated filter media is springs or some type of baseflow coming into the practice. This is a more difficult problem as bioretention is not supposed to receive this type of constant flow. It will be necessary to identify and reroute springs or baseflow or perhaps replace the bioretention practice with a different type of practice.
8. Another possible source of poor drainage or clogging is that there can be too much water on top of the filter media when the bioretention practice fills up. Most specifications call for a maximum ponding depth of 12", but sometimes the ponding depth can be 18 or even 24". While this increases the amount of head pushing water down through the filter media, it can also lead to compaction or too much sediment building up. If the bioretention practice has a ponding depth greater than 12", consider configuring the outlet or large storm overflow to reduce the ponding depth to 12" or less. Check with the local stormwater authority to ensure that doing this will not compromise the required treatment volume of the practice.

Adding sand to a wick drain. The vertical perforated PVC pipe has already been placed in the auger hole.

9. If clogging is too severe to be fixed with wick drains or other remedies listed above, it may be necessary to rebuild the bioretention practice by digging up the existing soil, taking out any filter fabric that is between the filter media and underdrain stone, and rebuilding and replanting according to the design specifications.
10. Whatever the chosen remedy, check to ensure that the practice is filtering at the proper rate after the next several storm events.

The Chesapeake Stormwater Network (CSN) has produced an excellent reference guide for inspecting and diagnosing Bioretention issues, *Technical Bulletin #10, Bioretention Illustrated.* This tool can be used as an additional reference and can be downloaded using this link: http://chesapeakestormwater.net/category/publications/

Infiltration:

- Clogging of infiltration practices can be simple to resolve or fatal:
- On the *simple* side, clogging (or poor drainage) may arise from sediment, vegetative debris, parking lot grit, or other debris clogging the top few inches of soil or stone.
- With luck, the practice will have an observation well (vertical perforated PVC pipe with cap that extends through the stone reservoir in an infiltration trench or basin). Check the observation well three days after a storm event of ½" or more. If water is standing in the observation well to the surface, then the whole profile may be clogged (see below under *fatal*). If the observation well has only a few inches or no water and there is still water standing on the surface, then surface clogging is a likely culprit.
- For infiltration practices in soil (no stone reservoir), auger several holes around the infiltration surface area. If saturated soil seems to be on top of good, clean, dry soil, then surface clogging seems likely.
- For infiltration trenches and basins with a gravel reservoir, dig several holes around the surface to determine, again, whether there seems to be a layer of gravel clogged with sediment, leaves, vegetative debris, parking lot grit, etc. If possible, dig down to where the gravel meets the underlying soil to see whether a layer of filter fabric is present (which may be common with older practices). If this is the case, blinding of the filter fabric may be a cause of the clogging.
- For surface clogging, remove the affected material down to the level where the soil or gravel seems clean, and replace with clean material. If filter fabric seems to be a problem, it will be necessary to dig up the gravel, remove the filter fabric, and rebuild the reservoir layer in accordance with the current design specifications. In either case, check after a storm event to ensure that this has resolved the issue.
- On the *fatal* side, the underlying soil may not be suitable for infiltration, either due to soil characteristics, compaction during construction, or other causes. Check the original design package to see whether any soil testing was done at the time. It may be worthwhile to auger down to the infiltration interface layer (e.g., where stone reservoir meets the underlying soil and then another several inches below this interface), and take several soil samples for lab analysis to compare to current soil specifications (see information below about infiltration soil analysis).

- It may be that a geotechnical analysis would reveal that there is a good infiltration soil layer, but it is lower than the existing interface. This would still require a complete rebuild and excavation down to the suitable soil layer. Restoring porosity at the designed elevation would require replacing soil above this suitable layer and avoiding compaction.
- Another option would be to convert the practice to a bioretention practice with an underdrain. Check with the local stormwater authority to see whether this would require any site plan or stormwater plan amendments or other permits.
- Many updated state stormwater manuals and specifications include protocols for infiltration soil testing and analysis that reference various ASTM standards. For example, see: *Virginia 2013 BMP Standards & Specifications, Specification #8: Infiltration, Appendix 8-A, Infiltration and Soil Testing*.

Porous Pavement:

- As noted in **Section 12.3.6,** routine sweeping with a regenerative air vacuum (maximum power 2,500 rpm) is important to avoid more costly repairs that result from deferred maintenance. Preventative maintenance is the best and most cost-effective way to prevent clogging in the first place.
- If there is standing water on the pavement surface 48 to 72 hours after a storm event of ½" or more, then the pavement surface is clogged.
- Check the design plan or as-built plan to see whether the porous pavement design includes an underdrain. There may also be underdrain cleanouts at the edge of the porous pavement.
- If there is an underdrain, the first thing to check is whether the underdrain is clogged, crushed, or broken. Check to see whether there is standing water in the underdrain cleanout 48 to 72 hours after a storm event. If the underdrain is dry, pour water into the underdrain with a hose and see whether it comes out the other end. If the underdrain is clogged, snake it out, as this is the first and easiest thing to try.
- If the underdrain is working, then clogging may be due to: (1) clogged surface or bedding layer; or (2) underlying soil is not suitable for infiltration for designs with no underdrain. First, refer to the guidance in **Section 12.3.6,** and then proceed as follows:
- If there is no underdrain and the design is based on soil infiltration under the pavement, it will be worthwhile to check the soil because unclogging the surface layer will likely not fix the problem. Check the original design package for any soil infiltration testing. It is likely worthwhile to remove the entire pavement section in several places down to the soil layer and to do a geotechnical investigation of the soil profile. See: ASTM C-1701/1701M and/or *Virginia 2013 BMP Standards & Specifications, Specification #8: Infiltration, Appendix 8-A, Infiltration and Soil Testing* for examples of soil infiltration protocols (URL above).
- If the soil is not suitable for an infiltration design, it will probably be necessary to rebuild the pavement using an underdrain design or possibly adding subsurface drainage along the perimeter of the parking area.
- If there is an underdrain or the soil is suitable for infiltration, the best approach to try to unclog the pavement is restorative sweeping with a vacuum sweeper. Regenerative air sweepers may not have enough suction to relieve the clogging.
- If vacuum sweeping is not successful, it may be necessary to rebuild any layers fouled with sediment and fines. It is likely that this will be confined to the bedding layer and gravel used in the paver stone joints, but some clogging can possibly move down into the underlying stone reservoir layer.
- The North Carolina State University (NCSU) Stormwater Engineering Group has an informative Urban Waterways publication, *Maintaining Permeable Pavements (2011).*

Water standing on the parking surface 48 to 72 hours after a storm is an indication of clogging. Snow piles at the edge of the photo point to possible clogging from winter sanding or plowing.

Sand Filters:

Standing water on the parking lot is evidence that this perimeter sand filter (under the sidewalk) is clogged.

- See the section above on Bioretention/Swales as some of the procedures will be similar, especially for above-ground filters.
- Also see **Section 12.3.6** for guidance on routine maintenance of the sedimentation and filter chambers.
- As with Bioretention, there can be various causes for clogged filters:
- Filter fabric layer under the filter media that has blinded or clogged
- Clogging of the surface of the filter layer or filter cartridges
- Bad filter media (e.g., sand media)
- "Plumbing" issues with configuration of overflow and underdrain pipes
- Fortunately, filters are usually confined within concrete vaults or manholes, so diagnosing and rectifying clogging problems should be more straightforward. Check the original design or as-built plans. Some of the following guidance may also be helpful:
- For proprietary cartridge or special filter media structures, consult the vendor or manufacturer for recommended solutions.
- See **Section 12.3.6** for guidance on removing the top layer of filter media and replacing with clean material, as well as vacuuming out any sedimentation chambers.
- If it is suspected that overflow or outlet pipes are not configured correctly, check against the design plans and also standard drawings from the manufacturer.
- Chronic clogging problems are likely due to excessively dirty drainage areas, including uncontrolled sources of sediment, oil and grease wash off, vegetative debris from surrounding trees or shrubs, or other sources. It will be important to check and resolve any controllable sources of clogging in the drainage area (see **Section 12.3.1**).

Helpful Skills:

- Soil infiltration analysis techniques as per ASTM and/or current BMP design specifications
- Excavation, dewatering, and sediment disposal in some cases
- Knowledge of maintenance equipment, such as vac trucks, street sweepers, etc.
- Knowledge of preferred conditions for bioretention, sand filter media, or standard porous pavement types and bedding layers
- General practice of trying easier or less expensive strategies before jumping right to wholesale reconstruction of a practice

Equipment Typically Used for Unclogging Activities:

- Soil infiltration testing or geotechnical equipment
- Small or large excavators, loaders, dewatering equipment (pumps, dirt bags, etc.), trucks to haul material to on-site or off-site disposal or reuse areas, erosion and sediment control supplies
- Pavement demolition and repair equipment
- Mulch, plants, filter media, and other materials needed to rebuild practices

12.3.8 Vegetation

Applies Most Commonly To: Tree Planting, Swales, Bioretention, Green Roofs, and Ponds/Wetlands

Problem #1: Not enough vegetation; vegetation *is unhealthy*

Tree Planting, Swales, Bioretention:

- Test soil/media to ensure proper conditions exist for plant survival.
- Check water drawdown after a storm to make sure that wet/saturated conditions are not the cause of plant failure. If this IS an issue, see **Section 12.3.7.**
- Amend or enhance soil as needed; soil may need more organic material to support plants, but do not use uncomposted organic material or animal waste, as it will likely export undesirable nutrients to the stormwater system.
- If plants have continued to die, consider a different species or entire planting palette or revised planting plan **(photo to right shows the need for a whole new planting plan)**. Also consider using an appropriate bioretention or swale native seed mix to supplement use of plugs or other nursery stock.
- Consult a horticulturalist or plant nursery if there is evidence of disease or pests.
- Replant and add mulch or ground cover as needed.

Ponds and Wetlands:

- See **Section 12.3.12** for general guidance on pond and wetland vegetation maintenance, as well as the following.
- For emergent vegetation, determine whether water depths are too deep or shallow for survival (i.e., depths are different from design depths, or original design included improper vegetation).
- If a small amount of supplemental vegetation is needed, plant wetland plugs per nursery guidance.
- For large-scale plantings, drain the permanent pool and plant during the early spring.

Green Roof:

- Consult with a green roof plant vendor about possible causes of plant failure. Lack of watering during initial establishment could be the main culprit.
- Work with a qualified vendor to develop and install a new planting plan.
- Speak with building facilities maintenance personnel to ensure they understand need for watering and caring for new plants after they are installed.

Helpful Skills:

- Landscaping/gardening
- Consult with Cooperative Extension Office or independent laboratory for soil testing
- If original planting plan is deemed inadequate, consult a landscape architect or horticulturalist to determine whether a revised planting plan is needed.
- Knowledge of native plant and/or wetland plant nurseries in general region

Problem #2: Too much vegetation, overgrown (with invasive species), not maintained

General Approach for All Practices:

- Determine which invasive plants are present. For a list of regulated and prohibited invasive plants in New York State, see *New York State Prohibited and Regulated Plants* (NYS DEC, NYS Agriculture and Markets, 2014) at: http://www.dec.ny.gov/docs/lands_forests_pdf/isprohibitedplants2.pdf . Invasive plants shall be properly disposed of in a manner that renders them non-living and non-viable to prevent the establishment, introduction or spread of disposed species.
- Review whether the original planting plan relied on these plants; for example, some wetland plans may rely on "aggressive colonizers" such as cat tails.
- For more detailed information regarding appropriate control measures for each species, consult the Cornell Cooperative Extension Invasive Species Program at the following link: http://ccetompkins.org/environment/invasive-nuisance-species/invasive-plants. If invasive species have taken over the facility, wholesale removal and replanting with desirable species may be necessary.
- If (non-invasive) plants are overgrown, (**example in photo to right**), remove, thin, or trim back excessive vegetation.
- If an entire new planting plan is deemed necessary, use SMP-Specific Guidance in the remainder of this manual, along with landscaping goals for the site location, to devise a plan that allows for adequate growth over a long period of time. A simple, clear planting design (**example in photo below**) with a long-term plan has the best chance of being maintained through time. Maintenance crews need to know which plants are part of the design versus weeds and how the practice should look from year to year.
- Develop a plan to ensure proper weeding, pruning, trimming, and replanting to maintain the plan over time.
- See **Section 12.3.12** for general guidance on pond and wetland vegetation maintenance, as well as the following.

Helpful Skills:

- Knowledge of exotic and invasive species is needed. Consult a local Cooperative Extension Office.
- Specific measures may include mechanical hand pulling, regrading (requires construction equipment), or herbicide/pesticide application *safe for aquatic environments*.
- Landscape architect
- Knowledge of wetland plants (for ponds/wetlands)
- Knowledge of SMP design (to understand hydrologic regime for plant selection)

Equipment Typically Used for Vegetation Maintenance Activities

- Soil auger to diagnose issues of soil drainage that may affect vegetation health
- Rakes, shovels, wheelbarrows, and other "landscaping" equipment
- Light excavation or grading equipment for larger jobs
- Equipment to deliver, unload, and move filter media, mulch, and other materials
- Plants and/or seed mix, plus a way to move and store plant stock without damaging it or drying it out
- Planting bars, soil drills, etc.
- For planting in standing water (e.g., ponds, wetlands), pumps or pump-around systems and dirt bags or other ways to temporarily dewater planting area

12.3.9 Embankment and Overflow Condition

Applies Most Commonly To: Swales, Bioretention, and especially Ponds/Wetlands

Problem #1: Rill and channel erosion and bare dirt areas of embankments

Swales, Bioretention:

- Erosion and areas of bare dirt indicate two basic issues: 1) soils and moisture levels are not suitable for the plants or turf used; and 2) vegetation cannot take hold because of concentrated flow, physical wear, or poor soil conditions. Address these issues first with a soil/media test to ensure proper conditions exist for plant survival.
- High salt content from winter deicing of pavement is a common culprit of poor soil conditions for roadside plants. If this is the case, restore area with plant species that can tolerate salt levels, or replace edge plants with a stone diaphragm to intercept runoff from road.
- Amend or enhance soil as needed; soil may need more organic material to support dense ground cover.
- For concentrated flow and physical wear, redirect concentrated flow so that it disperses in mulched and vegetated areas. Stake in mulch and replant with vigorous plants recommended through the soils test.
- If plants have continued to die, consider a different species or entire planting palette or a revised planting plan (see **Section 12.3.8** and **photo to right)**. Also consider using an appropriate bioretention or swale native seed mix to supplement use of plugs or other nursery stock.
- Consult a horticulturalist or plant nursery if there is evidence of disease or pests.
- Replant and add mulch or ground cover as needed.

Ponds and Wetlands:

- Where erosion has deposited soil within the pond or wetland water line, remove this material and reshape the slope.
- If a small amount of supplemental vegetation is needed, plant wetland plugs per nursery guidance.
- To address rill and channel erosion, first obtain a soil sample test to get soil amendment recommendations. Undercut the eroded sections and replace with clean amended soil, based on the soil test, and reseed as appropriate for the season.
- It may be necessary to stake in seed blankets or erosion-resistant lining (e.g., erosion-control matting or even rock in extreme situations) to stabilize eroded areas. Again, choose seed types appropriate for the season.
- Based on soil test guidance, reseed bare areas to prevent further erosion.
- For persistent problems, reroute the flow to more stable receiving areas using berms, diversions, etc.

Helpful Skills:

- Landscaping/gardening
- Consult with Cooperative Extension Office or independent laboratory for soil testing.
- If original planting plan is deemed inadequate, consult a landscape architect or horticulturalist to determine whether a revised planting plan is needed.
- Knowledge of sediment and erosion control practices and resources appropriate for the area

Problem #2: Settlement, loss of armoring material, erosion of emergency overflow

General Approach for All Practices:

- Settlement, loss of armoring material, erosion and accumulated debris can affect the dimension, water velocity or capacity of the emergency overflow such that embankment failure could occur in flood events (**photos below**).
- Inspect for exposure of soil or geotextile base material in the overflow and re-armor areas of exposure.
- In cases of settlement, a qualified engineer should be sought to assess its capacity and impact on pond capacity.
- Erosion of spillways should be repaired and revegetated as described for embankments.

Helpful Skills:

- Knowledge of sediment and erosion control practices for the area
- Completion of self-guided training on dam safety through Association of State Dam Safety Officials: http://www.damsafety.org

Problem #3: Impounding structure (embankment or dam) integrity issues due to tunneling or digging animals, woody vegetation, or seepage

Ponds/Wetlands:

- Impounding structure stability is a serious concern, especially where trees have become established on the slopes, or there's evidence of animal burrows or seepage.
- The best approach for trees on the crest, slopes, and adjacent to an impounding structure or embankment is to cut them down before they reach significant size. If large trees have been cut down but their root systems not removed, carefully monitor the area around the remaining stumps for signs of seepage.
- Exercise judgement for trees on the surrounding side slopes that are NOT impounding structures (not designed to hold back water in the pool). Sometimes a forested edge can enhance the appeal of a pond, but access for maintenance must also be available, and some trees can drop debris into ponds, leading to quality issues.
- Animal burrows can be dangerous to the structural integrity of the embankment because they weaken it and can create pathways for seepage. Professional exterminators may be needed to trap and remove animal pests.
- Seepage as water flow or boiling sand on the lower portion of the exterior slope or toe area of an impounding structure should be brought to the attention of a qualified engineer.
- Leakage around conveyance structures such as barrel pipes or spillways should be monitored for increase since the last inspection. A qualified engineer is needed to resolve issues of piping or seepage along the barrel pipe through a dam.
- Turbidity or cloudiness in seepage should also be brought to the attention of a qualified engineer.

Helpful Skills:

- Completion of self-guided training on dam safety through the Association of State Dam Safety Officials: http://www.damsafety.org

Equipment Typically Used for Embankment and Overflow Maintenance Activities

- Excavation or grading equipment for larger jobs
- Equipment to deliver, unload, and move filter media, mulch, and other materials
- Plants and/or seed mix, seed blanket and erosion control materials
- Rod and level for settlement measurements
- Clear glass bottle for seepage visual test

12.3.10 Structural Damage

Applies Most Commonly To: Any Practice

Problem: Structural damage to pipes, headwalls, standpipes, inlet/outlet structures, grates, curbs, and other structural components

- Structural components are necessary for water to flow into and out of stormwater practices as intended. This is a broad category that involves components composed of concrete, metal, plastic, and other materials. Some common examples include:
- Deteriorated or broken curbs that allow water to bypass a practice
- Slumping or sinkholes where soil meets a concrete drop inlet or outlet structure
- Broken or collapsed inlets
- Connections in an inlet or manhole structure that are not parged and are leaky
- Collapsed or crushed pipes (especially corrugated metal)
- Missing or broken steps or other safety features in a manhole or outlet control structure
- Root penetration and clogging of underdrain or other pipes
- Broken check dams
- There are too many particular instances to mention here, but the general idea is to inspect and repair any structural components that are affecting the performance of a practice or leading to a potential health or safety issue.

Helpful Skills:

- General contracting skills—concrete work, metal, proper joint sealing
- Routing out clogged pipes
- Perhaps CCTV experience to look for broken or clogged pipes

Equipment Typically Used for Fixing Erosion:

- General contracting
- CCTV

12.3.11 Pool Stability

Applies Most Commonly To: Ponds/Wetlands

Problem: Flooded or dry pond – outlet issues

General Approach for Ponds and Wetlands:

- Note high-water marks on structures or pond banks and compare with outlet structure weir.
- If the outlet weir is submerged, investigate downstream for plugs such as beaver dams, woody debris or sediment bars. Refer to **Section 12.3.2** for removal of obstructions.
- If the pond is retaining more water than it is supposed to and there is no flow from the outlet with no visible blockages in the outlet pipe, look for obstructions above the weir or outlet pipe. Woody debris, vegetation and silt can plug outfall weirs or blind rock outfall protection. Removal of such blockages tends to be a hand exercise. A jet/vacuum truck or other heavy equipment may be needed to clear excessive or precarious blockages (**photo on right**).
- If the pond is too low and not holding water in the designated pool, the outlet structure should be closely inspected to see whether it has settled from the original construction or there is leakage through joints or cracks. Finding no deficiencies with the structure, investigate the pond embankment as described in **Section 12.3.9** for evidence of seepage.
- If there is no evidence of seepage and the outlet structure has no apparent structural defects, an engineer should be consulted to review the pond design and determine the proper outlet elevation.

Helpful Skills:

- The ability to navigate uneven surfaces, to follow ditch banks and to sight drainage obstructions is implicit with this task.
- Ability to use a level to sight adequate elevation fall is helpful.

Equipment Typically Used for Pool Stability Evaluations

- Bright flashlight for pipe inspection
- Manhole hook for manhole cover access
- Brush hook to clear debris and walking surfaces
- Rod and level to check elevation differentials

12.3.12 Pool Quality

Applies Most Commonly To: Ponds/Wetlands

Problem #1: Littoral shelves and pond edge: not enough vegetation; vegetation *is unhealthy;* invasive plants have taken over

Ponds and Wetlands:

- If there is not enough vegetation or no vegetation, determine whether maintenance practices have killed the plants. If so, work with the owner to educate those responsible for pond maintenance on correct methods. Consult plans for original planting and replant.
- For emergent vegetation, determine whether water depths are too deep or shallow for survival (i.e., depths are different from design depths, or original design included improper vegetation).
- If a small amount of supplemental vegetation is needed, plant wetland plugs per nursery guidance.
- For large-scale plantings, drain the permanent pool and plant during the early spring. If ponds are overgrown so that less than 25% of the surface area is visible, the pond water level should be lowered to enable selective plant removal.
- Invasive plants, such as phragmites or common reed, should be removed with their roots. Be sure to restore areas that have been disturbed with replacement vegetation because root removal exposes soil to erosion. Invasive plants shall be properly disposed of in a manner that renders them non-living and non-viable to prevent the establishment, introduction or spread of disposed species.
- Native plants selected based on environmental conditions have the greatest chance for survival.
- Consult a horticulturalist or plant nursery if there is evidence of disease or pests.

Helpful Skills:

- Landscaping/gardening
- If original planting plan is deemed inadequate, consult a landscape architect or horticulturalist to determine whether a revised planting plan is needed.
- Knowledge of native plants and/or wetland plant nurseries in general region
- Familiarity with New York invasive terrestrial and wetland plants and their control: http://nyis.info/

Problem #2: Pond color, scum, odor, algae, and plant overgrowth

- Ponds that have algae covering more than 20% of the surface should have maintenance to remove it. Raking or mechanical harvesting of filamentous algae offers short-term control, but feasible long-term strategies should be considered.
- Pond maintenance companies should be relied on to identify the algae and appropriately control them. Pond specialists can control the algae growth in ponds, but its growth and reproduction are dependent on nutrients. When nutrients are in abundance, so will be the algae or vegetation.
- Plants can be used in shallow shelfs at inlets to take up nutrients. However, they must be maintained, and cuttings shall be removed to take nutrients out of the pond system.
- If (non-invasive) plants are overgrown, remove or trim back excessive vegetation. Remove cuttings and trimmings. Do not allow vegetative debris to remain in the pond.
- Pond clarity and color can be impacted by excessive sediment discharge or flow shortcircuiting. For issues of clarity and color, follow the recommendations in **Section 12.3.6**.
- If invasive aquatic plants are identified, follow DEC guidelines for reporting and controlling invasives (see **Section 12.3.8**).
- Some color, odor, and pond quality issues can be caused by leaks, spills, and other releases in the drainage area. Any petroleum odor or oily sheen (aside from natural rainbow sheen associated with decomposition of organic matter) should be reported to the appropriate state or local response agency. Other peculiar colors or odors can be investigated in collaboration with relevant agencies. Common issues are grease, paint, or other substances poured into storm drains, dumpster management, and stockpiles of various materials exposed to rainfall.

Helpful Skills:

- Ability to recognize invasive aquatic plants
- Specific measures may include mechanical hand pulling, regrading (requires construction equipment), or herbicide/pesticide application *safe for aquatic environments*.
- Knowledge of wetland plants and common types of algae and aquatic weeds
- Knowledge of types of pond maintenance practices

Equipment Typically Used for Pool Quality Investigations

- High-top rubber boots
- Canoes or small boats
- Brush hook to clear vegetation and access pond bank
- Secchi disk to check and compare pond color and clarity
- Large-mouth bottle to collect algae and water quality samples
- Various materials to control aquatic weeds and algae

References

Current References

Abu-Zreig, M., R.P. Rudra, H.R. Whiteley, M.N. Lalonde and N.K. Kaushik. 2003. Phosphorus Removal in Vegetated Filter Strips. *Journal of Environmental Quality*, 32, 613-619. https://doi.org/10.2134/jeq2003.6130

AECOM, Atlanta Regional Commission, Center for Watershed Protection, Center Forward, Georgia Environmental Protection Division and Mandel Design. 2016. Georgia Stormwater Management Manual Volumes 1 & 2. Available from: https://atlantaregional.org/

Albany Pool Communities. 2017. Green Infrastructure Toolkit. Available from: https://cdrpc.org/

AMEC Environment & Infrastructure. 2012. City of Atlanta Stormwater Guidelines: Green Infrastructure for Single Family Residences. Available from: https://www.atlantawatershed.org/

Barret, M.E. 2005. Performance Comparison of Structural Stormwater Best Management Practices. *Water Environment Research, 77*(1), 78-86. doi: 10.2175/106143005x41654

Borne, K.E. 2014. Floating treatment wetland influences on the fate and removal performance of phosphorus in stormwater retention ponds. *Ecological Engineering*, 69, 76-82. http://dx.doi.org/10.1016/j.ecoleng.2014.03.062

Brown, R.A., W.F. Hunt and S.G. Kennedy. 2009. Designing Bioretention with and Internal Water Storage (IWS) Layer. North Carolina Cooperative Extension. Available from: https://digital.ncdcr.gov/

Cahill, T.H. Low-Impact Development & Sustainable Stormwater Management.

Cannon, M., M. Sheils and C. Bohlen. 2019. Reducing N in the Watershed: An Analysis of Green Infrastructure and Low Impact Development Stormwater Solutions. New England Environmental Finance Center & Casco Bay Estuary Partnership. Available from: https://neefc.org/

Center for Watershed Protection. 2007. National Pollutant Removal Performance Database Version 3. Available from: https://owl.cwp.org/

Center for Watershed Protection. 2009. Maryland Stormwater Manual Design Manual Volumes I & II. Maryland Department of the Environment (MDE). Baltimore, MD. Available from: https://mde.maryland.gov/

Center for Watershed Protection. 2012. West Virginia Stormwater Management and Design Guidance Manual. West Virginia Department of Environmental Protection (WVDEP). Available from: https://dep.wv.gov/

Center for Watershed Protection. 2017. Making Urban Trees Count. https://www.cwp.org/making-urban-trees-count/

Center for Watershed Protection. 2020. District of Columbia Stormwater Management Guidebook. Department of Energy and Environment. Available from: https://doee.dc.gov/swguidebook

Charlotte-Mecklenburg Storm Water Services. 2013. Charlotte-Mecklenburg BMP Design Manual. Available from: https://charlottenc.gov/StormWater/

Chesapeake Stormwater Network. 2012. Stormwater Hotspots and Pollution Prevention Practices. Available from: http://chesapeakestormwater.net/

City of Albany. 2016. City of Albany Complete Streets Policy & Design Manual. Available from: https://www.cdtcmpo.org/

City of Chicago. 2016. City of Chicago Stormwater Management Ordinance Manual. Available from: https://www.chicago.gov/

City of Fayetteville Engineering Division. 2014. Fayetteville Arkansas Drainage Criteria Manual. Available from: https://www.fayetteville-ar.gov/

City of Philadelphia. 2014. City of Philadelphia Green Streets Design Manual. Available from: https://www.phila.gov/

City of Philadelphia. 2017. Philadelphia Complete Streets Design Handbook. Available from: https://www.philadelphiastreets.com/

City of San Francisco. 2010.San Francisco Stormwater Design Guidelines. Available from: https://sfwater.org/

City of Springfield. Green Infrastructure Technical Guidelines. Available from: https://www.springfield-ma.gov/dpw/

Clary, J., J. Jones, M. Leisenring, P. Hobson, and E. Strecker. 2017. International Stormwater BMP Database 2016 Summary Statistics. Water Environment & Reuse Foundation. Available from: https://bmpdatabase.org/

Collins, K.A., T.J. Lawrence, E.K. Stander, R.J. Jontos, S.S. Kaushal, T.A. Newcomer. N.B. Grimm and M.L. Cole Ekberg. 2010. Opportunities and Challenges for Managing Nitrogen in Urban Stormwater: A Review and Synthesis. *Ecological Engineering*, 36, 1507-1519. doi: 10.1016/j.ecoleng.2010.03.015

Comprehensive Environmental Inc. 2012. Stormwater Practices Research Report. Vermont Agency of Transportation. Available from: https://vtrans.vermont.gov/

Comprehensive Environmental Inc. and New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual Volumes II & III. Available from: https://www.des.nh.gov/

County of San Diego Department of Public Works. 2014. County of San Diego Low Impact Development Handbook Stormwater Management Strategies. Available from: https://www.sandiegocounty.gov/

Craul, T. and P. Craul. 2006. Soil Design Protocols for Landscape Architects and Contractors. John Wiley & Sons, Inc. Hoboken, New Jersey.

Davis, A.P., M. Shokouhian, H. Sharma, C. Minami and D. Winogradoff. 2003. Water Quality Improvement through Bioretention: Lead, Copper, and Zinc Removal. *Water Environment Research*, 75(1), 73-82. doi: 10.2175/106143003x140854

Davis, A.P., W.F. Hunt, R.G. Traver, and M. Clar. 2009. Bioretention Technology: Overview of Current Practice and Future Needs. *Journal of Environmental Engineering,* 135(3), 109-117. https://doi.org/10.1061/(ASCE)0733-9372(2009)135:3(109)

Delaware Department of Natural Resources and Environmental Control (DNREC) Division of Watershed Stewardship. 2019. Delaware Post Construction Stormwater BMP Standards & Specifications. Available from: http://www.dnrec.delaware.gov/

Deng, Y., C. Morris, S. Rakshit, E. Landa, P. Punamiya and D. Sarkar. 2016. Water Treatment Residuals and Scrap Tire Rubber as Green Sorbents for Removal of Stormwater Metals. *Water Environment Research*, 88(6), 500-509. doi: 10.2175/106143016X14504669768697

Dropkin, E. and N. Bassuk. 2016. Cornell Urban Horticulture Institute. Woody Shrubs for Stormwater Retention Practices (Northeast and Mid-Atlantic Regions). Available from: http://www.hort.cornell.edu/uhi/outreach/pdfs/woody_shrubs_stormwater_hi_res.pdf

Dunnett, N., D. Gedge, J. Little, and E. Snodgrass. 2011. Small Green Roofs. Timber Press. Portland, Oregon.

Eastern Washington Low Impact Develoment Guidance Manual. Available from: http://www.wastormwatercenter.org/

Fardel, A., P. Peyneau, B. Béchet, A. Lakel and F. Rodriguez. 2019. Analysis of Swale Factors Implicated in Pollutant Removal Efficiency Using a Swale Database. *Environmental Science and Pollution Research*, 26, 1287-1302. https://doi.org/10.1007/s11356-018-3522-9

Fassman, E. 2012. Stormwater BMP treatment performance variability for sediment and heavy metals. *Separation and Purification Technology*, 84, 95-103. doi: 10.1016/j.seppur.2011.06.033

Follet, R. F. 1995. Fate and Transport of Nutrients: Nitrogen, Working Paper No. 7. United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). Available from: https://www.nrcs.usda.gov/

Georgia Department of Transportation. n.d. Advanced Design Workshops: Wet Detention Pond Design. Available from: http://www.dot.ga.gov/

Georgia Department of Transportation. 2018. Drainage Design for Highways. Atlanta, GA. Available from: http://www.dot.ga.gov/

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2010. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Nutrients. Available from: https://bmpdatabase.org/

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2011. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Solids (TSS, TDS and Turbidity). Available from: https://bmpdatabase.org/

Gilchrist, S., M. Borst and E.K. Stander. 2013. Factorial Study of Rain Garden Design for Nitrogen Removal. *Journal of Irrigation and Drainage Engineering*, 190(43). doi: 10.1061/(ASCE)IR.1943-4774.0000678

Greenman, R.L. 1948. Engineering Experiment Station Bulletin 107: The Use and Treatment of Granular Backfill. Michigan Engineering Experiment Station. East Lansing, MI. Available from: https://www.michigan.gov/

Gulliver, J.S. 2019. Iron-Enhanced Swale Ditch Checks for Phosphorus Retention. Minnesota Department of Transportation. http://www.dot.state.mn.us/

Harris, R., J. Clark, and N. Matheny. 2003. Arboriculture. Prentice Hall. Englewood Cliffs, New Jersey.

Hathaway, J.M. 2008. Urban Waterways Removal of Pathogens in Stormwater. North Carolina Cooperative Extension Service. Available from: http://lshs.tamu.edu/

Herrera Environmental Consultants, Inc. 2020. Bioretention Media Blends to Improve Stormwater Treatment: Final Phase of Study to Develop New Specifications Final Report. King County. Available from: https://www.herrerainc.com/

High Performance Landscape Guidelines http://designtrust.org/publications/hp-landscape-guidelines/

Hightshoe, G. 1987. Native Trees, Shrubs, and Vines for Urban and Rural America. John Wiley & Sons, Inc. New York, New York.

Hirschman, D.J., B. Seipp, and T. Schueler. 2017. Performance Enhancing Devices for Stormwater Best Management Practices. Available from: https://owl.cwp.org/

Hirschman, D.J., J. Hathaway, K. Lindow, and T. Schueler. 2018. Updating the Runoff Reduction Method. Metro Government of Nashville & Davidson County, Tennessee Metro Water Services, Stormwater Division. Available from: https://hirschmanwater.com/

Hsieh, C. and A.P. Davis. 2005. Evaluation and Optimization of Bioretention Media for Treatment of Urban Storm Water Runoff. *Journal of Environmental Engineering*, 131(11), 1521-1531. doi: 10.1061/(ASCE)0733-9372(2005)131:11(1521)

Hsieh, C., A.P. Davis and B.A. Needelman. 2007. Bioretention Column Studies of Phosphorus Removal from Urban Stormwater Runoff. *Water Environment Research*, 79(2), 177-184. doi: 10.2175/106143006X111745

Hunt, W.F., A.P. Davis and R.G. Traver. 2012. Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design. *Journal of Environmental Engineering*, 138(6), 698-707. doi: 10.1061/(ASCE)EE.1943-7870.0000504

Hurley, S., P. Shrestha and A. Cording. 2017. Nutrient Leaching from Compost: Implications for Bioretention and Other Green Stormwater Infrastructure. *Journal of Sustainable Water in the Built Environment*. doi: 10.1061/JSWBAY.0000821

Huynh, K. n.d. Abstract: Enhanced Removal of Pathogens in Stormwater through Filtration with Iron-Amended Media. Available from: https://renuwit.org/

Hydraflow Support from Autodesk Civil3D Help. https://knowledge.autodesk.com/support/civil-3d

HydroCAD® Stormwater Modeling Support. https://www.hydrocad.net/support.htm

Hydrology Studio Help Center. http://learn.hydrologystudio.com/hydrology-studio/

Iowa Department of Natural Resources. 2020. Iowa Storm Water Manual. Available from: https://www.iowadnr.gov/

Jani, J., Y. Yang, M.G. Lusk and G.S. Toor. 2020. Composition of Nitrogen in Urban Residential Stormwater Runoff: Concentrations, Loads, and Source Characterization of Nitrate and Organic Nitrogen. *PLoS ONE*, 15(2). https://doi.org/10.1371/journal.pone.0229715

Jay, J. 2016. Bioretention Soil Media: Understanding the effects of compost and finding predictors for phosphorus leaching. Available from: https://digital.lib.washington.edu/

Jay, J.G., S.L. Brown, K. Kurtz and F. Grothkopp. 2017. Predictors of Phosphorus Leaching from Bioretention Soil Media. *Journal of Environmental Quality*, 46, 1098-1105. doi:10.2134/jeq2017.06.0232

Jayakaran, A.D., T. Knappenberger, J.D. Stark and C. Hinman. 2019. Remediation of Stormwater Pollutants by Porous Asphalt Pavement. *Water,* 520 (11). doi:10.3390/w11030520

Kim, H., E.A. Seagren and A.P. Davis. (2003). Engineered Bioretention for Removal of Nitrate from Stormwater Runoff. *Water Environment Research*, 75(4), 355-367. doi: 10.2175/106143003x141169

Koch, B.J., C.M. Febria, M. Gevrey, L.A. Wainger and M.A. Palmer. 2014. Nitrogen Removal by Stormwater Management Structures: A Data Synthesis. *Journal of the American Water Resources Association*, 50(6), 1594-1607. doi: 10.1111/jawr.12223

Kumwimba, M.N., F. Meng, O. Iseyemi, M.T. Moore, Z. Bo, W. Tao, T.J. Liang and L. Ilunga. 2018. Removal of non-point source pollutants from domestic sewage and agricultural runoff by vegetated drainage ditches (VDDs): Design, mechanism, management strategies, and future directions. *Science of the Total Environment*, 639, 742-759. https://doi.org/10.1016/j.scitotenv.2018.05.184

Ladislas, S., C. Gérente, F. Chazarenc, J. Brisson and Y. Andrès. 2015. Floating Treatment Wetlands for Heavy Metal Removal in Highway Stormwater Ponds. *Ecological Engineering*, 80, 85-91. http://dx.doi.org/10.1016/j.ecoleng.2014.09.115

Lau, A.Y.T., D.C.W. Tsang, N.J.D. Graham, Y.S. Ok, X. Yang and X. Li. 2017. Surface-modified biochar in a bioretention system for Escherichia coli removal from stormwater. *Chemosphere*, 169, 89-98. http://dx.doi.org/10.1016/j.chemosphere.2016.11.048

Law, N.L. 2014. Recommendations of the Expert Panel to Define Removal Rates for Urban Filter Strips and Stream Buffer Upgrade Practices. Available from: https://owl.cwp.org/

Leopold, D. 2005. Native Plants of the Northeast. Timber Press. Portland, Oregon.

Lewis, K. 2014. Fall Digging Hazards. Available from: http://www.ruppertnurseries.com/fall-digging-hazards/

Li, L. and A.P. Davis. 2014. Urban Stormwater Runoff Nitrogen Composition and Fate in Bioretention Systems. *Environmental Science and Technology*, 48, 3403-3410. https://dx.doi.org/10.1021/es4055302

Li, M., M. Swapp, M.H. Kim, K. Chu, and C.Y. Sung. 2013.Comparing Bioretention Designs with and without an Internal Water Storage Layer for Treating Highway Runoff. *Water Environment Research,* 86. doi: 10.2175/106143013X13789303501920.

Li, Y.L., A. Delectic and D.T. McCarthy. 2014. Removal of E. coli from urban stormwater using antimicrobial-modified filter media. *Journal of Hazardous Materials*, 271, 73-81. http://dx.doi.org/10.1016/j.jhazmat.2014.01.057

Lienden, C., L. Shan, S. Rao, E. Ranieri and T.M. Young. 2010. Metals Removal from Stormwater by Commercial and Non-Commercial Granular Activated Carbons. *Water Environment Research*, 82(4), 351-356. doi:10.2175/106143009X12487095236874

Lim, H.S., W. Lim, J.Y. Hu, A. Ziegler and S.L. Ong. 2015. Comparison of Filter Media Materials for Heavy Metal Removal from Urban Stormwater Runoff Using Biofiltration Systems. *Journal of Environmental Management,* 147, 24-33. http://dx.doi.org/10.1016/j.jenvman.2014.04.042

Low-Impact Development & Sustainable Stormwater Management. Thomas H. Cahill (Wiley)

Maguire, R.O. and J.T. Sims. 2002. Soil Testing to Predict Phosphorus Leaching. *Journal of Environmental Quality*, 31, 1601-1609. https://doi.org/10.2134/jeq2002.1601

Maine Department of Environmental Protection. 2016. Maine Stormwater Management Design Manual Volumes I, II & III. Available from: https://www.maine.gov/dep/

Maryland Department of the Environment. 2009. Maryland Stormwater Design Manual. Available from: http://mde.maryland.gov/

Maryland Department of the Environment. 2013. Stormwater Pollution Prevention Guidance: Vehicle Maintenance and Repair, Fueling, Washing or Storage Loading and Unloading, Outdoor Storage. Available from: https://mde.maryland.gov/

Maryland Department of the Environment. 2017. Alternative/Innovative Technology List of Approved Stormwater Practices. Available from: https://mde.maryland.gov/

Massachusetts Department of Environmental Protection. 2008. Massachusetts Stormwater Handbook Volumes 1, 2 & 3. Available from: https://www.mass.gov/

McCarthy, J. 2008. New Hampshire Stormwater Manual Volume I. Available from: https://www.des.nh.gov/

McLemore, A.J., J.R. Vogel and S. Taghvaeian. 2017. Bioretention Cell Design Guidance for Oklahoma. Oklahoma Cooperative Extension Service. Available from: https://shareok.org/

Metropolitan Government of Nashville and Davidson County Department of Water and Sewerage Services. 2016. Stormwater Management Manual. Available from: https://www.nashville.gov/

Metropolitan North Georgia Water Planning District. 2010. Post-Construction Stormwater Technology Assessment Protocol for Metropolitan North Georgia. Available from: https://northgeorgiawater.org/proprietary-best-management-practices/

Michelsen, E. 2012. Design & Construction of Regenerative Stormwater Conveyance. South River Federation. Available from: http://chesapeakestormwater.net/

Minnesota Pollution Control Agency (MPCA). 2013. Nitrogen in Minnesota Surface Waters. Available from: https://www.pca.state.mn.us/

Minnesota Pollution Control Agency (MPCA). 2020. Minnesota Stormwater Manual. Available from: https://stormwater.pca.state.mn.us/

Mohseni, O. 2020. Monitoring and Performance Analysis of the TH 610 Iron-Enhanced Filtration System. Minnesota Department of Transportation. St. Paul, MN. Available from: http://www.dot.state.mn.us/research

Muerdter, C., C. Wong and G. LeFevre. 2018. Emerging Investigator Series: The Role of Vegetation in Bioretention for Stormwater Treatment in the Build Environment: Pollutant Removal, Hydrologic Function, and Ancillary Benefits. *Environmental Science: Water Research & Technology,* 4, 592-612. https://doi.org/10.1039/C7EW00511C

Muthukrishnan, S. 2010. Treatment of heavy Metals in Stormwater Runoff Using Wet Pond and Wetland Mesocosms. *Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy*, 11(9). Available from: https://scholarworks.umass.edu/soilsproceedings/vol11/iss1/9

Natarajan, P., and J.S. Gulliver. 2015. Assessing Iron-Enhanced Swales for Pollution Prevention. Minnesota Pollution Control Agency (MPCA). Minneapolis, MN. Available from: https://experts.umn.edu/

National Association of City Transportation Officials (NACTO). n.d. Urban Street Stormwater Guide. https://nacto.org/publication/urban-street-stormwater-guide/

National Cooperative Highway Research Program (NCHRP). 2006. Evaluation of Best Management Practices for Highway Runoff Control: Low Impact Development Design Manual for Highway Runoff Control (LID Design Manual).

Nelson, J. 2007. Planting Trees. Available from: http://web.extension.illinois.edu/

New Jersey Corporation for Advanced Technology Program (NJCAT). 2017. NJCAT Technology Verification StormKeeper® Chamber Sediment Strip® Lane Enterprises Inc. Available from: http://www.njcat.org/

New Jersey Corporation for Advanced Technology Program (NJCAT). 2020. Stormwater Technologies: Laboratory Verified and NJDEP Certified. http://www.njcat.org/verification-process/technology-verification-database.html

New Jersey Department of Environmental Protection. 2006. New Jersey Tier II Stormwater Test Requirements – Amendments to TARP Tier II Protocol. Available from: https://www.njstormwater.org/

New Jersey Department of Environmental Protection. 2011. NJ Stormwater Technical Manual. Available from: https://www.njstormwater.org/

New Jersey Department of Environmental Protection. 2020. New Jersey Stormwater Best Management Practices Manual. Available from: https://www.njstormwater.org/

New Jersey Department of Environmental Protection. 2021. New Jersey Stormwater Manufactured Treatment Devices. https://www.nj.gov/dep/stormwater/treatment.html

New York City Department of Environmental Protection (NYC DEP). n.d. New York City Stormwater Design Manual. Available from: https://www1.nyc.gov/site/dep/index.page

New York City Department of Environmental Protection (NYC DEP). 2010. NYC Green Infrastructure Plan. Available from: https://www1.nyc.gov/site/dep/index.page

New York City Department of Environmental Protection (NYC DEP). 2012. Guidelines for the Design and Construction of Stormwater Management Systems. Available from: https://www1.nyc.gov/site/dep/index.page

New York City Department of Environmental Protection (NYC DEP). 2015. Protection Requirements for Right-of-Way Green Infrastructure Practices. Available from: https://www1.nyc.gov/site/dep/index.page

New York City Department of Environmental Protection (NYC DEP). 2017. Procedure Governing Limited Geotechnical Investigation for Right-of-Way Green Infrastructure Practices. Available from: https://www1.nyc.gov/site/dep/index.page

New York City Department of Environmental Protection (NYC DEP). 2017. Procedure Governing Limited Survey for Green Infrastructure. Available from: https://www1.nyc.gov/site/dep/index.page

New York City Department of Environmental Protection (NYC DEP). 2017. Standard Designs and Guidelines for Green Infrastructure Practices. Available from: https://www1.nyc.gov/site/dep/index.page

New York Natural Heritage Program. 2016. Plant and Community Guides. Website. Available from: http://www.acris.nynhp.org/

New York State Department of Environmental Conservation (NYS DEC). 2016. New York State Standards and Specifications for Erosion & Sediment Control. Available from https://www.dec.ny.gov/

New York State Department of Environmental Conservation (NYS DEC). 2017. Maintenance Guidance for Stormwater Management Practices. Available from https://www.dec.ny.gov/

New York State Department of Environmental Conservation (NYS DEC). 2020. SPDES General Permit for Stormwater Discharges from Construction Activity, Permit No. GP-0-20-001. Albany, NY. Available from: https://www.dec.ny.gov/

New York State Department of Health (NYS DOH). 2016. NYCRR Part 75, Standards for Individual Onsite Water Supply and Individual Onsite Wastewater Treatment Systems. Available from: https://www.health.ny.gov/

New York State Department of Health (NYS DOH). 2020. NYCRR Part 5, subpart 5-1 Standards for Water Wells – Appendix 5B. Available from: https://www.health.ny.gov/

New York State Department of Transportation (NYS DOT). 2009. Engineering Instruction (EI) 09-020 Special Specifications for Bioretention and Dry Swale Soil and Soil Phosphorous Testing. Available from: https://www.dot.ny.gov/

New York State Department of Transportation (NYS DOT). 2013. Item 208.01001139 Rain Garden Soil Mix (NYCDPR). Available from: https://www.dot.ny.gov/

New York State Department of Transportation (NYS DOT). 2014. Item 208.01030022 Bioretention and Dry Swale Soil Specification, Item 208.01040022 Laboratory Testing for Soil Phosphorous Concentration Specification. Available from: https://www.dot.ny.gov/

New York State Department of Transportation (NYS DOT). 2014. Item 420.10130201 – Top Course Porous Asphalt Pavement with Mineral Fiber F3, Item 420.10190201 – Top Course Porous Asphalt Pavement with Mineral Fiber F9, Item 420.01190201 – Binder Course Porous Asphalt Pavement F9. Available from: https://www.dot.ny.gov/

New York State Department of Transportation (NYS DOT). 2018. Highway Design Manual Chapter 2 – Design Criteria. Available from: https://www.dot.ny.gov/

North Carolina Department of Environment and Natural Resources (NCDENR). 2014. NCDENR Stormwater BMP Manual. Available from: http://www.wellcontractors.nc.gov/

North Carolina Department of Environmental Quality (NC DEQ). 2020. NCDEQ Stormwater Design Manual. Available from: https://deq.nc.gov/

North Central Texas Council of Governments (NCTCOG). 2004. Floatables Management Study Floatables Control Technologies. Available from: https://www.nctcog.org/

Oregon Department of Transportation Highway Division. 2014. Hydraulics Design Manual. Available from: https://www.oregon.gov/odot/

Osman, M., K.W. Yusof, H. Takaijudin, H.W. Goh, M.A. Malek, N.A. Azizan, A.A. Ghani and A.S. Abdurrasheed. 2019. A Revies of Nitrogen Removal for Urban Stormwater Runoff in Bioretention System. *Sustainability*, 11(19). doi: 10.3390 /su11195415

Palmer, E.T., C.J. Poor, C. Hinman and J.D. Stark. 2013. Nitrate and Phosphate Removal through Enhanced Bioretention Media: Mesocosm Study. *Water Environment Research*, 85(9), 823-832. doi: 10.2175/106143013X13736496908997

Peng, J., Y. Cao, M.A. Rippy, A.R.M.N. Afrooz and S.B. Grant. 2016. Indicator and Pathogen Removal by Low Impact Development Best Management Practices. *Water*, 8(12). doi:10.3390/w8120600

Pennsylvania Department of Environmental Protection. 2006. Pennsylvania Stormwater Best Management *Practices Manual*. Available from https://www.dep.pa.gov/

Perry, S., J. Garbon and B. Lee. n.d. Urban Stormwater Runoff Phosphorus Loading and BMP Treatment Capabilities. Available from: http://www.imbriumsystems.com/

Philadelphia Water Department. Green City, Clean Waters Community Orientation Packet. Available from: https://www.phila.gov/water/

Philadelphia Water Department. 2020. Stormwater Management Guidance Manual. Available from: https://www.pwdplanreview.org/

Reddy, K.R., T. Xie and S. Dastgheibi. 2014. Removal of Heavy Metals from Urban Stormwater Runoff Using Different Filter Materials. *Journal of Environmental Chemical Engineering*, 2, 282-292. http://dx.doi.org/10.1016/j.jece.2013.12.020

Reschke, C. 2014. Ecological Communities of New York State. New York Natural Heritage Program. Albany, New York. http://www.dec.ny.gov/docs/wildlife_pdf/ecocomm2014.pdf

Riverside County Flood Control Water Conservation District. 2018. Riverside County Santa Margarita River Watershed Region Design Handbook for Low Impact Development Best Management Practices. Available from: https://rcflood.org/

Roseen, R., J. Houle, T. Ballestero, A. Watts, T. Puls. 2011. Stormwater Management Strategies for reduction of Nitrogen and Phosphorus Loading to Surface Waters. University of New Hampshire Stormwater Center (UNHSC). Available from: https://www.unh.edu/unhsc/

Roseen, R.M. and R.M. Stone. 2013. Evaluation and Optimization of Bioretention Design for Nitrogen and Phosphorus Removal. Available from: https://www.epa.gov/

Rosenquist, S.E., W.C. Hession, M.J. Eick and D.H. Vaughan. 2010. Variability in adsorptive phosphorus removal by structural stormwater best management practices. *Ecological Engineering*, 36, 664-671. doi: 10.1016/j.ecoleng.2009.12.008

Rutgers Cooperative Extension Water Resources Program. Rain Garden Manual of New Jersey. Available from: http://water.rutgers.edu/Rain_Gardens/RGWebsite/RainGardenManualofNJ.html

Salon P.R. and C. F. Miller. 2012. A Guide to: Conservation Plantings on Critical Areas for the Northeast USDA, NRCS. Available from: http://plant-materials.nrcs.usda.gov/nypmc/

Schueler, T., and C. Lane. 2012. Recommendations of the Expert Panel to Define Removal Rates for New State Stormwater Performance Standards. Available from: https://www.chesapeakebay.net/

Shammaa, Y. and D.Z. Zhu. 2001. Techniques for Controlling Total Suspended Solids in Stormwater Runoff. *Canadian Water Resources Journal*, 26(3), 359-375.doi: 10.4296/cwrj2603359

Shammaa, Y., D.Z. Zhu, L.L. Gyürék and C.W. Labatiuk. 2002. Effectiveness of Dry Ponds for Stormwater Total Suspended Solids Removal. *Canadian Journal of Civil Engineering*, 29, 316-324. doi: 10.1139/L02-008

Shaw, D. and R. Schmidt. 2003. Plants for Stormwater Design: Species Selection for the Upper Midwest. Minnesota Pollution Control Agency. Available from: https://www.pca.state.mn.us/water/plants-stormwater-design

Snodgrass, E. and L.Snodgrass. 2006. Green Roof Plants: A Resource and Planting Guide. Timber Press. Portland, Oregon.

Startman, D. 2002. Using Micro and Macrotopography in Wetland Restoration. USDA NRCS. Available from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_041138.pdf

StormCAD Learning Resource Guide. https://communities.bentley.com/products/hydraulics___hydrology/w/hydraulics_and_hydrology__wiki/10562/learning-resource-guide-for-new-users-of-bentley-stormcad

Stormwater Management Academy. 2015. Best Management Practices for Stormwater Runoff. University of Central Florida. Orlando, FL. Available from: https://www.fdot.gov/

Tennessee Department of Environment and Conservation Division of Water Resources. 2014. Tennessee Permanent Stormwater Management and Design Guidance Manual. Available from: https://tnpermanentstormwater.org/manual.asp

Thompson, W. and K. Sorvig 2008. Sustainable Landscape Construction. Island Press. Washington DC.

Tota-Maharaj, K. and M. Scholz. 2010. Efficiency of Permeable Pavement Systems for the Removal of Urban Runoff Pollutants Under Varying Environmental Conditions. *Environmental Progress & Sustainable Energy*, 29(3), 358-369. doi: 10.1002/ep.10418

Town of Greenwich Department of Public Works. 2021. Town of Greenwich Drainage Manual Low Impact Development and Stormwater Management. Available from: https://www.greenwichct.gov/

Trenouth, W.R. and B. Gharabaghi. 2015. Soil Amendments for Heavy Metals Removal from Stormwater Runoff Discharging to Environmentally Sensitive Areas. *Journal of Hydrology*, 529, 1478-1487. http://dx.doi.org/10.1016/j.jhydrol.2015.08.034

United States Department of Agriculture (USDA). 1986. Urban Hydrology for Small Watersheds TR-55. Technical Release 55. Available from: https://www.nrcs.usda.gov/

United States Department of Agriculture (USDA). 1997. Agriculture Handbook Number 590: Ponds – Planning, Design, Construction. Available from: https://nrcspad.sc.egov.usda.gov/distributioncenter/default.aspx

United States Department of Agriculture (USDA). 1998. Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers. Available from: https://www.fs.usda.gov/

United States Department of Transportation Federal Highway Administration. 2008. Hydraulic Design Series No. 4 Introduction to Highway Hydraulics. Publication No. FHWA-NHI-08-090. Available from: https://www.fhwa.dot.gov/

United States Environmental Protection Agency (USEPA). Environmental Technology Verification Program Verification Reports and Statements. Available from: https://archive.epa.gov/nrmrl/archive-etv/web/html/vrvs.html#wqpc

United States Environmental Protection Agency (USEPA). 1995. Federal Guidance for the Establishment, Use and Operation of Mitigation Banks. Federal Register, 60(228), 58605-58614. Available from: https://www.epa.gov/

University of New Hampshire Stormwater Center (UNHSC). 2009. Subsurface Gravel Wetland Design Specification. Available from: https://www.unh.edu/unhsc/

University of New Hampshire Stormwater Center (UNHSC). 2017. UNHSC Design Specifications for Bioretention Soil Mix (BSM). Available from: https://www.unh.edu/unhsc/

Urban, J. 2008. Up by Roots: Healthy Soils and Trees in the Built Environment. International Society of Arboriculture. Champaign, Illinois.

Vermont Agency of Natural Resources. 2017. Vermont Stormwater Management Manual Rule and Design Guidance. Available from: https://dec.vermont.gov/

Vermont Urban & Community Forestry Program. 2018. Vermont Green Streets Guide. Available from: https://vtcommunityforestry.org/

Virginia Department of Conservation and Recreation (VA DCR). 1999. Virginia Stormwater Management Handbook Volume I & II.

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.9: Bioretention, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.10: Dry Swales, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.11: Wet Swales, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.12: Filtering Practices, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.13: Constructed Wetlands, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.14: Wet Pond, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Conservation and Recreation (VA DCR). 2013. Virginia DCR Stormwater Design Specification No.15: Extended Detention (ED) Pond, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.1: Rooftop (Impervious Surface) Disconnection, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.2: Sheet Flow to a Vegetated Filter Strip or Conserved Open Space, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.3: Grass Channels, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.4: Soil Compost Amendment, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.5: Vegetated Roof, Version 2.4. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.6: Rainwater Harvesting, Version 2.2. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.7: Permeable Pavement, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Environmental Quality (VA DEQ). 2013. Virginia DEQ Stormwater Design Specification No.8: Infiltration Practices, Version 2.0. Available from: https://swbmp.vwrrc.vt.edu/

Virginia Department of Transportation (VDOT). 2013. BMP Design Manual of Practice. Available from: https://www.virginiadot.org/

Wang, J., Y. Zhao, L. Yang, N. Tu, G. Xi and X. Fang. 2017. Removal of Heavy Metals from Urban Stormwater Runoff Using Bioretention Media Mix. *Water*, 9(854). doi:10.3390/w9110854

Wang, R., X. Zhang and M. Li. 2019. Predicting Bioretention Pollutant Removal Efficiency with Design Features: A Data-Driven Approach. *Journal of Environmental Management*, 242, 403-414. https://doi.org/10.1016/j.jenvman.2019.04.064

Water Research Foundation (WRF), ASCE Environmental and Water Resources Institute (EWRI), US Environmental Protection Agency (USEPA), Federal Highway Administration (FHWA) and American Public Works Association (APWA). 2020. International Stormwater BMP Database. Available from: https://bmpdatabase.org/

Weiss, J.D., M. Hondzo and M. Semmens. 2006. Storm Water Detention Ponds: Modeling Heavy Metal Removal by Plant Species and Sediments. *Journal of Environmental Engineering*, 132(9), 1034-1042. doi: 10.1061/(ASCE)0733-9372(2006)132:9(1034)

Washington Department of Ecology. Emerging Stormwater Treatment Technologies (TAPE). https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies#update

Wright, T., C. Swann, K. Cappiella and T. Schueler. 2005. Manual 11: Unified Subwatershed and Site Reconnaissance: A User’s Manual. Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD. Available from: https://owl.cwp.org/

Wright Water Engineers, Inc. and Geosyntec Consultants, Inc. 2010. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Fecal Indicator Bacteria. Available from: https://bmpdatabase.org/

Wright Water Engineers, Inc. and Geosyntec Consultants, Inc. 2011. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Metals. Available from: https://bmpdatabase.org/

Yu, J., H. Yu and L. Xu. 2013. Performance Evaluation of Various Stormwater Best Management Practices. *Environmental Science and Pollution Research,* 20, 6160-6171. https://doi.org/10.1007/s11356-013-1655-4

Zhang, K., F. Yong, D. McCarthy and A. Deletic. 2018. Predicting Long Term Removal of Heavy Metals from Porous Pavements for Stormwater Treatment. *Water Research*, 142, 236-246. https://doi.org/10.1016/j.watres.2018.05.038

Zinger, Y., G. Blecken, T.D. Fletcher, M. Viklander and A. Deletić. 2013. Optimizing Nitrogen Removal in Existing Stormwater Biofilters: Benefits and Tradeoffs of a Retrofitted Saturated Zone. *Ecological Engineering*, 51, 75-82. http://dx.doi.org/10.1016/j.ecoleng.2012.12.007

Zubin-Stathopoulos, N. 2013. Heavy Metal Performance in Bioretention Stormwater: A Comparison of Five Facilities. State University of New York College of Environmental Science and Forestry, ProQuest Dissertations Publishing. Available from: https://proquest.com/

References from 2015 Design Manual & Prior

Allen, P. and R. Narramore. 1985. Bedrock controls on stream channel enlargement with urbanization, North Central Texas. *Water Resources Bulletin*. 21(6): 1037-1048.

American Forests. www.americanforests.org

American National Standards Institute. 2004. ANSI Z60.1-2004. American Standards for Nursery Stock. 112 p.

Arendt, Randall. 1994. Designing Open Space Subdivisions: A Practical Step-by-Step Approach. Natural Lands Trust, Inc. Media, PA. Available from www.natlands.org or www.greenerprospects.com

Army Corps of Engineers (ACOE), North Pacific Division. 1956. Snow Hydrology, Summary Report of the Snow Investigations. Portland, OR.

ASTM International. 2005. ASTM E2396-05. Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems. Available from: www.astm.org

ASTM International. 2005. ASTM E2397-05. Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems. Available from: www.astm.org

ASTM International. 2005. ASTM E2398-05. Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems. Available from: www.astm.org

ASTM International. 2005. ASTM E2399-05. Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems (includes tests to measure moisture retention potential and saturated water permeability of media). Available from: www.astm.org

ASTM International. 2006. ASTM E2400-06. Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof. Available from: www.astm.org

ASTM International. 2006. ASTM E631-06. Standard Terminology of Building Constructions. Available from: www.astm.org

ASTM International. 2007. ASTM C29 / C29M-07. Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate. Available from: www.astm.org

ASTM International. 2008. ASTM E2114-08. Standard Terminology for Sustainability Relative to the Performance of Buildings. Available from: www.astm.org

ASTM International. 2018. ASTM E2788/E2788M-18 - Standard Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems. Available from: www.astm.org

Avnimelech, Y., M. Kochva, Y. Yotal, and D. Shkedy. 1988. The Use of Compost as a Soil Amendment.

Balusek, J. D. 2003. Quantifying decreases in stormwater runoff from deep-tilling, chisel-planting and *compost amendments*. Dane County Land Conservation Department. Madison, Wisconsin.

Bannerman, R.; D. Owens; R. Dodds; and N. Hornewer. 1993. Sources of Pollutants in Wisconsin Stormwater. *Water Science and Technology*. 28(3-5): 241-259.

Bannerman, R. 2003. Rain Gardens, a How-to Manual for Homeowners. University of Wisconsin. PUB-WT-776.

Barr Engineering Company. 2003. Minnesota Urban Small Sites BMP Manual: Stormwater Best *Management Practices for Cold Climates*. Metropolitan Council Environmental Services. St. Paul, Minnesota.

Bengtsson, L. 1990. Urban Snow Hydrology. Proceedings of an International Conference on Urban Hydrology Under Wintry Conditions. Narvik, Norway.

Blankinship, Donna Gordon. Jan/Feb 2005. *Creeks are Coming Back into the Light*. Article from Stormwater Magazine Vol. 6, No. 1. Forester Communications. Caledonia, MI. Available from www.stormh2o.com

Booth, D., D. Montgomery, and J. Bethel. 1996. Large woody debris in the urban streams of the Pacific Northwest. *In* Effects of Watershed development and Management on Aquatic Systems. L. Roesner (ed.) Engineering Foundation Conference. Proceedings. Snowbird, UT. August 4-9, 1996. Pp. 178-197

Booth, D. 1990. Stream channel incision following drainage basin urbanization. Water Resources Bulletin. 26(3): 407-417.

Brooklyn Botanic Garden. 2004. Using Spectacular Wetland Plantings to Reduce Runoff.

Buttle, J. and F. Xu. 1988. Snowmelt Runoff in Suburban Environments. Nordic Hydrology, 19:19-40.Cappiella, K. and K. Brown. 2001. Impervious Cover and Land Use in the Chesapeake Bay Watershed. Center for Watershed Protection, Ellicott City, Maryland.

Cappiella, K., T. Schueler, T. Wright. 2004. Urban Watershed Forestry Manual. Available from www.cwp.org

Caraco, D. and R. Claytor. 1997. Stormwater BMP design supplement for cold climates. Center for Watershed Protection. Ellicott City, MD

The Cardinal Group, Inc. Accessed 2002. www.greenroofs.ca.

Center for Watershed Protection, 1996. *Design of Filtering Systems.* Available from www.cwp.org.

Center for Watershed Protection. 1998. Better Site Design: A Handbook for Changing Development Rules in Your Community. Available from www.cwp.org

Center for Watershed Protection. 1998. Nutrient Loading from Conventional and Innovative Site Development. Prepared for: Chesapeake Research Consortium. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection. 2002. The Vermont Stormwater Management Manual, Volume I – Stormwater Treatment Standards. Vermont Agency of Natural Resources. April 2002. Available from: http://www.vtwaterquality.org/stormwater/docs/sw_manual-vol1.pdf

Center for Watershed Protection. August 2003. *New York State Stormwater Management Design Manual*. Prepared for New York State Department of Environmental Conservation, Albany, New York.

Chollak, T. and P. Rosenfeld. 1998. Guidelines for Landscaping with Compost-Amended Soils City of Redmond Public Works.

City of Austin, TX. 1988. Water Quality Management. In, Environmental Criteria Manual. Environmental and Conservation Services. Austin, TX.

City of Chicago. Accessed 2005. *Guide to Rooftop Gardening.*

City of Portland. 2000. *Stormwater Management Manual.* City of Portland. Portland, Oregon.

City of Portland, Oregon. 2004. Stormwater Management Manual. Bureau of Environmental Services, Portland, OR. Available from http://www.portlandonline.com/bes/

City of Portland. 2008. Soil Specification for Vegetated Stormwater Facilities. Portland Stormwater Management Manual. Portland, Oregon

City of Toronto Tree Advocacy Planting Program website: http://www.city.toronto.on.ca/parks/treeadvocacy.htm

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Ellicott City, MD.

Composting Council (TCC). 1997. Development of a landscape architect specification for *compost utilization*. Alexandria, VA.

Crawford, J. and D. Lenat. 1989. Effects of land use on water quality and the biota of three streams in the Piedmont Province of North Carolina. USGS. Water Resources Investigations Report 89-4007. Raleigh, NC, 67 pp.

Crunkilton, R. et al. 1996. Assessment of the response of aquatic organisms to long-term insitu exposures of urban runoff. In: Effects of Watershed Development and Management on Aquatic Ecosystems: Proceedings of an Engineering Foundation Conference. Snowbird, UT.

CSN Technical Bulletin No. 4, Technical Support for the Baywide Runoff Reduction Method, Version 2.0. Available at www.chesapeakestormwater.net.

Demers, C. and R. Sage. 1990. Effects of road deicing salts on chloride levels in four Adirondack streams. Water, Air and Soil Pollution. 49: 369-373.

Dunne T. and L. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York, NY.

Ferguson, B. 2005. *Porous Pavements.* CRC Press.

Flinker, P., 2005. Rhode Island Urban Environmental Design Manual “Green Rooftop Systems” Narrative. Sustainable Watersheds Office Rhode Island Department of Environmental Management.

Flinker, P., H. Dodson, S. la Cour, H. Blanchette, K. Wilson, R Claytor, and N. Kelly. 2005. The Urban Environmental Design Manual. Rhode Island Department of Environmental Management, Providence, Rhode Island.

Galli, J. 1991. Thermal impacts associated with urbanization and stormwater management best management practices. Metropolitan Washington Council of Governments. Maryland Department of Environment. Washington, D.C. 188 pp.

Galli, J. 1990. Peat-Sand Filters: A Proposed Stormwater Management Practice for Urbanized Areas. MWCOG. Washington, DC.

Granger, R., D. Gray and D. Dyck. 1984. Snowmelt Infiltration to frozen Prairie Soils. Canadian Journal of Earth Science, 21:669-677

Hammer, T. 1972. Stream channel enlargement due to urbanization. Water Resources Research. 8(6): 1530-1540.

Harrington, B. W. 1987. Design Procedures for Stormwater Management Extended Detention Structures. Report to Water Resources Administration. Maryland Department of the Environment. Annapolis, MD.

Hollis, F. 1975. The effects of urbanization on floods of different recurrence intervals. *Water Resources Research*, 11:431-435.

Holman-Dodds, L. 2004. Chapter 6. Assessing infiltration-based stormwater practices. PhD Dissertation. Department of Hydroscience and Engineering. University of Iowa. Iowa City, IA.

Horner, et al. 1996. Watershed Determinates of Ecosystem Functioning. In: *Effects of Watershed Development and Management on Aquatic Ecosystems.* Roesner, L.A. (editor). Snowbird Utah. August 4-9, 1996. Engineering Foundation.

International Society of Arboriculture website: http://www.isa-arbor.com/publications.

Iowa Rain Garden Design and Installation Manual, 2008 www.iowastormwater.org

Jeffries, D. 1988. Snowpack Release of Pollutants. National Water Research Institute, Report No. 88-06. Burlington, ON, Canada.

Kessner, K., 2000. How to Build a Rainwater Catchment Cistern. The March Hare, Summer 2000, Issue 25, http://www.dancingrabbit.org/building/cistern.html

King County Department of Development & Environmental Services, *Achieving the Post-construction Soil Standard*, January 1, 2005.

Kundell, J. and T. Rasmussen. 1995. Recommendations of the Georgia Board of Regent’s scientific panel on evaluating the erosion measurement standard defined by the Georgia erosion and sedimentation act. In Proceedings of the 1995 Georgia Water Resources Conference. Athens, Georgia.

Lacey, John. 2008. NYSDEC Deep-Ripping and Decompaction, *Guidelines for Infiltration and De-compaction*, New York State Department of Environmental Conservation.

Lenhart, J. 2007. Compost as a soil amendment for water quality treatment facilities. Proceedings 2007 LID Conference. Wilmington, NC

Leopold, L. 1994. A View of the River. Harvard University Press, Cambridge, MA.

Liptan, T. and E. Strecker. 2003. *Ecoroofs – A More Sustainable Infrastructure*. Presented at Urban Stormwater: Enhancing Programs at the Local Level. February 17-20, 2003. Cosponsored by US EPA, Chicago Botanic Gardens and Conservation Technology Information Center. Chicago, Illinois.

Low Impact Development Center, Inc. (LID). http://www.lid-stormwater.net/

Low Impact Development Center. *Guideline for Soil Amendments*. Available from: https://lowimpactdevelopment.org/

MacRae, C. 1996. Experience from morphological research on Canadian streams: is control of the two-year frequency runoff event the best basis for stream channel protection? *In* Effects of Watershed development and Management on Aquatic Systems. L. Roesner (ed.) Engineering Foundation Conference. Proceedings. Snowbird, UT. August 4-9, 1996. pp. 144-160.

MacRae, C. and M. DeAndrea, 1999. Assessing the impact of urbanization on channel morphology. 2nd International Conference on Natural Channel Systems. Niagra Falls, OT.

MacRae C. and A. Rowney. 1992. The role of moderate flow events and bank structure in the determination of channel response to urbanization. 45th Annual Conference. Resolving Conflicts and Uncertainty in Water Management. Proceeding of the Canadian Water Resources Association. June 1992. Kingston, Ontario.

Magco, Inc. Accessed 2003. Intensive and Extensive Green Roofs.

Marsalek, J. 1991. Urban Drainage in Cold Climates: Problems, Solutions and Research Needs. IN: New Technologies in Urban Drainage. Elsevier Applied Science. New York, N.Y.

Maryland Department of the Environment (MDE). Green Roof - Fact Sheet. Maryland's Stormwater Management Manual. Available from: http://www.mde.state.md.us/

Maryland Environmental Design Program (MEDP). Accessed 2009. http://www.dnr.state.md.us/ed/rainbarrel.html

Masterson, J and R. Bannerman. 1994. Impacts of storm water runoff on urban streams in Milwaukee Co., Wisconsin. In Proceedings of the American Water Resources Association, National Symposium on Water Quality. pp. 123-133.

May, C. R. Horner, J. Karr, B. Mar, and E. Welch. 1997. Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion. *Watershed Protection Techniques*, 2(4): 483-494.

Metropolitan Washington Council of Governments (MWCOG). 1989. Save the Anacostia Report. Metropolitan Washington Council of Governments. Washington, D.C.

Metropolitan Washington Council of Governments (MWCOG), 1992. Watershed Restoration Sourcebook. Department of Environmental Programs, MWCOG, Washington, DC.

Metropolitan Council, 2001. Minnesota Urban Small Sites Best Management Practices (BMP) Manual.

McCuen, R. 1979. Downstream effects of stormwater management basins. Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY11.

McCuen R. and G. Moglen. 1988. Multicriterion stormwater management methods. Journal of Water Resources Planning and Management. (114) 4.

Monroe County Environmental Management Council. 1987. The use of road deicing salt on state roads in Monroe County. Monroe County, NY.

Morisawa, M and E. La Flure. 1979. Hydraulic geometry, stream equalization and urbanization. In the Proceedings of the Tenth Annual Geomorphology Symposia Series entitled “Adjustments of the Fluvial System” held in Binghamton, NY. September 21-22, 1979. Kendall/Hunt Publishing Company, Dubuque, IA.

Natural Resources Conservation Service. 1984. Engineering Field Manual for Conservation Practices. USDA. Washington D.C.

Natural Resources Defense Council. 2000. Testing the Waters: A Guide to Water Quality at Vacation Beaches. Available online at. http://www.nrdc.org

New York City Department of Design & Construction Office of Sustainable Design http://www.nyc.gov/html/ddc/downloads/pdf/ddc_sd-sitedesignmanual.pdf

New York City Department of Environmental Protection (NYC DEP). 1999. Development of a water quality guidance value for Phase II Total Maximum Daily Loads (TMDLs) in the New York City Reservoirs. Prepared by Dr. Kimberlee Kane, Dr. Michael A. Principe, and Dr. Carol Stepczuk, Division of Drinking Water Quality Control, Bureau of Water Supply, Quality and Protection.

New York Floral Association: New York Floral Atlas website: http://www.newyork.plantatlas.usf.edu/

New York State Department of Agriculture and Markets. https://agriculture.ny.gov/

New York State Department of Environmental Conservation (NYS DEC). 1989. Guidelines for Design of Dams. Albany, NY.

Oberts, G. 1994. Influence of snowmelt dynamics on stormwater runoff quality. *Watershed Protection Techniques*. 1(2):55-61.

Peck, S. and M. Kuhn. Accessed 2003. *Design Guidelines for Green Roofs*. http://www.cmhc-schl.gc.ca/en/imquaf/himu/himu_002.cfm

Pinkham, Richard. Nov/Dec 2001. *Daylighting: New Life for Buried Streams.* Article from Stormwater Magazine Vol. 2, No. 6. Forester Communications. Caledonia, MI. Available from www.stormh2o.com

Pitt, R. 1995. Effects of Urban Runoff on Aquatic Biota. In Handbook of Ecotoxicology. Lewis Publishers/CRC Press, Inc., Boca Raton, Florida.

Portland Bureau of Environmental Services (PBES). December 2004. Liberty Centre Parking Garage. http://www.portlandonline.com/bes/index.cfm?c=38135

Prince George's County, MD. 1999. Low-Impact Development Design Strategies: An Integrated Design Approach. Prince George's County, Maryland, Department of Environmental Resources, Largo, Maryland. Available from www.epa.gov

Rabanal, F. and T. Grizzard. 1995. Concentrations of selected constituents in runoff from impervious surfaces in four urban land use catchments of different land use. In Proceedings of the 4th Biennial Stormwater Research Conference. Clearwater, FL.

Rain Gardens, A how-to manual for homeowners, Wisconsin department of Natural Resources DNR Publication PUB-WT-776 2003.

Richey, J.S. 1982. Effects of urbanization on a lowland stream in urban Washington. PhD Dissertation. University of Washington.

Roa-Espinosa. 2006. An introduction to soil compaction and the subsoiling practice. technical note. Dane County Land Conservation Department. Madison, Wisconsin.

Roofscapes, Inc. Accessed 2005. Green Technology for the Urban Environment. www.roofmeadow.com.

Sauer V. *et al*. 1983. Flood Characteristics of Urban Watersheds in the United States. US Geological Survey Water Supply Paper 2207.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments. Washington, DC

Schueler, T. 1992. Design of Stormwater Wetland Systems. Metropolitan Washington Council of Governments. Washington, DC.

Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100-111.

Schueler, T. 1995. Site Planning for Urban Stream Protection. Center for Watershed Protection, Ellicott City, Maryland.

Schueler, T. 1999. Microbes and Urban Watersheds. *Watershed Protection Techniques.* 3(1): 551-596.

Schueler, T. 2000. *"The Compaction of Urban Soils"* The Practice of Watershed Protection. P. 210-214. Center for Watershed Protection

Scott, J., C. Steward and Q. Stober. 1986. Effects of urban development on fish population dynamics in Kelsey Creek, Washington. Transactions of the American Fisheries Society. 115:555-567.

SERAIEG, Southern Extension and Research Activity Information Exchange Group, Interpreting Soil Organic Matter Tests, (2005). http://www.clemson.edu/agsrvlb/sera6/SERA6-ORGANIC_doc.pdf

Smullen, J. and K. Cave. 1998. Updating the U.S. Nationwide Urban Runoff Quality Database. 3rd International Conference on Diffuse Pollution. August 31 - September 4, 1998. Scottish Environment Protection Agency, Edinburg Scotland.

Snodgrass, E. Accessed 2003. http://www.greenroofplants.com/

Soils for Salmon. 2003. Soil Restoration and compost amendments. Available from: http://www.soilsforsalmon.org/

Spence, B., G. Lomnicky, R. Hughes, and R. Novitzki. 1996. An Ecosystem Approach to Salmonid Conservation. TR-401-96-6057. ManTech Environmental Research Services Corporation, Corvallis, OR. Available from: http://www.nwr.noaa.gov

Spinello, A.G., D.L. Simmons. 1992. Base Flow of 10 South-Shore Streams, Long Island, New York, 1976-1985, and the Effects of Urbanization on Base Flow and Flow Duration. United States Geological Survey. *Water Resources Investigative Report* 90-4205.

Stensrod, O. and Gosback, J. September 1978. Translated May 1989, Johansen, J. and Seifert R. *Water Cistern Construction for Small Houses.* Alaska Building Research Series, HCM-01557.

Stephens, K. A., Graham, P. and D. Reid. 2002. *Stormwater Planning: A Guidebook for British Columbia*. British Columbia Ministry of Water, Land and Air Protection.

Steuer, Jeffrey, William Selbig, Nancy Hornewer, and Jeffrey Prey. 1997. Sources of Contamination in an Urban Basin in Marquette, Michigan and an Analysis of Concentrations, Loads, and Data Quality. U.S. Geological Survey, Water-Resources Investigations Report 97-4242.

Taylor, B.L. 1993. The influences of wetland and watershed morphological characteristics and relationships to wetland vegetation communities. Master's thesis. Dept. of Civil Engineering. University of Washington, Seattle, WA.

Technology Acceptance and Reciprocity Partnership (TARP) Protocol for Stormwater Best Management Practice Demonstrations, updated 2003.

Texas Water Development Board (TWDB). *2005. The Texas Manual on Rainwater Harvesting 3rd Edition.*

Toronto and Region Conservation Authority and Credit Valley Conservation Authority. 2010. Low Impact Development Stormwater Management Planning and Design Guide. Available from: https://cvc.ca/

Trimble, S. 1997. Contribution of stream channel erosion to sediment yield from and urbanizing watershed. *Science*. 278: 1442-1444.

United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). PLANTS database: http://plants.usda.gov/

United States Environmental Protection Agency (USEPA). 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA-840-B-92-002. U.S. EPA, Office of Water, Washington, DC.

United States Environmental Protection Agency (USEPA). 1999. Storm Water Technology Fact Sheet, Porous Pavement.

United States Environmental Protection Agency (USEPA). 2005. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas,* EPA Document - EPA-841-B-05-004.

University of New Hampshire Stormwater Center (UNHSC). 2009. Design Specifications for Porous Asphalt Pavement and Infiltration Beds.

The Urban Garden Center (UGC). http://www.urbangardencenter.com

US Composting Council. www.compostingcouncil.org

Velazquez, L. S. 2005. *Greenroofs.com*. http://www.greenroofs.com

Waschbusch *et al*. 2000. Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin, 1994-1995. In: National Conference on Tools for Urban Water Resource Management and Protection. US EPA February 2000: pp. 15-55.

Washington State Department of Ecology. 1992. Stormwater Management Manual for the Puget Sound Basin (Technical Manual).

Watershed Management Institute (WMI). 1997. Operation, Maintenance, and Management of Stormwater Management Systems. Prepared for: US EPA Office of Water. Washington, DC.

Winer, R. 2000. National Pollutant Removal Database for Stormwater Treatment Practices: 2nd Edition. Center for Watershed Protection. Ellicott City

Woodward - Clyde Consultants 1992. Source Identification and Control Report. Prepared for the Santa Clara Valley Nonpoint Source Control Program. Oakland, California.

Yoder, C., R. Miltner, and D. White. 1999. Assessing the Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds. pp 16-28. In R. Kirschener (ed.) Proceedings of the *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments.* EPA/625/R-99/002

Yoder C., 1991. The integrated biosurvey as a tool for evaluation of aquatic life use attainment and impairment in Ohio surface waters. in Biological Criteria: Research and Regulation; 1991.

Zuzel, J., R. Greewalt, and R.R. Allmaras. 1983. Rain on Snow: Shallow, Transient Snowpacks with Frozen Soils. Proceedings of the Western Snow Conference. pp. 67-75.

Glossary

ALTERNATIVE SIZING CRITERIA - The sizing criteria that can be achieved on construction projects that include redevelopment activities.

ALTERNATIVE STORMWATER MANAGEMENT PRACTICE - Stormwater management practices that are outlined in Chapter 9 for potential application to redevelopment activities and are designed and implemented in accordance with the recommendations in Chapter 9.

ANTI-SEEP COLLAR - An impermeable diaphragm usually of sheet metal or concrete constructed at intervals within the zone of saturation along the conduit of a principal spillway to increase the seepage length along the conduit and thereby prevent piping or seepage along the conduit.

ANTI-VORTEX DEVICE - A device designed and placed on the top of a riser or at the entrance of a pipe to prevent the formation of a vortex in the water at the entrance.

"AS-BUILT" - Drawing or certification of conditions as they were actually constructed.

AQUATIC BENCH - A ten to fifteen foot wide bench which is located around the inside perimeter of a permanent pool and is normally vegetated with aquatic plants; the goal is to provide pollutant removal and enhance safety in areas using stormwater pond SMPs.

AQUIFER - A geological formation which contains and transports groundwater.

AUXILIARY SPILLWAY - A dam spillway designed and constructed to discharge flow in excess of the principal spillway design discharge.

BAFFLES - Guides, grids, grating or similar devices placed in a pond to deflect or regulate flow and create a longer flow path.

BANKFULL FLOW - The condition where streamflow just fills a stream channel up to the top of the bank and at a point where the water begins to overflow onto a floodplain.

BARREL - The closed conduit used to convey water under or through an embankment: part of the principal spillway.

BASE FLOW - The stream discharge from ground water.

BERM - A shelf that breaks the continuity of a slope; a linear embankment or dike.

BETTER SITE DESIGN - Incorporates non-structural and natural approaches to new and redevelopment projects to reduce effects on watersheds by conserving natural areas, reducing impervious cover and better integrating stormwater treatment.

BIORETENTION - A water quality practice that utilizes landscaping and a designed filter media to treat urban stormwater runoff by collecting it in shallow depressions, filtering it through the media then infiltrating it into the native soil or collecting it through an outlet drainage system.

CHANNEL - A natural stream that conveys water; a ditch or channel excavated for the flow of water.

CHANNEL STABILIZATION - Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, structural linings, vegetation and other measures.

CHECK DAM - A small dam constructed in a gully or other small watercourse to decrease the stream flow velocity (by reducing the channel gradient), minimize channel scour, and promote deposition of sediment.

CHUTE - A high velocity, open channel for conveying water to a lower level without erosion.

CLAY (SOILS) - 1. A mineral soil separate consisting of particles less than 0.002 millimeter in equivalent diameter. 2. A soil texture class. 3. (Engineering) A fine grained soil (more than 50 percent passing the No. 200 sieve) that has a high plasticity index in relation to the liquid limit.

COCONUT ROLLS - Also known as coir rolls, these are rolls of natural coconut fiber designed to be used for streambank stabilization and as a possible organic constituent of bioretention media.

COMPACTION (SOILS) - Any process by which the soil grains are rearranged to decrease void space and bring them in closer contact with one another, thereby increasing the weight of solid material per unit of volume, increasing the shear and bearing strength and reducing permeability.

CONDUIT - Any channel intended for the conveyance of water, whether open or closed.

CONSERVATION DESIGN - Includes laying out the elements of a development project in such a way that the site design takes advantage of a site's natural features, preserves the more sensitive areas and identifies any site constraints and opportunities to prevent effects.

CONSERVATION EASEMENT - a voluntary, legal agreement that protects the natural resources of a parcel of land by restricting future land use and/or development on the property "in perpetuity" (permanently). This agreement is held between a landowner and a government agency or land trust, with the landowner maintaining ownership. The conservation easement can either be sold or donated, resulting in a variety of tax benefits for the landowner. The easement is recorded with the property's deed and transfers to all future landowners.

CONTOUR - 1. An imaginary line on the surface of the earth connecting points of the same elevation. 2. A line drawn on a map connecting points of the same elevation.

CONTRIBUTING AREA - the total on-site and off-site area, including pervious and impervious surfaces, that is tributary to an SMP.

CONVENTIONAL SITE DESIGN - For the purposes of this document, conventional design can be viewed as the style of suburban development that has evolved during the past 50 years and generally involves larger lot development, clearing and grading of significant portions of a site, wider streets and larger cul-de-sacs, enclosed drainage systems for stormwater conveyance and large "hole-in-the-ground" detention basins.

CORE TRENCH - A trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CRADLE - A structure usually of concrete shaped to fit around the bottom and sides of a conduit to support the conduit, increase its strength and in dams, to fill all voids between the underside of the conduit and the soil.

CREST - 1. The top of a dam, dike, spillway or weir, frequently restricted to the overflow portion. 2. The summit of a wave or peak of a flood.

CRUSHED STONE - Aggregate consisting of angular particles produced by mechanically crushing rock.

CURVE NUMBER (CN) - A numerical representation of a given area's hydrologic soil group, plant cover, impervious cover, interception and surface storage derived in accordance with Natural Resources Conservation Service methods. This number is used to convert rainfall volume into runoff volume.

CUT - Portion of land surface or area from which earth has been removed or will be removed by excavation; the depth below original ground surface to excavated surface.

CUT-AND-FILL - Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

CUTOFF - A wall or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CZARA - Acronym used for the Coastal Zone Act Reauthorization Amendments of 1990. These amendments sought to address the issue of nonpoint source pollution issue by requiring states to develop Coastal Nonpoint Pollution Control Programs in order to receive federal funds.

DAM - A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, sediment or other debris.

DESIGN GUIDANCE - Features that enhance the performance but may not be necessary for all applications and may be modified if it does not improve the performance of the practices in a specific site.

DESIGN POINT – A location, on-site or off-site including but not limited to a concentrated point (end section, catch basin, etc.), the entire perimeter of a waterbody or permanent pool (wetland, stream, etc.), the full length of an existing on-site channel that is not being disturbed, or the full length of a natural flow spreader, where stormwater runoff from a given subcatchment or subcatchments converges and discharges.

DETENTION - The temporary storage of storm runoff in a SMP with the goals of controlling peak discharge rates and providing gravity settling of pollutants.

DETENTION STRUCTURE - A structure constructed for the purpose of temporary storage of stream flow or surface runoff and gradual release of stored water at controlled rates.

DEVIATION FROM STANDARDS - Non-compliance with the technical standards set by this technical standard. To be in compliance with this technical standard (Design Manual), projects must meet both performance and sizing criteria. The Department will only accept deviations from the technical standards that involve the use of an alternative post-construction stormwater management practice or a modification to one of the practices from this technical standard that has been demonstrated to be equivalent to this technical standard.

DIKE - An embankment to confine or control water, for example, one built along the banks of a river to prevent overflow or lowlands; a levee.

DISCONNECTED IMPERVIOUS AREA - Impervious area that is not directly connected to a stream or drainage system, but which directs runoff towards pervious areas where it can infiltrate, be filtered, and slowed down.

DISTRIBUTED RUNOFF CONTROL (DRC) - A stream channel protection criteria which utilizes a non-uniform distribution of the storage stage-discharge relationship within a SMP to minimize the change in channel erosion potential from predeveloped to developed conditions.

DISTURBED AREA - An area in which the natural vegetative soil cover has been removed or altered and, therefore, is susceptible to erosion.

DIVERSION - A channel with a supporting ridge on the lower side constructed across the slope to divert water from areas where it is in excess to sites where it can be used or disposed of safely. Diversions differ from terraces in that they are individually designed.

DRAINAGE - 1. The removal of excess surface water or ground water from land by means of surface or subsurface drains. 2. Soils characteristics that affect natural drainage.

DRAINAGE AREA (WATERSHED) - All land and water area from which runoff may run to a common (design) point.

DROP STRUCTURE - A structure for dropping water to a lower level and dissipating surplus energy; a fall. The drop may be vertical or inclined.

DRY SWALE - An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media.

EFFECTIVE BYPASS - The runoff that leaves the site untreated. Example: flow that pass over the weir in a filter system not treated (i.e., not effected by the primary removal mechanism).

ENERGY DISSIPATOR - A designed device such as an apron of riprap or a concrete structure placed at the end of a water transmitting apparatus such as pipe, paved ditch or paved chute for the purpose of reducing the velocity, energy and turbulence of the discharged water.

EROSION - 1. The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice or gravity. The following terms are used to describe different types of water erosion:

> Accelerated erosion - Erosion much more rapid than normal, natural or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophes that expose base surfaces, for example, fires.
>
> Gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 or 2 feet to as much as 75 to 100 feet.

Rill erosion - An erosion process in which numerous small channels only several inches deep are formed. See rill.

Sheet erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not subsequently be removed by surface runoff.

EROSIVE VELOCITIES - Velocities of water that are high enough to wear away the land surface. Exposed soil will generally erode faster than stabilized soils. Erosive velocities will vary according to the soil type, slope, structural, or vegetative stabilization used to protect the soil.

EXFILTRATION - The downward movement of water through the soil; the downward flow of runoff from the bottom of an infiltration SMP into the soil.

EXTENDED DETENTION (ED) - A stormwater design feature that provides for the gradual release of a volume of water over a 12 to 48 hour interval in order to increase settling of urban pollutants and protect downstream channels from frequent storm events.

EXTREME FLOOD (Q_F) - The storage volume required to control those infrequent but large storm events in which overbank flows approach the floodplain boundaries of the 100-year flood.

FILTER BED - The section of a constructed filtration device that houses the filter media and the outflow piping.

FILTER FENCE - A geotextile fabric designed to trap sediment and filter runoff.

FILTER MEDIA - The sand, soil, or other organic material in a filtration device used to provide a permeable surface for pollutant and sediment removal.

FILTER STRIP - A strip of permanent vegetation above ponds, diversions and other structures to retard flow of runoff water, causing deposition of transported material, thereby reducing sediment flow.

FINES (SOIL) - Could include particles small enough to pass through a U.S. standard #200 sieve.

FLOODPLAIN - The land area that is subject to inundation from a flood that has a one percent chance of being equaled or exceeded in any given year. This is typically thought of as the 100-year flood.

FLOW SPLITTER - An engineered, hydraulic structure designed to divert a percentage of storm flow to a SMP located out of the primary channel, or to direct stormwater to a parallel pipe system, or to bypass a portion of baseflow around a SMP.

FOREBAY - Storage space located near a stormwater SMP inlet that serves to trap incoming coarse sediments before they accumulate in the main treatment area.

FREEBOARD (HYDRAULICS) - The distance between the maximum water surface elevation anticipated in design and the top of retaining banks or structures. Freeboard is provided to prevent overtopping due to unforeseen conditions.

FOURTH ORDER STREAM - Designation of stream size where many water quantity requirements may not be needed. A first order stream is identified by "blue lines" on USGS quad sheets. A second order stream is the confluence of two first order streams, and so on.

FRENCH DRAIN - A type of drain consisting of an excavated trench refilled with pervious material, such as coarse sand, gravel or crushed stone, through whose voids water percolates and flows to an outlet.

GABION - A flexible woven-wire basket composed of two to six rectangular cells filled with small stones. Gabions may be assembled into many types of structures such as revetments, retaining walls, channel liners, drop structures and groins.

GABION MATTRESS - A thin gabion, usually six or nine inches thick, used to line channels for erosion control.

GRADE - 1. The slope of a road, channel or natural ground. 2. The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit. 3. To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.

GRASS CHANNEL - A open vegetated channel used to convey runoff and to provide treatment by filtering out pollutants and sediments.

GRAVEL - 1. Aggregate consisting of mixed sizes of 1/4 inch to 3 inch particles which normally occur in or near old streambeds and have been worn smooth by the action of water. 2. A soil having particle sizes, according to the Unified Soil Classification System, ranging from the No. 4 sieve size angular in shape as produced by mechanical crushing.

GRAVEL DIAPHRAGM - A linear trench filled with gravel used as pretreatment and inflow regulation in stormwater filtering systems.

GRAVEL FILTER - Washed and graded sand and gravel aggregate placed around a drain or well screen to prevent the movement of fine materials from the aquifer into the drain or well.

GREEN INFRASTRUCTURE – In the context of stormwater management, the term green infrastructure includes a wide array of practices at multiple scales to manage and treat stormwater, maintain and restore natural hydrology and ecological function by infiltration, evapotranspiration, capture and reuse of stormwater, and establishment of natural vegetative features. On a regional scale, green infrastructure is the preservation and restoration of natural landscape features, such as forests, floodplains and wetlands, coupled with policies such as infill and redevelopment that reduce overall imperviousness in a watershed or ecoregion. On the local scale green infrastructure consists of site- and neighborhood-specific practices and runoff reduction techniques. Such practices essentially result in runoff reduction and or establishment of habitat areas with significant utilization of soils, vegetation, and engineered media rather than traditional hardscape collection, conveyance and storage structures. Some examples include green roofs, trees and tree boxes, pervious pavement, rain gardens, vegetated swales, planters, reforestation, and protection and enhancement of riparian buffers and floodplains.

GROUND COVER - Plants which are low-growing and provide a thick growth which protects the soil as well as providing some beautification of the area occupied.

GULLY - A channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains or during the melting of snow. The distinction between gully and rill is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lessor depth and would be smoothed by ordinary farm tillage.

HEAD (HYDRAULICS) - 1. The height of water above any plane of reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various terms such as pressure head, velocity head, and head loss.

HERBACEOUS PERENNIAL (PLANTS) - A plant whose stems die back to the ground each year.

HI MARSH - A pondscaping zone within a stormwater wetland which exists from the surface of the normal pool to a six inch depth and typically contains the greatest density and diversity of emergent wetland plants.

HI MARSH WEDGES - Slices of shallow wetland (less than or equal to 6 inches) dividing a stormwater wetland.

HOT SPOT - Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

HYDRAULIC GRADIENT - The slope of the hydraulic grade line. The slope of the free surface of water flowing in an open channel that has uniform flow.

HYDROGRAPH - A graph showing variation in stage (depth) or discharge of a stream of water over a period of time.

HYDROLOGIC SOIL GROUP (HSG) - A Natural Resource Conservation Service classification system in which soils are categorized into four runoff potential groups. The groups range from A soils, with high permeability and little runoff production, to D soils, which have low permeability rates and produce much more runoff.

HYDROSEED - Seed or other material applied to areas in order to re-vegetate after a disturbance.

HYPOXIA - Lack of oxygen in a waterbody resulting from eutrophication.

IMPERVIOUS COVER (I) - Impermeable surfaces that cannot effectively infiltrate rainfall. This includes paved, concrete and compacted gravel surfaces (i.e. parking lots, driveways, roads, runways, and sidewalks); building rooftops and miscellaneous impermeable structures such as patios, pools, and sheds.

INDUSTRIAL STORMWATER PERMIT - An NPDES permit issued to a commercial industry or group of industries which regulates the pollutant levels associated with industrial storm water discharges or specifies on-site pollution control strategies.

INFEASIBLE – A practice that is not technologically possible, or not economically practicable and achievable in light of best industry practices.

INFILTRATION RATE (F_C) - The rate at which stormwater percolates into the subsoil measured in inches per hour.

INFILTRATION TRENCH - A shallow excavated channel backfilled with gravel and designed to provide temporary storage and permit percolation of runoff into the soil substrate.

INFLOW PROTECTION - A water handling device used to protect the transition area between any water conveyance (dike, swale, or swale dike) and a sediment trapping device.

LEVEL SPREADER - A device for distributing stormwater uniformly over the ground surface as sheet flow to prevent concentrated, erosive flows and promote infiltration.

LONG TERM RUNOFF VOLUME - Total runoff over a long period of time (>25 years).

MANNING'S FORMULA (HYDRAULICS) - A formula used to predict the velocity of water flow in an open channel or pipeline:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where V is the mean velocity of flow in feet per second; R is the hydraulic radius; S is the slope of the energy gradient or for assumed uniform flow the slope of the channel, in feet per foot; and n is the roughness coefficient or retardance factor of the channel lining.

MICROPOOL - A smaller permanent pool which is incorporated into the design of larger stormwater ponds to avoid resuspension or settling of particles and minimize impacts to adjacent natural features.

MICROTOPOGRAPHY - The complex contours along the bottom of a shallow marsh system, providing greater depth variation which increases the wetland plant diversity and increases the surface area to volume ratio of a stormwater wetland.

MULCH - Covering on surface of soil to protect and enhance certain characteristics, such as water retention qualities.

MUNICIPAL STORMWATER PERMIT - A SPDES permit issued to municipalities to regulate discharges from municipal separate storm sewers for compliance with EPA established water quality standards and/or to specify stormwater control strategies.

NATURAL AREAS - This is undisturbed land or previously disturbed land that has been restored and that retains pre-development hydrologic and water quality characteristics.

NEW DEVELOPMENT – Any land disturbance that does not meet the definition of Redevelopment Activity included in this glossary.

NITROGEN-FIXING (BACTERIA) - Bacteria having the ability to fix atmospheric nitrogen, making it available for use by plants. Inoculation of legume seeds is one way to insure a source of these bacteria for specified legumes.

NON-EROSIVE VELOCITY – The velocity within a channel that does not cause exposed soil to move or vegetative lining to unravel.

NON-STRUCTURAL STORMWATER CONTROL – Natural measures that reduce pollution level, do not require extensive construction or engineering efforts and/or promote pollutant reduction by eliminating the pollutant source.

NORMAL DEPTH - Depth of flow in an open conduit during uniform flow for the given conditions.

NPDES - Acronym for the National Pollutant Discharge Elimination System, which regulates point source and non-point source discharge.

Off-site - Areas outside of the "project area" that may contribute to the same design point as the "project area."

OFF-LINE - A stormwater management system designed to manage a storm event by diverting a percentage of stormwater events from a stream or storm drainage system.

ON-LINE - A stormwater management system designed to manage stormwater in its original stream or drainage channel.

ONE YEAR STORM ($Q_{P\,1}$) - A stormwater event which statistically has a 100% chance of being equaled or exceeded on average in a given year.

ONE HUNDRED YEAR STORM ($Q_{P\,100}$) A extreme rainfall which statistically has a one percent chance of being equaled or exceeded in any given year.

OPEN CHANNELS - Also known as swales, grass channels, and biofilters. These systems are used for the conveyance, retention, infiltration and filtration of stormwater runoff.

OUTFALL - The point where water flows from a conduit, stream, or drain.

OUTLET - The point at which water discharges from such things as a stream, river, lake, tidal basin, pipe, channel or drainage area.

OUTLET CHANNEL - A waterway constructed or altered primarily to carry water from man-made structures such as terraces, subsurface drains, diversions and impoundments.

PEAK DISCHARGE RATE - The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

PERFORMANCE CRITERIA - The design criteria listed under the “Required Elements” sections in Chapters 5, 6 and 10 of this Manual. It does not include the Sizing Criteria (i.e. WQv, RRv, Cpv, Qp and Qf) in Chapters 4, 9 and 10.

PERMANENT SEEDING - Results in establishing perennial vegetation which may remain on the area for many years.

PERMEABILITY - The rate of water movement through the soil column under saturated conditions

PERMISSIBLE VELOCITY (HYDRAULICS) - The highest average velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. A safe, non-eroding or allowable velocity

PH - A number from 0 to 14 denoting the common logarithm of the reciprocal of the hydrogen ion concentration. A pH of 7.0 denotes neutrality, higher values indicate alkalinity and lower values indicate acidity.

PHOSPHORUS INDEX - In this context, the Phosphorus Index or P Index is a risk assessment tool to quantify the potential for phosphorus runoff from soil. It is determined by laboratory testing using the Mehlick-3 phosphorus soil test and dividing the analytical result (in mg/l or ppm) by 1.2. Values greater than 100 are considered very high. Values ranging between 50 and 100 are considered high. Values between 25 and 50 are medium; values less than 25 are low. In general, a soil with a very high or high P-Index is less able to retain phosphorus because its sorption sites are already occupied. Conversely, a soil with a low or medium P Index is better able to retain phosphorus and reduce phosphorus runoff from soil.

PIPING - Removal of soil material through subsurface flow channels or “pipes” developed by seepage water.

PLUGS - Pieces of turf or sod, usually cut with a round tube, which can be used to propagate the turf or sod by vegetative means.

POCKET WETLAND - A stormwater wetland design adapted for the treatment of runoff from small drainage areas (< 5 acres) and which has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.

POND BUFFER - The area immediately surrounding a pond which acts as filter to remove pollutants and provide infiltration of stormwater prior to reaching the pond. Provides a separation barrier to adjacent development.

POND DRAIN - A pipe or other structure used to drain a permanent pool within a specified time period.

PONDSCAPING - Landscaping around stormwater ponds which emphasizes native vegetative species to meet specific design intentions. Species are selected for up to six zones in the pond and its surrounding buffer, based on their ability to tolerate inundation and/ or soil saturation.

POROSITY - Ratio of pore volume to total solids volume.

PRETREATMENT - Techniques employed in stormwater SMPs to provide storage or filtering to help trap coarse materials before they enter the system.

REDEVELOPMENT ACTIVITY - Disturbance and reconstruction of existing impervious area, including impervious areas that were removed from a project site within five (5) years of preliminary project plan submission to the local government (i.e. site plan, subdivision, etc.).

REQUIRED ELEMENT -Features of the design that are integral to the performance of the practice and must be used in all applications.

RETENTION - The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

REVERSE-SLOPE PIPE - A pipe which draws from below a permanent pool extending in a reverse angle up to the riser and which determines the water elevation of the permanent pool.

RIGHT-OF-WAY - Right of passage, as over another's property. A route that is lawful to use. A strip of land acquired for transport or utility construction.

RIP-RAP - Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

RISER - A vertical pipe or structure extending from the bottom of a pond SMP and houses the control devices (weirs/orifices) to achieve the discharge rates for specified designs.

ROUGHNESS COEFFICIENT (HYDRAULICS) - A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.

RR TECHNIQUE (AREA REDUCTION) – A green infrastructure technique that provides runoff reduction credit by subtracting a reduced Water Quality Volume, deducting a portion or the entirety of the contributing drainage area or contributing impervious area, from the required Water Quality Volume.

RR TECHNIQUE (VOLUME REDUCTION) – A green infrastructure technique that provides runoff reduction credit as a percentage of the provided Water Quality Volume.

RUNOFF (HYDRAULICS) - That portion of the precipitation on a drainage area that is discharged from the area in the stream channels. Types include surface runoff, ground water runoff or seepage.

RUNOFF COEFFICIENT (RV) - A value derived from a site impervious cover value that is applied to a given rainfall volume to yield a corresponding runoff volume.

SAFE CONVEYANCE – Discharging runoff through the practice outlet/overflow at a non-erosive velocity.

SAFE PASSAGE – Safely passing the Spillway Design Flood (SDF) and Service Spillway Design flood (SSDF) as defined in the NYSDEC "Guidelines for Design of Dams."

SAFETY BENCH - A flat area above the permanent pool and surrounding a stormwater pond designed to provide a separation from the pond pool and adjacent slopes.

SAND - 1. (Agronomy) A soil particle between 0.05 and 2.0 millimeters in diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System, a soil particle larger than the No. 200 sieve (0.074mm) and passing the No. 4 sieve (approximately 1/4 inch).

SEDIMENT - Solid material, both mineral and organic, that is in suspension, being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

SEEPAGE - 1. Water escaping through or emerging from the ground.2. The process by which water percolates through the soil.

SEEPAGE LENGTH - In sediment basins or ponds, the length along the pipe and around the anti-seep collars that is within the seepage zone through an embankment.

SERVICE SPILLWAY - The primary pipe or weir which carries baseflow and storm flow through the embankment.

SETBACKS - The minimum distance requirements for location of a structural SMP in relation to roads, wells, septic fields, other structures.

SHEET FLOW - Water, usually storm runoff, flowing in a thin layer over the ground surface.

SIDE SLOPES (ENGINEERING) - The slope of the sides of a channel, dam or embankment. It is customary to name the horizontal distance first, as 1.5 to 1, or frequently, 1 ½: 1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

SILT - 1. (Agronomy) A soil separate consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System a fine grained soil (more than 50 percent passing the No. 200 sieve) that has a low plasticity index in relation to the liquid limit.

SITE - At minimum applies to areas of disturbance. This technical standard refers to contributing areas to one design point as “site” or “project area”.

SITE LIMITATIONS **–S**ite conditions that prevent the use of an infiltration technique and or infiltration of the total WQv. Typical site limitations include: seasonal high groundwater, shallow depth to bedrock, and soils with an infiltration rate less than 0.5 inches/hour. The existence of site limitations shall be confirmed and documented using actual field testing (i.e. test pits, soil borings, and infiltration test) or using information from the most current United States Department of Agriculture (USDA) Soil Survey for the County where the project is located.

SOIL TEST - Chemical analysis of soil to determine needs for fertilizers or amendments for species of plant being grown.

SPILLWAY - An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled to regulate the discharge of excess water.

STABILIZATION - Providing adequate measures, vegetative and/or structural that will prevent erosion from occurring.

STAGE (HYDRAULICS) - The variable water surface or the water surface elevation above any chosen datum.

STEEP SLOPES - means land area designated on the current United States Department of Agriculture (“USDA”) Soil Survey as Soil Slope Phase “D”, (provided the map unit name is inclusive of slopes greater than 25%) , or Soil Slope Phase E or F, (regardless of the map unit name), or a combination of the three designations.

STILLING BASIN - An open structure or excavation at the foot of an outfall, conduit, chute, drop, or spillway to reduce the energy of the descending stream of water.

STORMWATER FILTERING - Stormwater treatment methods which utilize an artificial media to filter out pollutants entrained in urban runoff.

STORMWATER MANAGEMENT PRACTICE (SMP) – A standard stormwater management practice that appears in Chapter 3 of this Manual, is sized in accordance with Chapter 4 or 10, and is designed in accordance with Chapter 6 or 10 of this Manual.

STORMWATER PONDS - A land depression or impoundment created for the detention or retention of stormwater runoff.

STORMWATER SIZING CRITERIA – Criteria comprised of the following four elements: Water Quality Treatment, Runoff Reduction, Channel Protection, Overbank Flooding, and control of extreme storms as defined in Chapters 4 and 10 of this Manual for standard practices and any other requirements for enhanced treatment.

STORMWATER WETLANDS - Shallow, constructed pools that capture stormwater and allow for the growth of characteristic wetland vegetation.

STREAM BUFFERS - Zones of variable width which are located along both sides of a stream and are designed to provide a protective natural area along a stream corridor.

STREAM CHANNEL PROTECTION (CP_V) - A design criteria which requires 24-hour detention of the one year post-developed, 24-hour storm event for the control of stream channel erosion.

STRUCTURAL SMPS - Devices which are engineered and constructed to provide temporary storage and treatment of stormwater runoff.

SUBGRADE - The soil prepared and compacted to support a structure or a pavement system.

TAILWATER - Water, in a river or channel, immediately downstream from a structure.

TECHNICAL RELEASE NO. 20 (TR-20) - A Soil Conservation Service (now NRCS) watershed hydrology computer model that is used to compute runoff volumes and route storm events through a stream valley and/or ponds.

TECHNICAL RELEASE No. 55 (TR-55) - A watershed hydrology model developed by the Soil Conservation Service (now NRCS) used to calculate runoff volumes and provide a simplified routing for storm events through ponds.

TEMPORARY SEEDING - A seeding which is made to provide temporary cover for the soil while waiting for further construction or other activity to take place.

TEN YEAR STORM ($Q_{P\ 10}$) - The peak discharge rate associated with a 24-hour storm event that has a 100% chance of being equaled or exceeded in a given ten year.

TIME OF CONCENTRATION - Is quantified from the hydraulically most distant point by time NOT the remotest point.

TOE (OF SLOPE) - Where the slope stops or levels out. Bottom of the slope.

TOE WALL - Downstream wall of a structure, usually to prevent flowing water from eroding under the structure.

TOPSOIL - Fertile or desirable soil material used to top dress road banks, subsoils, parent material, etc.

TOTAL IMPERVIOUS AREA - This is the total area of impervious cover, within the contributing area to an SMP, that prevents water from infiltrating into the underlying soils.

TOTAL SUSPENDED SOLIDS - The total amount of soil particulate matter, including both organic and inorganic material, suspended in the water column.

TRASH RACK - Grill, grate or other device at the intake of a channel, pipe, drain or spillway for the purpose of preventing oversized debris from entering the structure.

TROUT WATERS - Waters classified as (T) or (TS) by the New York State DEC.

TWO YEAR STORM ($Q_{P\ 2}$) - The peak discharge rate associated with a 24 hour storm event that has a 100% chance of being equaled or exceeded in a given two year.

ULTIMATE CONDITION - Full watershed build-out based on existing zoning.

ULTRA-URBAN - Densely developed urban areas in which little pervious surface exists.

VELOCITY HEAD - Head due to the velocity of a moving fluid, equal to the square of the mean velocity divided by twice the acceleration due to gravity (32.16 feet per second per second).

VOLUMETRIC RUNOFF COEFFICIENT (R_v) - The value that is applied to a given rainfall volume to yield a corresponding runoff volume based on the percent impervious cover in a drainage basin.

WALKING ZONE – The clear width of the sidewalk where pedestrian can walk unobstructed.

WATER QUALITY EFFICIENCY - A term that is intended to indicate the performance of the SMP by itself (not the full system including bypass).

WATER QUALITY VOLUME (WQ_V) - The volume of stormwater runoff, generated from the 90th percentile rain event, that shall be captured and treated by stormwater management practice(s) or the runoff from the 1-year, 24-hour storm event.

WATER SURFACE PROFILE - The longitudinal profile assumed by the surface of a stream flowing in an open channel; the hydraulic grade line.

WEDGES - Design feature in stormwater wetlands which increases flow path length to provide for extended detention and treatment of runoff.

WET SWALE - An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

WETTED PERIMETER - The length of the line of intersection of the plane or the hydraulic cross-section with the wetted surface of the channel.

WING WALL - Side wall extensions of a structure used to prevent sloughing of banks or channels and to direct and confine overflow.

New York State of Opportunity | Department of Environmental Conservation

APPENDIX A

NYSDEC Guidelines for Design of Dams

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New York State

DEC

Division of Water

Guidelines for Design of Dams

January 1985
Revised January 1989

New York State Department of Environmental Conservation

George E. Pataki, *Governor*   John P. Cahill, *Commissioner*

GUIDELINES FOR
DESIGN OF DAMS

NEW YORK STATE

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

DIVISION OF WATER

BUREAU OF FLOOD PROTECTION

DAM SAFETY SECTION

50 WOLF ROAD

ALBANY, NEW YORK 12233-3507

GUIDELINES FOR DESIGN OF DAMS

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The January 1988 revision involves:

Page	Item
2	Introduction
4	Corrected definition for the Service Spillway Design Flood (SSDF)
6	Construction Inspection
11	Insertion of Section 6A, Flashboard Policy
14	Filter and drainage diaphragm replacing antiseep collars for pipe conduits
19	Vegetation Control
22	Insertion of Loading Condition 3A
25	Cofferdams
28	The addition of references 3, 4, 5 and 6

PREFACE TO THE JANUARY 1989 EDITION

The January 1989 revision involves:

Page	Item
7	Hydrology Investigations
7	Existing Dams - Service Spillway Design Flood Criteria

1.0 INTRODUCTION

1.1 General

The Department of Environmental Conservation receives many requests for detailed information about designs for dams requiring a permit under Article 15, Section 0503 of the Environmental Conservation law. This brochure has been developed by the department for the general guidance of design engineers.

These guidelines represent professional judgment of the Dam Safety Section's staff engineers. The guidelines convey sound engineering practices in an average situation. Where unusual conditions exist and the guidelines are not applicable, it is the duty of the design engineer to notify the department which will then consider deviation from the guidelines.

Since these are only general guidelines for small dam construction in an average situation, compliance will not necessarily result in approval of the application. The determination by the department of the acceptability of the design and adequacy of the plans and specifications will be made on a case-by-case basis. The primary responsibility of proper dam design shall continue to be that of the applicant.

In the administration of this law, the department is concerned with the protection of both the health, safety and welfare of the people and the conservation and protection of the natural resources of the State. (See Reference 1 and 2).

Water stored behind a dam represents potential energy which can create a hazard to life and property located downstream of the dam. At all times the risks associated with the storage of water must be minimized. This document deals with the engineering guidelines for the proper design of a dam. In order for a dam to safely fulfill its intended function, the dam must also be constructed, operated and maintained properly.

Supervision of construction or reconstruction of the dam by a licensed professional engineer is required to insure that the dam will be built according to the approved plans. See Article 15-0503, Item 5 of the New York State, Environmental Conservation Law (Reference 1).

For the proper operation and maintenance of a dam, see "An Owners Guidance Manual for the Inspection and Maintenance of Dams in New York State" (Reference 6).

1.2 Application

A permit is required if the dam:

- is at least 10 feet high or
- stores 1 million gallons (3.07 acre feet) or
- has a drainage area of 1 square mile.

Waste surface impoundments which are large enough to meet the above mentioned criteria shall not require an Article 15 dam permit. Hazardous waste surface impoundments will continue to be regulated by the Bureau of Hazardous Waste Technology, Division of Hazardous Substances

Regulation of the Department of Environmental Conservation, under 6NYCRR-Part 373, Hazardous Waste Management Regulation. Surface impoundments which are part of an approved waste water treatment process will be regulated within a SPDES permit issued by the Division of Water.

1.3 Application Forms

Applications, including the Supplement D-1 (hydrological, hydraulic and soils information), can be obtained from and should be submitted to the Regional Permit Administrator. The addresses of the Regional Permit Administrators are shown on page 31. Detailed information on application procedures is contained in the Uniform Procedures Regulations, Part 621.

Information on all pertinent items should be given. Construction plans and specifications should be prepared in sufficient detail to enable review engineers to determine if the proposed design and construction is in compliance with department guidelines. Thorough engineering review will be given each application. The time for this review and any additional time if revisions are necessary should be a consideration in each application.

2.0 DEFINITIONS

Appurtenant works are structures or materials built and maintained in connection with dams. These can be spillways, low-level outlet works and conduits.

Auxiliary spillway is a secondary spillway designed to operate only during large floods.

Cofferdam is a temporary structure enclosing all or part of the construction area so that construction can proceed in the dry.

Conduit is an enclosed channel used to convey flows through or under a dam.

Dam is any artificial barrier and its appurtenant works constructed for the purpose of holding water or any other fluid.

Department is the Department of Environmental Conservation (DEC).

Detention/Retention Basin is any structure that functions as a dam.

Earth Dam is made by compacting excavated earth obtained from a borrow area.

Energy Dissipator is a structure constructed in a waterway which reduces the energy of fast-flowing water.

Flood Routing is the computation which is used to evaluate the interrelated effects of the inflow hydrograph, reservoir storage and spillway discharge from the reservoir.

Freeboard is the vertical distance between the design high water level and the top of the dam.

Gravity Dam is constructed of concrete and/or masonry and/or laid-up stone that relies upon its weight for stability.

Height is the vertical dimension from the downstream toe of the dam at its lowest point to the top of the dam.

Low-Level Outlet is an opening at a low level used to drain or lower the water.

Major Size Dam is at least 25 feet high and holds at least 15 acre feet of water or is at least 6 feet high and holds at least 50 acre feet of water.

Maximum Impoundment Capacity is the volume of water held when the water surface is at the top of the dam.

Probable Maximum Flood (PMF) is the flood that can be expected from the severest combination of critical meteorologic and hydrologic conditions possible for the particular region. It is the flow resulting from the PMP.

Probable Maximum Precipitation (PMP) is the maximum amount of precipitation that can be expected over a drainage basin.

Seepage Collar is built around the outside of a pipe or conduit under an embankment dam to lengthen the seepage path along the outer surface of the conduit.

Service Spillway is the principal or first-used spillway during flood flows.

Service Spillway Design Flood(SSDF) is the flow discharged through the service spillway.

Spillway is a structure which discharges flows.

Spillway Design Flood(SDF) is the largest flow that a given project is designed to pass safely.

Toe of Dam is the junction of the downstream face of a dam and the natural ground surface, also referred to as downstream toe. For an earth dam the junction of the upstream face with the ground surface is called the upstream toe.

3.0 HAZARD CLASSIFICATION

3.1 General

The height of the dam, its maximum impoundment capacity, the physical characteristics of the dam site and the location of downstream facilities should be assessed to determine the appropriate hazard classification. Applications should include the design engineer's description of downstream conditions and his judgment of potential downstream hazards presented in the form of a letter designation and a written description.

3.2 Letter Designation

Class "A": dam failure will damage nothing more than isolated farm buildings, undeveloped lands or township or country roads.

Class "B": dam failure can damage homes, main highways, minor railroads, or interrupt use or service of relatively important public utilities.

Class "C": dam failure can cause loss of life, serious damage to homes, industrial or commercial buildings, important public utilities, main highways, and railroads.

3.3 Written Description

The written description is an elaboration of the letter designation. It includes descriptions of the effect upon human life, residences, buildings, roads and highways, utilities and other facilities if the dam should fail.

4.0 DESIGN AND CONSTRUCTION DOCUMENTS

4.1 Engineer Qualifications

The design, preparation of construction plans, estimates and specifications and supervision of the construction, reconstruction or repair of all structures must be done under the direction of a professional engineer licensed to practice in New York State. (See References 1 and 7).

4.2 Design Report

A design report, submitted with the application, should include an evaluation of the foundation conditions, the hydrologic and hydraulic design and a structural stability analysis of the dam. The report should include calculations and be sufficiently detailed to accurately define the final design and proposed work as represented on the construction plans. Any deviations from the guidelines should be fully explained.

4.3 Construction Plans

Construction plans should be sufficiently detailed for department evaluation of the safety aspects of the dam. The cover sheet should include a vicinity map showing the location of the dam. The size of the plans should be not less than 18 x 24 inches and no more than 30 x 48 inches. As-built plans of the project are required upon completion of construction.

4.4 Construction Inspection

The dam's performance will largely be controlled by the care and thoroughness exercised during its construction. Undisclosed subsurface conditions way be encountered which may materially affect the design of the dam. To ensure a safe design, the designer must be able to confirm design assumptions and revise the dam design if unanticipated conditions are encountered. Construction inspection is required in order to ensure that the construction work complies with the plans mid specifications and meets standards of good workmanship. Therefore, construction inspection of a dam is required by a licensed professional engineer to monitor and evaluate conditions as they are disclosed and to observe material placement and workmanship as construction progresses.

The engineer involved in the construction of the dam work will be required to submit a periodic construction report to the Department covering the critical inspection activities for the dam's construction/reconstruction. Prior to permit issuance the applicant shall submit, for review and approval, a proposed schedule of construction inspection activities to be performed by the applicant's engineer. Upon permit issuance, the approved schedule shall be part of the required work.

4.5 Specifications

Materials specifications will be required for items incorporated in the dam project. Materials specifications including format found acceptable are those issued by the following agencies and organizations.

State: New York State Department of Transportation

Federal: COE - Corps of Engineers
SCS - Soil Conservation Service

Industry: ASTM - American Society for Testing and Materials
ACI - American Concrete Institute
AWWA - American Water Works Association
CSI - Construction Specifications Institute

5.0 HYDROLOGIC CRITERIA

5.1 Hydrologic Design Criteria

A table of hydrologic design criteria giving the spillway design flood, the service spillway design flood and minimum freeboards for various hazard classifications can be found in Table 1.

5.2 Design Flood

The National Weather Service has published data for estimating hypothetical storms ranging from the frequency-based storm to the Probable Maximum Precipitation event. For the frequency-based storms Technical Paper TP-40 (Ref 17) and TP-49 (Ref 18) will be used to determine rainfall. For the Probable Maximum Precipitation event, Hydrometeorological Report HMR-51 (Ref 16) will be used.

When using the above mentioned TP's and HMR's, the minimum storm duration will be six hours. For large drainage areas in which the time of concentration exceeds six hours, the precipitation amounts must be increased by the applicable duration adjustment.

The Soil Conservation Service (SCS) has developed Technical Release 55 (TR-55) "Urban Hydrology for Small Watersheds". TR-55 presents simplified procedures for estimating runoff and peak discharge and is an acceptable procedure for designing spillways for small watersheds. In developing TR-55 the SCS uses a storm period of 24 hours for the synthetic rainfall distribution.

Although the "rational method" (Q=CIA) is used for estimating design flows for storm drains and road culverts, it normally is not an acceptable method for determining peak discharge for the design of a dam spillway. The rational method should not be used for watershed areas larger than 200 acres because of its inaccuracy above that range. The greatest weakness of the "rational method" for predicting peak discharges lies in the difficulty of estimating the duration of storms that will produce peak flow. The greatest probability for error, both as to magnitude and understanding relates to the term "intensity" or "rate of rainfall". Although the units are inches per hour, the term does not mean the total inches of rain falling in a period of one hour. "Intensity" should be related to the time of concentration. "Intensities" would be higher for storms of short duration and would be lower for storms of longer duration.

Table I indicates that the appropriate Spillway Design Flood will be a percentage of the 100 year flood or the PMF. Therefore, in order to correctly determine the peak flow, the rainfall values used will be for the 100 year flood or the PMF and the appropriate peak discharge will be computed. After the peak discharge has been found, this value will then be multiplied by the appropriate percentages. For example a small dam in the Class "B" hazard category will have the discharge based on the rainfall from a 100 year flood and this discharge will then be multiplied by 2.25 to obtain the peak discharge. The percentages should be applied to the discharge vllues in the final step of the calculations. It is incorrect to apply the percentages to the rainfall values.

5.3 Existing Dams - Design Flood

Existing dams that are being rehabilitated should have adequate spillway capacity to pass the following floods without overtopping:

Hazard Classification	Spillway Design Flood (SDF)
A	100 year
B	150% of 100 year
C	50% of PMF

The Service Spillway Design Flood (SSDF) for existing dams is the same as shown for the new dams on Table 1.

TABLE 1 - NEW DAMS

HYDROLOGIC DESIGN CRITERIA TABLE

HAZARD CLASSIFICATION	SIZE DAM	SPILLWAY DESIGN FLOOD (SDF)	SERVICE SPILLWAY DESIGN FLOOD (SSDF)	MINIMUM FREEBOARD (FT.)
"A"	*SMALL	100 year	5 year	1
"A"	*LARGE	150% of 100 yr.	10 year	2
"B"	SMALL	225% of 100 yr.	25 year	1
"B"	LARGE	40% of PMF	50 year	2
"C"	SMALL	50% of PMF	25 year	1
"C"	LARGE	PMF	100 year	2

*SMALL

Height of dam less than 40 feet. Storage at normal water surface less than 1000 acre feet.

*LARGE

Height at dam equal to or greater than 40 feet. Storage at normal water surface equal to or greater than 1000 acre feet.

NOTE:

Size classification will be determined by either storage or height, whichever gives the larger size category.

6.0 HYDRAULICS OF SPILLWAYS

6.1 Spillways

Spillways protect the dam from overtopping. Consideration must be given to dams and reservoirs upstream of the dam in question when designing the spillway. A dam should be provided with either a single spillway or a service spillway-auxiliary spillway combination.

6.2 Single Spillway

For a single spillway, the structure should have the capacity and the durability to handle sustained flows as well as extreme floods and be non-erodible and of a permanent-type construction. Free overall spillways, ogee spillways, drop inlet or morning glory spillways, and chute spillways are common types. An earth or grass-lined spillway is not durable under sustained flow and should not be used as a single spillway.

6.3 Criteria for a single spillway are as follows:

6.3.1 Sufficient spillway capacity should be provided to safely pass the spillway design flood with flood routing through the reservoir. (See Table 1 for spillway design flood).

6.3.2 Assuming no inflow, the spillway should have sufficient discharge capacity to evacuate 75% of the storage between the maximum design high water and the spillway crest within 48 hours.

6.3.3 The spillway will have an energy dissipater at its terminus.

6.3.4 A drop inlet or morning glory spillway, as a single spillway, is only acceptable on a Hazard Class "A" structure with a drainage area of less than 50 acres. In this case, sufficient storage capacity should be provided between the spillway crest and top of dam to contain 150% of the entire spillway design flood runoff volume.

6.4 Service Spillway - Auxiliary Spillway Combination:
In the case of the service spillway - auxiliary spillway combination, the service spillway discharges normal flows and the more frequent floods, while the auxiliary spillway functions only during extreme floods.

Service spillways must be durable under conditions of sustained flows; whereas auxiliary spillways do not. Service spillways should have sufficient capacity to pass frequent floods and thus reduce the frequency of use of the auxiliary spillway. The service spillway usually does not have sufficient capacity to pass the entire spillway design flood. Drop inlet or morning glory spillways are common types of service spillways. This type of structure will consist of a vertical inlet riser connected to a service spillway conduit with an energy dissipator at the outlet. An auxiliary spillway is capable of handling high but short duration flows. It may be an excavated grass-lined channel if the designer is able to limit velocities to the non-erodible range for grass. It cannot carry prolonged flows because of eventual deterioration of the grass linings. For spillways which will be required to discharge flows at a high velocity, a more permanent type of material such as concrete will be required. An auxiliary spillway may be located adjacent to a dam abutment or anywhere around the rim of the reservoir. It should be located sufficiently apart from the dam to prevent erosion of any embankment materials. A spillway over the dam is not acceptable. It may either discharge back into the natural watercourse below the dam, or so long as a flood hazard is not created, into a watercourse within an adjacent drainage basin.

6.5 Criteria for an auxiliary spillway-service spillway combination are as follows:

6.5.1 Sufficient service spillway capacity should be provided to safely pass the service spillway design flood with flood routing through the reservoir. (See Table 1 for service spillway design flood).

6.5.2 The service spillway normally should be provided with an energy dissipater at its outlet end.

6.5.3 The auxiliary spillway crest must be placed at or above the service spillway design high water, and not less than 1 foot above the service spillway crest.

6.5.4 The auxiliary spillway-service spillway combination must provide sufficient discharge capacity to safely pass the spillway design flood with flood routing through the reservoir (See Table 1 for spillway design flood).

6.5.5 Assuming no inflow, the auxiliary spillway-service spillway combination should have sufficient capacity to evacuate the storage between the maximum design high water and the auxiliary spillway crest within 12 hours.

6.5.6 Assuming no inflow, the service spillway should have sufficient capacity to evacuate 75% of the storage between the auxiliary spillway crest and the service spillway crest within 7 days.

6.5.7 Auxiliary spillways shall not be placed on fill.

6.5.8 Velocities in auxiliary spillways should not exceed the maximum permissible velocities (non-erodible velocities) of the spillway materials.

6.5.9 If an auxiliary spillway is located near an embankment,it should be located so as not to endanger the stability of the embankment. The following criteria will help guard against damage to the embankment:

a. Discharge leaving the exit channel should be directed away from the embankment and should be returned to a natural watercourse far enough downstream as to have no erosive effect on the embankment toe.

b. The spillway exit channel, from the spillway crest to a section beyond the downstream toe of dam, should be uniform in cross-section, contain no bends, and be longitudinally perpendicular to the spillway crest. Curvature may be introduced below the toe of dam if it is certain that the flowing water will not impinge on the toe of dam.

6.0 A FLASHBOARD POLICY

Background

Flashboards are used to raise the water surface of an impoundment. However, the installation of flashboards along the crest of a spillway may permanently reduce the size of the spillway opening. Our records indicate that in some instances the reduction of spillway capacity with the installation of flashboards has resulted in overtopping and subsequent dam failure. Two examples are the Tillson Lake Dam (#1942420) in Ulster County and the Lake Algonquin Dam (#171-2700) in Hamilton County.

In 1939 flashboards were placed across the spillway of the 40 foot high Tillson Lake Dam in such a manner as to greatly reduce the spillway opening. Storm flow caused dam overtopping which eroded the earth slope in front of the 100 foot wide, 30 foot high concrete core wall. Failure of the core wall resulted in a tremendous amount of erosion to farm land, loss of farm machinery, chickens, several local bridges and basement flooding. The dam was rebuilt and failed in 1955 because flashboards were again in place and did not fail during storm flow.

In 1949 the Lake Algonquin Dam failed because flashboards were not removed for the winter. A January storm caused overtopping and subsequent dam failure at the right abutment. The dam failure resulted in the loss of a home, several farm buildings and a road.

When wood flashboards are installed properly they will be supported by steel pins. These steel pins will be designed to fail when the depth of flow over the top of the flashboards reaches a certain level. Critical to the design of the flashboard system are the diameter of the steel pin, the ultimate strength of the steel and the spacing of the pins. In very few cases is the Consulting Engineer or Contractor who designed the flashboards able to provide sufficient quality control to ascertain that the as-built condition is similar to the design proposal.

Many field maintenance personnel do not understand the need for flashboards to fail when the depth of flow over the flashboards reaches a certain level. Therefore, there is a tendency to insert the flashboards in such a manner so that they will never fail, thus permanently reducing spillway capacity and increasing the possibility of dam failure by overtopping. This is what nearly happened at the Gore Mountain Dam at North Creek. During the period of 1977-1980 DEC operations personnel installed wide flange beams to support the wood flashboards. The approved design for the flashboard supports were one inch diameter steel pins. However, operations personnel decided they would have less maintenance problems if they permanently secured the wood flashboards between the six inch wide flange beams. Under this support the flashboards would never fail.

Around February 15, 1981 a sudden thaw and rain caused the water level at Gore Mountain Dam to rise within eight inches of the top of dam. This level was about two feet, four inches over the top of the flashboards. The extra sturdy wide flange beam support system precluded any chance of flashboard failure. Fortunately this abnormally high level was reported to the DEC by a local resident while he was snowmobiling. During the fall of 1981, DEC revised the flashboard support system so that the flashboards were properly supported by one inch diameter steel pins and the steel pins would fail in bending when the depth of flow over the top of the flashboards reached one foot.

For the foregoing reasons the Dam Safety Section has developed the following policy regarding the installation of flashboards on dams.

New Dams

Flashboards shall not be installed on any new dams. The dam owner or hydroelectric developer shall determine the normal pool elevation for the proposed impoundment and provide a permanently fixed spillway crest at the selected elevation. If pool elevation fluctuations are desired, they should be achieved by means of adequately sized gates, drains, siphons or other acceptable methods.

Existing Dams

A permanently fixed spillway crest is the preferred method of establishing normal pool elevation.

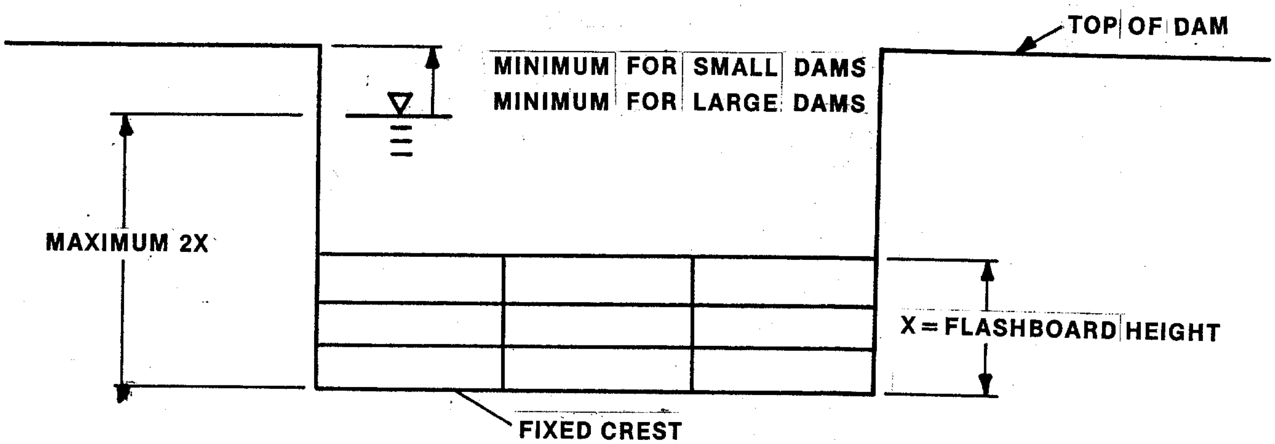
The installation or continued use of flashboards on existing dams will be considered on a case by case basis. Flashboards on existing dams will only be acceptable if the dam is able to satisfy the hydraulic and structural stability criteria contained in the Guidelines for Design of Dams. If the flashboards are designed to fail in order to satisfy either criterion, detailed failure calculations must be submitted for Department review and approval. The maximum pool elevation the flashboards are designed to fail at shall be the lower of:

1. Two times the height of the flashboards measured from the bottom of the flashboards, or

2. Two times the freeboard specified in Table 1 of these Guidelines, for a dam of the pertinent size and hazard classification, measured downward from the top of dam.

The maximum pool elevation that would be reached under Spillway Design Flood conditions, without the flashboards failing, shall also be determined.

Flashboards shall be installed, operated and maintained as intended in their design and in accordance with the terms and/or conditions of any permits or approvals. The approved flashboard configuration (pin spacing, pin size, board height, board size, etc.) shall not be modified without prior Department approval.



7.0 OUTLET WORKS AND CONDUITS

7.1 Outlet Works

A low-level outlet conduit or drain is required for emptying or lowering the water in case of emergency; for inspection and maintenance of the dam, reservoir, and appurtenances; and for releasing waters to meet downstream water requirements. The outlet conduit may be an independent pipe or it may be connected to the service spillway conduit. The low level drain is required to have sufficient capacity to discharge 90% of the storage below the lowest spillway crest within 14 days, assuming no inflow into the reservoir.

7.2 Control

Outlet conduits shall have an upstream control device (gate or valve) capable of controlling the discharge for all ranges of flow.

7.3 Conduits

Only two types of conduits are permitted on Hazard Class "B" and "C" structures; precast reinforced concrete pipe and cast-in-place reinforced concrete.

On Hazard Class "A" structures, welded steel pipe or corrugated metal pipe may be used providing the depth of fill over the pipe does not exceed 15 feet and the pipe diameter does not exceed 24 inches.

All outlet conduits shall be designed for internal pressure equal to the full reservoir head and for the superimposed embankment loads, acting separately.

The minimum size diameter conduit used as the barrel of a drop inlet service spillway shall be 12 inches.

The joints of all pipe conduits shall be made watertight.

Any pipe or conduit passing through an embankment shall have features constructed into the embankment whereby seepage occurring along the pipe or conduit is collected and safely conveyed to the downstream toe of the embankment. This can be accomplished by using a properly designed and constructed filter and drainage diaphragm. The filter and drainage diaphragm will be required unless it can be shown that antiseep collars will adequately serve the purpose.

Antiseep collars will not be permitted for dams with a height in excess of 20 feet. If antiseep, collars are used in lieu of a drainage diaphragm, they shall have a watertight connection to the pipe. Collar material shall be compatible with pipe materials. The antiseep collars shall increase the seepage path along the pipe by at least 15%.

A means of dissipating energy shall be provided at the outlet end of all conduits 12 inches or more in diameter. If a plunge pool is used, the conduit should be cantilevered 8 feet over a concrete, steel or treated timber support located near or at the downstream toe of the embankment. The plunge pool should be riprap-lined if a conduit 18 inches or more in diameter is used. The foregoing may apply to smaller pipes if the embankment's downstream slope is steep and the soil erodible.

8.0 GEOTECHNICAL INVESTIGATION

8.1 Foundations

8.1.1 Subsurface explorations (drill holes, test pits and/or auger holes) should be located along the centerline of the dam, at the proposed service and auxiliary spillway locations, and in other critical areas. The depth of the subsurface explorations should be sufficient to locate and determine the extent and properties of all soil and rock strata that could affect the performance of the dam, the reservoir and appurtenant structures. Referring to information such as geologic bulletins, soil survey maps, groundwater resources bulletins, etc., may aid the designer in determining the scope of the exploration program needed and interpreting the results of the program. For even the smallest low hazard dams, at least three explorations should be made along the centerline of the dam, one in the deepest part of the depression across which the dam will be built and one on each side. At least one exploration should be made at the proposed auxiliary spillway location. For small low-hazard dams, to be built on a foundation known from the geology of the area to be essentially incompressible and impervious to a great depth, the minimum depth of explorations should be 5 feet unless bedrock is encountered above this depth. In other cases the minimum depth of explorations should be 10 feet, with one or more borings extending to a depth equal to the proposed height of the dam. If it is proposed to excavate in the reservoir area, the possibility of exposing pervious foundation layers should be investigated by explorations or a review of the geology of the area. If rock is encountered in explorations, acceptable procedures, such as coring, test pits, or geologic information, should be used to verify whether or not it is bedrock.

8.1.2 Sufficient subsurface explorations should be made to verify the suitability of encountered rock for use as a foundation and/or construction material. Testing of the rock materials shall ascertain its strength, compressibility, and resistance to degradation, and its ability to safely withstand the loads expected to be imposed upon it by the proposed project.

8.1.3 Soils encountered in explorations should be described accurately and preferably classified in accordance with the Unified Soil Classification System.

8.1.4 For Hazard Class "C" dams, appropriate field and/or laboratory tests should be performed in order to aid in evaluating the strength, compressibility, permeability, and erosion resistance of the foundation soils. Also, appropriate laboratory tests should be performed on samples of the proposed embankment materials in order to ascertain their suitability for use in the dam. Field and/or laboratory tests may be required also for dams of lower hazard classification in the case of critical foundation strength or permeability conditions.

8.1.5 Stability of the foundation under all operating conditions should be evaluated.

8.1.6 Settlement of the dam and appurtenant works should be evaluated and provisions made in the design to counteract the effects of any anticipated settlements.

8.1.7 Whenever feasible, seepage under the dam should be controlled by means of a complete cutoff trench extending through all pervious foundation soils into a relatively impervious soil layer. If the dam is to be built on an impervious foundation, the cutoff or key trench should be excavated to a depth of at least 3 feet into the foundation soils and backfilled with compacted embankment material. Where the final depth of cutoff cannot be established with certainty during design, a note should appear on the plans stating that the final depth of the cutoff trench will be determined by the engineer during the time of construction. Backfilling of the cutoff or key trench should be performed in the dry, unless special construction procedures are used. The bottom width of the trench should be at least 8 feet and should be increased in the case of dams more than 20 feet high. The widths of complete cutoffs my be made considerably less if the cutoff is extended vertically a minimum distance of 4 feet into impervious material. In the case of a cutoff or key trench extending to bedrock, the trench does not have to extend into rock. However, all shattered and disintegrated rock should be removed and surface fissures filled with cement grout. The need for pressure grouting rock foundations should be evaluated and, if necessary, adequately provided for.

8.2 Borrow Sources for Embankment Materials

Sufficient subsurface explorations should be made in borrow areas to verify the suitability and availability of an adequate supply of borrow materials. Logs of explorations should be included for review with the plans and specifications. Exposure of pervious soils and fissured rock below normal water surface of the proposed pond, at borrow areas located in or connected to the reservoir area, should be avoided.

If pervious soils or fissured rock conditions are encountered during borrow operations these exposed areas should be sealed with a sufficient thickness of compacted impervious material. In no case should this seal be less than two feet thick and consideration should be given to utilizing a greater thickness where site conditions and hazard classifications dictate.

Borrow areas should be located with due consideration to the future safety of the dam and should be shown on the plans. In general, no borrow should be taken within a distance measured from the upstream toe of the dam equal to twice the height of the dam or 25 feet, whichever is greater.

9.0 EARTH DAMS

9.1 Geometry

9.1.1 The downstream slope of earth dams without seepage control measures should be no steeper than 1 vertical on 3 horizontal. If seepage control measures are provided, the downstream slope should be no steeper than 1 vertical on 2 horizontal.

9.1.2 The upstream slope of earth dams should be no steeper than 1 vertical on 3 horizontal.

9.1.3 The side slopes of homogenous earth dams may have to be made flatter based on the results of design analyses or if the embankment material consists of fine grained plastic soils such as CL, MH or CH soils as described by the Unified Soil Classification System.

9.1.4 The minimum allowable top width (W) of the embankment shall be the greater dimension of 10 feet or W, as calculated by the following formula:

$W = 0.2H + 7$; where H is the height of the embankment (in feet)

9.1.5 The top of the dam should be sloped to promote drainage and minimize surface infiltrations and should be cambered so that the design freeboard is maintained after post-construction settlement takes place.

9.2 Slope Stability

Where warranted and especially for new Hazard Class "C" dams, the department may require that slope stability analyses be provided for review. The method of analyses and appropriate factors of safety for the applicable loading conditions shall be as indicated by U. S. Army Corps of Engineers publications (latest edition) (Ref. 11).

Earth dams, in general, should have seepage control measures, such as interior drainage trenches, downstream pervious zones, or drainage blankets in order to keep the line of seepage from emerging on the downstream slope, and to control foundation seepage. Hazard Class "A" dams less than 20 feet in height and Hazard Class "B" dams less than 10 feet in height, if constructed on and of erosion-resistant materials, do not require special measures to control seepage.

In zoned embankments, consideration should be given to the relative permeability and gradation of embankment materials. No particle greater in size than six inches in maximum dimension should be allowed to be placed in the impervious zone of the dam.

9.3 Compaction Control and Specifications

Before compaction begins, the embankment material should be spread in lifts or layers having a thickness appropriate to the type of compaction equipment used. The maximum permissible layer thickness should be specified in the plans or specifications.

Specifications should require that the ground surface under the proposed dam be stripped of all vegetation, organic and otherwise objectionable materials. After stripping, the earth foundation should be moistened, if dry, and be compacted before placement of the first layer of embankment material. Inclusion of vegetation, organic material, or frozen soil in the embankment, as well as placing of embankment material on a frozen surface is prohibited and should be so stated in the specifications.

For all dams, compaction shall be accomplished by appropriate equipment designed specifically for compaction. The type of compaction equipment should be specified in the plans or specifications.

The degree of compaction should be specified either as a minimum number of complete coverages of each layer by the compaction equipment or, in the case of higher or more critical dams, based on standard ASTM test methods.

When the degree of compaction is specified as a number of complete coverages or passes, the final number of passes required shall be determined by the engineer during construction.

In order to insure that the embankment material is compacted at an appropriate moisture content, a method of moisture content control should be specified. For Hazard Class "A" dams less than 20 feet high, the moisture content may be controlled visually by a qualified inspector. Hand tamping should be permitted only in bedding pipes passing through the dam. All other compaction adjacent to structures should be accomplished by means of manually directed power tampers.

Backfill around conduits should be placed in layers not thicker than 4 inches before compaction with particle size limited to 3 inches in greatest dimension and compacted to a density equal to that of the adjacent portion of the dam embankment regardless of compaction equipment used.

Care should be exercised in placing and compacting fill adjacent to structures to allow the structures to assume the loads from the fill gradually and uniformly. Fill adjacent to structures shall be increased at approximately the same rate on all sides of the structures.

The engineer in charge of construction is required to provide thorough and continuous testing to insure that the specified density is achieved.

9.4 VEGETATION CONTROL - TREES AND BRUSH

9.4.1 Trees and Brush

Trees and brush are not permitted on earth dams because:

a. Extensive root systems can provide seepage paths for water.

b. Trees that blow down or fall over can leave large holes in the embankment surface that will weaken the embankment and can lead to increased erosion.

c. Brush obscures the surface limiting visual inspection, provides a haven for burrowing animals and retards growth for grass vegetation.

Stumps of cut trees should be removed so grass vegetation can be established and the surface mowed. Stumps should be removed either by pulling or with machines that grind them down. All woody material should be removed to about 6 inches below the ground surface. The cavity should be filled with well compacted soil and grass vegetation established.

9.4.2 Grass Vegetation

Grass vegetation is an effective and inexpensive way to prevent erosion of embankment surfaces. It also enhances the appearance of the dam and provides a surface that can be easily inspected.

10.0 STRUCTURAL STABILITY CRITERIA FOR GRAVITY DAMS

10.1 Application

These guidelines are to be used for the structural stability analysis of concrete and/or masonry sections which form the spillway or non-overflow section of gravity dams.

These guidelines are based on the "Gravity Method of Stress and Stability Analysis" as indicated in Reference 13.

If the gravity dam has keyed or grouted transverse contraction joints, then the "Trial-Load Twist Method of Analysis" (Reference 13) may be used for the stability analysis.

Elastic techniques, such as the finite element method, my be used to investigate areas of maximum stress in the gravity dam or the foundation. However, the finite element method will only be permitted as a supplement to the Gravity Method. The Gravity Method will be required for the investigation of sliding and overturning of the structure.

10.2 Non-Gravity Dams

For non-gravity structures such as arch dams, the designer is required to present calculations based on appropriate elastic techniques as approved by the Dam Safety Section.

10.3 Loads

Loads to be considered in stability analyses are those due to: external water pressure, internal water pressure (pore pressure or uplift) in the dam and foundation, silt pressure, ice pressure, earthquake, weight of the structure.

10.4 Uplift

Hydrostatic uplift pressure from reservoir water and tailwater act on the dam. The distribution of pressure through a section of the dam is assumed to vary linearly from full hydrostatic head at the upstream face of the dam to tailwater pressure at the downstream face or zero if there is no tailwater. Reduction in the uplift pressures might be allowed in the following instances:

10.4.1 When foundation drains are in place. The efficiency of the drains will have to be verified through piezometer readings.

10.4.2 When a detailed flow net analysis has been performed and indicates that a reduction in uplift pressures is appropriate. Any reduction of pressure of more than 20% must be verified by borings and piezometer readings.

10.4.3 When a sufficient number of borings have been progressed and piezometer readings support the fact that actual uplift pressures are less than the theoretical uplift pressures.

10.5 Loading Conditions

Loading Conditions to be analyzed.

Case 1 - Normal loading condition; water surface at normal reservoir level.

Case 2 - Normal loading condition; water surface at normal reservoir level plus an ice load of 5,000 pounds per linear foot, where ice load is applicable. Dams located in more northerly climates, may require a greater ice load.

Case 3 - Design loading condition; water surface at spillway design flood level.

Case 3A- Maximum hydrostatic loading condition; maximum differential head between headwater and tailwater levels as determined by storms smaller in magnitude than the spillway design flood. This loading condition will only be considered when the is submerged under Case 3 loading condition.

Case 4 - Seismic loading condition; water surface at normal reservoir level plus a seismic coefficient applicable to the location.

10.6 Stability Analysis for New Dams

10.6.1 Field Investigation

Subsurface investigations should be conducted for new dams. Borings should be made along the axis of the dam to determine the depth to bedrock as well as the character of the rock and soils under the dam. The number and depth of holes required should be determined by the design engineer based on the complexity of geological conditions. The depth of holes should be at least equal to the height of the dam. Soil samples and rock cores should be collected to permit laboratory testing. The values of cohesion and internal friction of the foundation material should be determined by laboratory testing.

On proposed sites where the foundation bedrock is exposed, the requirements for borings may be waived in some cases. An engineering geologist's professional opinion of the rock quality and the acceptability of the design assumptions will be required in those cases.

10.6.2 Overturning

The resultant force from an overturning analysis should be in the middle third of the base for all loading conditions, except for the seismic analysis (Case 4), where the resultant shall fall within the limits of the base.

10.6.3 Cracking

The resultant force falling outside the middle third of the base and its resulting tension cracks will not be accepted in the design of new dams, except for the seismic loading condition (Case 4).

10.6.4 Sliding

Sliding safety factors may be computed using the Shear-Friction method of analysis when shear values are based on either the results of laboratory testing or an engineering geologist's professional opinion. When the Shear-Friction method is used, the structure should have a minimum safety factor of 2.0 for all loading conditions except for Case 4 (seismic loading) where the minimum acceptable sliding safety factor shall be 1.5.

Designs which are not based on laboratory testing or an engineering geologist's professional opinion must be analyzed using the Friction Factor of Safety. This analysis assumes that the value of shear or cohesion is zero. The minimum safety factor using this method should be 1.5 for all loading conditions except Case 4 where the minimum safety factor shall be 1.25.

10.7 Stability Analysis for Existing Dams

10.7.1 Field Investigations

Subsurface investigations should normally be conducted as part of a detailed structural stability investigation for an existing dam and should provide information regarding the materials of the dam and its foundation. The number and depth of holes required should be determined by the engineer based on the complexity of the composition of the dam and foundation. Samples should be collected and tested to determine the material properties. The program should also measure the uplift pressures at several locations along the base of the dam.

In cases where no subsurface investigations are conducted conservative assumptions regarding material properties and uplift pressures will be required.

10.7.2 Overturning

The resultant force from an overturning analysis should be in the middle third of the base for normal loading conditions (Case 1) and within the middle half of the base for the ice loading condition (Case 2) and the spillway design flood loading condition (Case 3). For the seismic loading condition (Case 4), the resultant force should fall within the limits of the base.

10.7.3 Cracking

If the overturning analysis indicates that the resultant force is outside the middle third, then tension exists at the heel of the dam which may result in the cracking of the concrete. For existing dams cracking will be permitted for all loading conditions except the normal loading condition (Case 1). If the criteria specified above in Overturning for the location of the resultant force are not satisfied, further study and/or remedial work will be required. The Bureau of Reclamation's Cracked Section Method of analysis is acceptable for investigating the stability of the dam for the above mentioned loading conditions. When the Cracked Section Method of analysis is used, the criteria for the minimum sliding factor of safety will have to be satisfied.

10.7.4 Sliding

Sliding safety factors may be computed using the Shear-Friction method of analysis when shear values are based on the results of laboratory testing of samples from subsurface investigations. When the Shear-Friction method is used, the structure should have a minimum safety factor of 2. 0 for Case 1 and Case 2; a value of 1.5 for Case 3 and a value of 1.25 for Case 4.

If no subsurface explorations are performed, the sliding safety factors must be computed using the Friction Factor of Safety. The minimum safety factor using this method should be 1.5 for Case 1; a value of 1.25 for Case 2 and Case 3; and a value of 1.0 for Case 4.

11.0 EXISTING DAMS: REHABILITATION AND MODIFICATION

Additional data should be submitted for dam rehabilitations or dam modifications, including a report by a professional engineer describing the performance and maintenance history of the existing dam. In addition, all data regarding construction, such as existing subsurface explorations, construction materials used for the dam, and plans and specifications should be submitted. If this information is not available, the engineer should inspect and evaluate the structure as to its condition, performance, maintenance history and other information regarding foundation soils and existing conditions.

The engineer should also assess the safety and adequacy of the existing structure against those criteria for spillway capacity and structural stability, indicated in the appropriate sections of these guidelines.

Where a new embankment is to be constructed against an existing dam embankment, the existing slope shall be benched as the new fill is spread and compacted in layers as described in the plans and specifications. This benching is done to provide an interlock between the existing and new embankments. Benching shall not be done in the upstream-downstream direction.

All topsoil and sod shall be stripped from the surface of the existing embankment before placing new material within the area of reconstruction.

Remove or seal all existing drainage structures which are not to be operative in the proposed design, in order to prevent a plane of seepage from developing through the dam.

12.0 COFFERDAMS

A cofferdam in most cases is a temporary structure enclosing all or part of the construction area. The purpose of the cofferdam is to provide protection so that construction can proceed in the dry.

12.1 When using a cofferdam the following criteria must be met:

12.1.1 Flood Plain Management

A hydraulic analysis must be performed to determine the backwater effect of the cofferdam. A range of flood discharges up to and including the 100 year return frequency flood shall be evaluated to determine the potential flood damages to lands and improvements upstream of the cofferdam not owned or otherwise controlled by the applicant. The analysis shall focus on determining if the project meets the flood plain management criteria of 6NYCRR-Part 500, if applicable, or regulations adopted by the local jurisdiction for participation in the National Flood Insurance Program.

12.1.2 Dam Safety

The applicant will have to demonstrate that cofferdam failure will not adversely impact lives and property. The evaluation will focus on the potential for flooding, loss of life and damage to properties downstream of the cofferdam not owned or otherwise controlled by the applicant.

If cofferdam failure could adversely impact properties downstream of the cofferdam, not controlled by the applicant, or if the cofferdam failure could adversely impact lives, then more specific information regarding the geotechnical, structural and hydraulic aspects of the cofferdam design will be required. The determination by the department of the acceptability of the cofferdam design will be made on a case-by-case basis.

13.0 MISCELLANEOUS

The earth embankment, earth spillways, and all disturbed earth adjacent to the embankment or other appurtenances should be seeded, except where riprap or other slope protective materials are specified.

Where destructive wave action is expected, the upstream slope of the embankment should be protected with rock riprap or other suitable material for effective erosion control.

A trash rack designed to prevent debris from entering and obstructing flow in the conduit should be provided on the vertical riser for any drop inlet spillway.

An anti-vortex device is required on the vertical riser for any drop inlet spillway with riser diameter greater than 12 inches.

Instrumentation

1.Piezometers - All earth dams 40 feet high or higher shall have at least two piezometers on the downstream slope of the embankment to measure saturation levels and hydrostatic pressures. All concrete dams 40 feet or higher should have at least two piezometers along the crest of the dam.

2.Weirs - on all dams with toe drains, weirs are required at the downstream end of the drain. The weirs measure the amount of seepage water through the embankment. Measurements of the seepage should be documented and correlated with the reservoir surface elevation. See Reference 6, pages 55-56.

14.0 EMERGENCY ACTION PLAN

An emergency action plan (EAP) should be developed by the owner of a high hazard dam (Class "C").

A copy of this EAP is to be provided to the Dam Safety Section of the department during the initial permit review period for new dams and for existing dams, if a copy of the EAP has not been previously submitted. See Reference 6, pages 69-73.

15.0 APPROVAL TO FILL RESERVOIR OF A NEW DAM

Before any water can be impounded by the dam, the dam owner shall adhere to the following:

15.1 For all Hazard Class "C" and [major size] Hazard Class "B" dams.

Within two weeks after completion of dam construction the permittee shall notify the Regional Permit Administrator in writing by certified mail of its completion and shall include a notarized statement from the owner's engineer that the project has been completely constructed under his care and supervision in accordance with plans and specifications as approved by the department. Any changes in the construction of the dam from the approved plans will be reflected in the "As-Built" plans.

The department will inspect the completed dam with the owner's engineer. During the inspection, the owner's engineer will submit "As Built" drawings and other construction records for review, such as foundation data and geological features, properties of embankment and foundation materials, concrete properties and construction history. Upon review of the data and the determination of the adequacy of the structure the "Approval to Fill" letter will be issued, permitting the owner to store water.

15.2 For all Hazard Class "A" and [Below Major Size] Hazard Class "B" dams.

Within two weeks after completion of dam construction the permittee shall notify the Regional Permit Administrator in writing by certified mail of its completion and shall include a notarized statement from the owner's engineer stating that the project has been completely constructed under his care and supervision in accordance with plans and specifications as approved by the department. Any changes in the construction of the dam from the approved plans will be reflected in the "As-Built" plans that will be submitted to the Department.

No water shall be impounded for at least 15 days subsequent to the notification to the Regional Permit Administrator.

REFERENCES

1. New York State Environmental Conservation Law "Article 15-0503".

2. New York Code of Rules and Regulations (6NYCRR) "Part 621 - Uniform Procedures".

3. New York Code of Rules and Regulations (6NYCRR) "Part 673 - Dam Safety Regulations"

4. New York Code of Rules and Regulations (6NYCRR) "Part 500 - Flood Plain Development Permits"

5. New York Code of Rules and Regulations (6NYCRR) "Part 373 - Hazardous Waste Management"

6. An Owners Guidance Manual For the Inspection and Maintenance of Dams in New York State.

7. New York State Education Law "Article 55".

8. Soil Conservation Service; U. S. Department of Agriculture SCS National Engineering Handbook; August, 1972 "Section 4 -Hydrology

Corps of Engineers; U. S. Army

9. Hydrologic Engineering Center
   "HEC-1 Flood Hydrograph Package"; 1981

10. ETL 1110-2-256; June 1981
    "Sliding Stability for Concrete Structures".

11. EM 1110-2-1902; April 1970
    "Stability of Earth and Rock-Fill Dams"

Bureau of Reclamation; U. S. Department of the Interior

12. "Design of Small Dams", 1977 Revised Reprint

13. "Design of Gravity Dams", 1976

14. "Earth Manual"

National Oceanic and Atmospheric Administration National Weather Service; U.S. Department of Commerce

15. Hydrometeorological Report 33; April 1956 "Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1000 Square Miles and Durations of 6, 12, 24 and 48 Hours"

16. Hydrometeorological Report 51; June 1978 "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian"

17. Technical Paper 40; May 1961 "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years"

18. Technical Paper 49; 1964 "Two-to-Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States"

New York State
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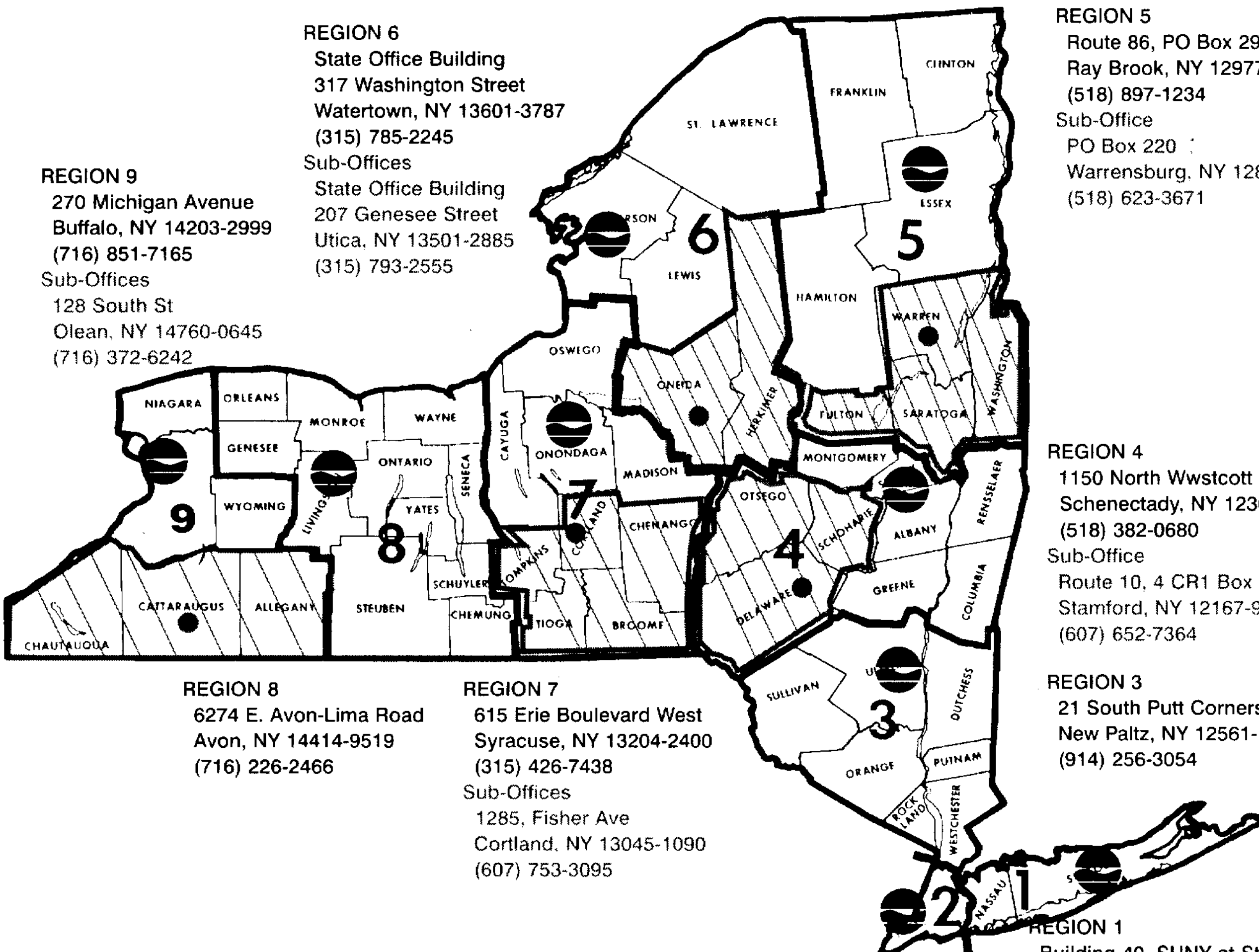
Division of Environmental Permits



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Olean, NY 14760-0645
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207 Genesee Street
Utica, NY 13501-2885
(315) 793-2555

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January 2000

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APPENDIX B

Water Quality Peak Flow Rate

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Appendix B: Water Quality Peak Flow Rate

The peak flow rate for the water quality design storm is needed for sizing flow-based practices and off-line practices. The conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than two (2) inches. This discrepancy can lead to practices that are inadequately sized for the required Water Quality Volume (WQ_V), calculated using **Chapter 4**.

This Appendix presents the steps taken to convert the required Water Quality Volume (WQ_V), calculated using **Chapter 4**, to the equivalent Water Quality Peak Flow Rate (WQ_F). The equivalent WQ_F is calculated through hydraulic and hydrologic modeling software utilizing the rainfall distribution generated in **Section 4.9.** It is important to note that a calculated rainfall value, different from the 90^{th} percentile rainfall value in **Chapter 4**, is utilized to generate a runoff volume equivalent to the required WQv. The following provides the step-by-step process to convert the required WQ_V to the equivalent WQ_F using the NRCC and NRCS website and HydroCAD. For purposes of this example, the project site is taken to be in Queens, NY.

Step 1 – Create the Distribution Curve

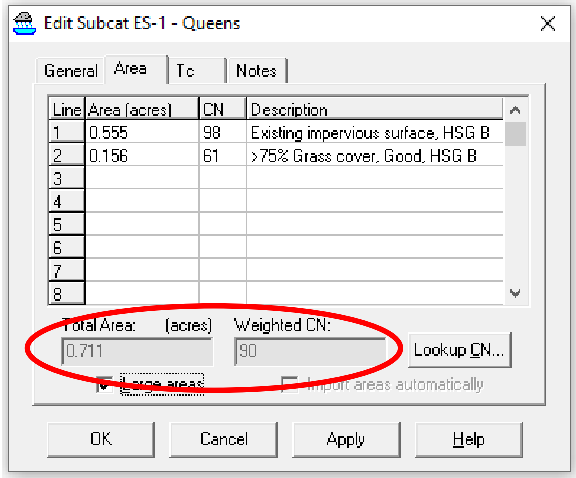
Using the steps provided in **Section 4.9,** create the synthetic rainfall distribution curve specific to the project site.

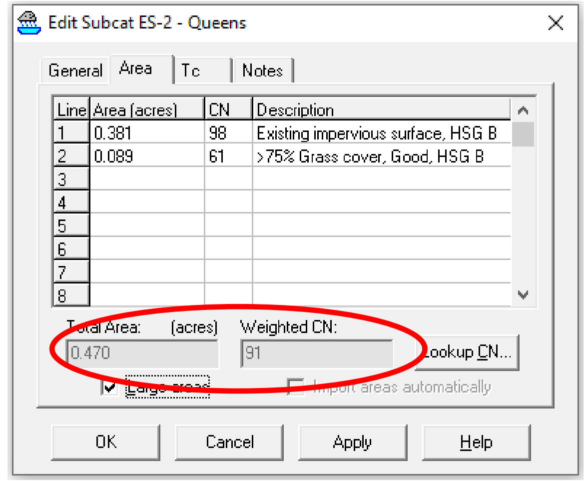
Step 2 – Determine the Water Quality Treatment Volume (WQ_V)

Calculate the required WQv per **Chapter 4** and/or **Chapter 9.** The example outlined below is for redevelopment activities, with a 15% reduction in impervious cover that will utilize a hydrodynamic separator. The required WQv is calculated using **Section 9.2.1.A** criteria II, where 100% WQv is captured and treated, for a minimum of 25% of the disturbed redevelopment impervious area. The subcatchment includes 1.18 acres contributing to the practice, of which the designer is required to treat 0.94 acres of impervious. As such, the required WQv is calculated to be 0.112 af or 4,887 cf.

Step 3 – Solve for the Calculated "P_{90}" Value

First, calculate the weighted Curve Number (CN_W) for the contributing drainage area to the practice. In this example, two (2) subcatchments are tributary to the hydrodynamic separator. Therefore, CN_W is the weighted average of the two (2) subcatchments:





$$CN_W = \frac{(A_1 x CN_1) + (A_2 x CN_2) + \cdots (A_N x CN_N)}{A}$$

Where:

A_N = Subcatchment Area

CN_N = Curve Number for Subcatchment

$$CN_W = \frac{(0.711\ acres\ x\ 90) + (0.470\ acres\ x\ 91)}{1.181\ acres}$$

$$CN_W = 90$$

Then, calculate the maximum basin retention (B) in inches, using CN_W

$$B = \frac{1{,}000}{CN_W} - 10$$

$$B = \frac{1{,}000}{90} - 10$$

$$B = 1.11\ inches$$

Next, calculate the runoff (Q), in inches, generated over the contributing area given the required WQv:

$$Q = \frac{Required\ WQv}{A}$$

$$Q = \frac{0.112\ af}{1.181\ acres}$$

$$Q = 0.09\ ft\ (1.14\ inches)$$

Finally, using the runoff (Q) in inches and maximum basin retention (B), determine the calculated rainfall value (P_{90}):

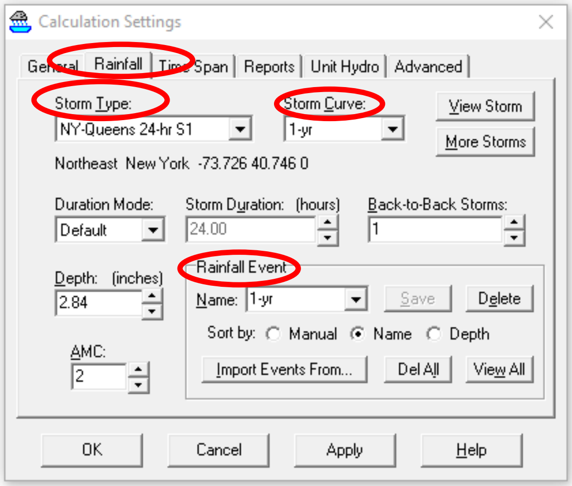
$$P_{90} = \frac{B + 2.5Q + (6.25Q^2 + 25SQ)^{0.5}}{5}$$

$$P_{90} = \frac{1.11\ inches + (2.5\ x\ 1.14\ inches) + (6.25\ x\ 1.14\ inches^2 + 25\ x\ 1.11\ inches\ x\ 1.14\ inches)^{0.5}}{5}$$

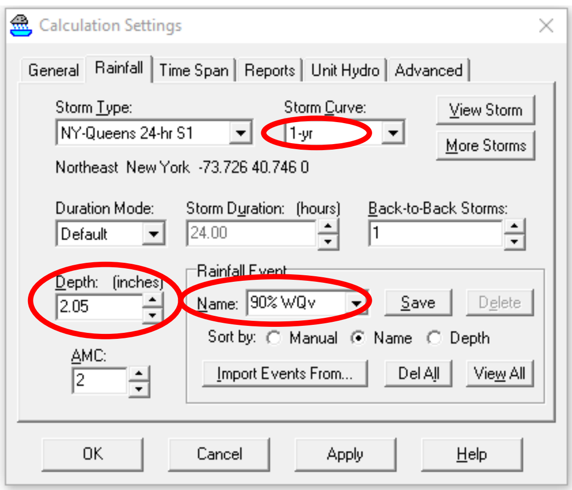
$$P_{90} = 2.05\ inches$$

Step 4 – Input the Calculated Rainfall Value in the Model

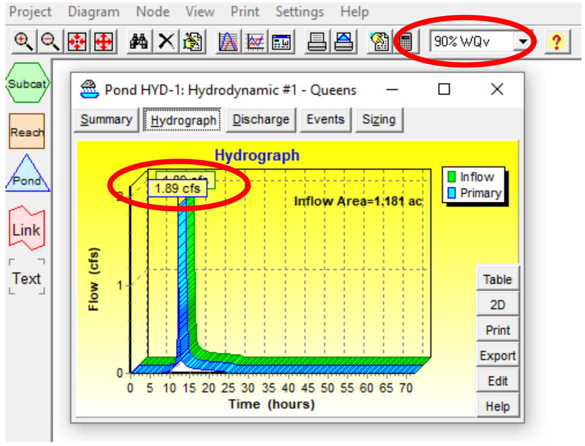
In the stormwater model, enter the “Calculation Settings” and click on the “Rainfall” tab. Ensure that in the rainfall tab, the “Storm Type” shown as the distribution curve created under **Step 1** and the “Storm Curve” corresponds to the “Rainfall Event” shown.



Type the rainfall depth, in inches, calculated under **Step 3** in the “Depth” box and change the “Rainfall Event Name” to be 90% WQv. Ensure that the “Storm Curve” is the 1-yr, then click “Save” and click “OK”.



In the ribbon, select “90% WQv” as the rainfall event. The value output in the model is the WQ_F corresponding to the required WQ_V for the practice.



A final check is to compare the WQv required (0.112 af) to the inflow volume at the practice.

```
Inflow Area =    1.181 ac,  79.25% Impervious,  Inflow Depth =  1.14"   for  90% WQv event
Inflow      =    1.85 cfs @   12.04 hrs,  Volume=        0.112 af
Primary     =    1.85 cfs @   12.04 hrs,  Volume=        0.112 af,  Atten= 0%,  Lag= 0.0 min

Routing by Dyn-Stor-Ind method, Time Span= 0.00-72.00 hrs, dt= 0.01 hrs
```

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APPENDIX C

Miscellaneous Details

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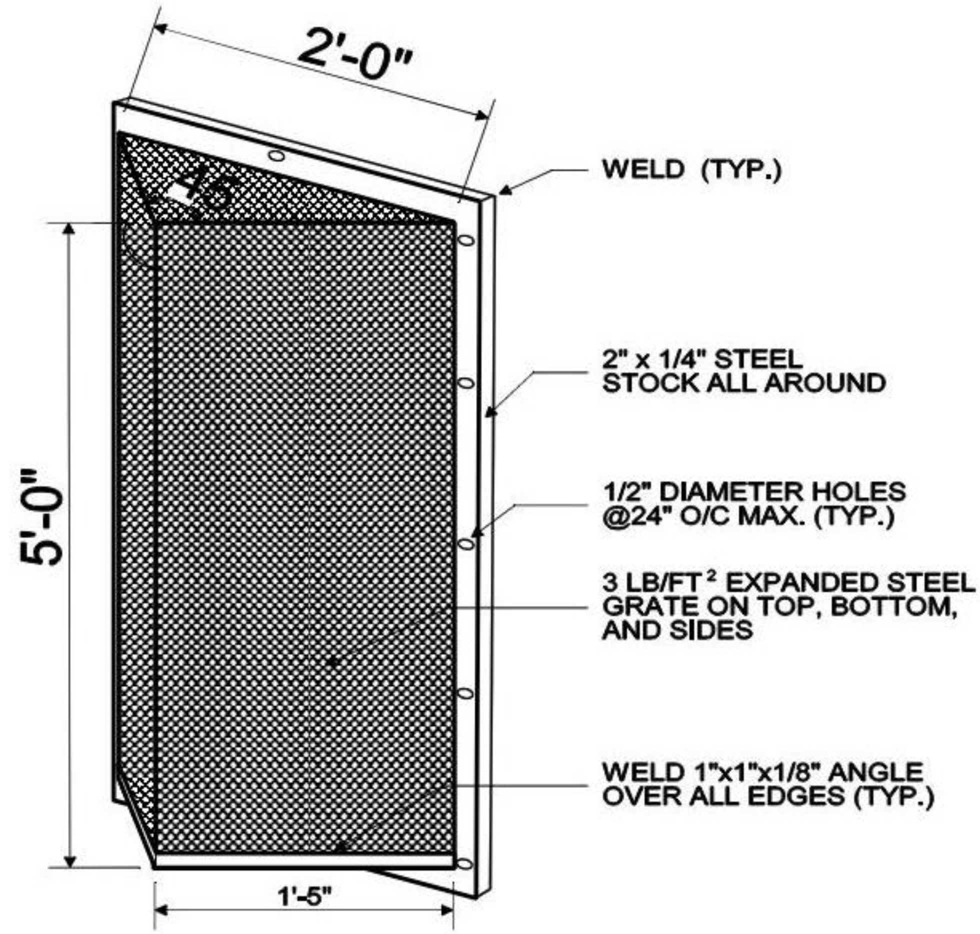
Appendix C: Miscellaneous Details

Miscellaneous Design Schematics for Compliance with Performance Criteria

Figure C.1 Trash Rack Protection for Low Flow Orifice



NOTES FOR TRASH RACK

1. TRASH RACK TO BE CENTERED OVER OPENING.
2. STEEL TO CONFORM TO ASTM A-36.
3. ALL SURFACES TO BE COATED WITH ZRC COLD GALVANIZING COMPOUND AFTER WELDING.

Figure C.2 Expanded Trash Rack Protection for Low Flow Orifice

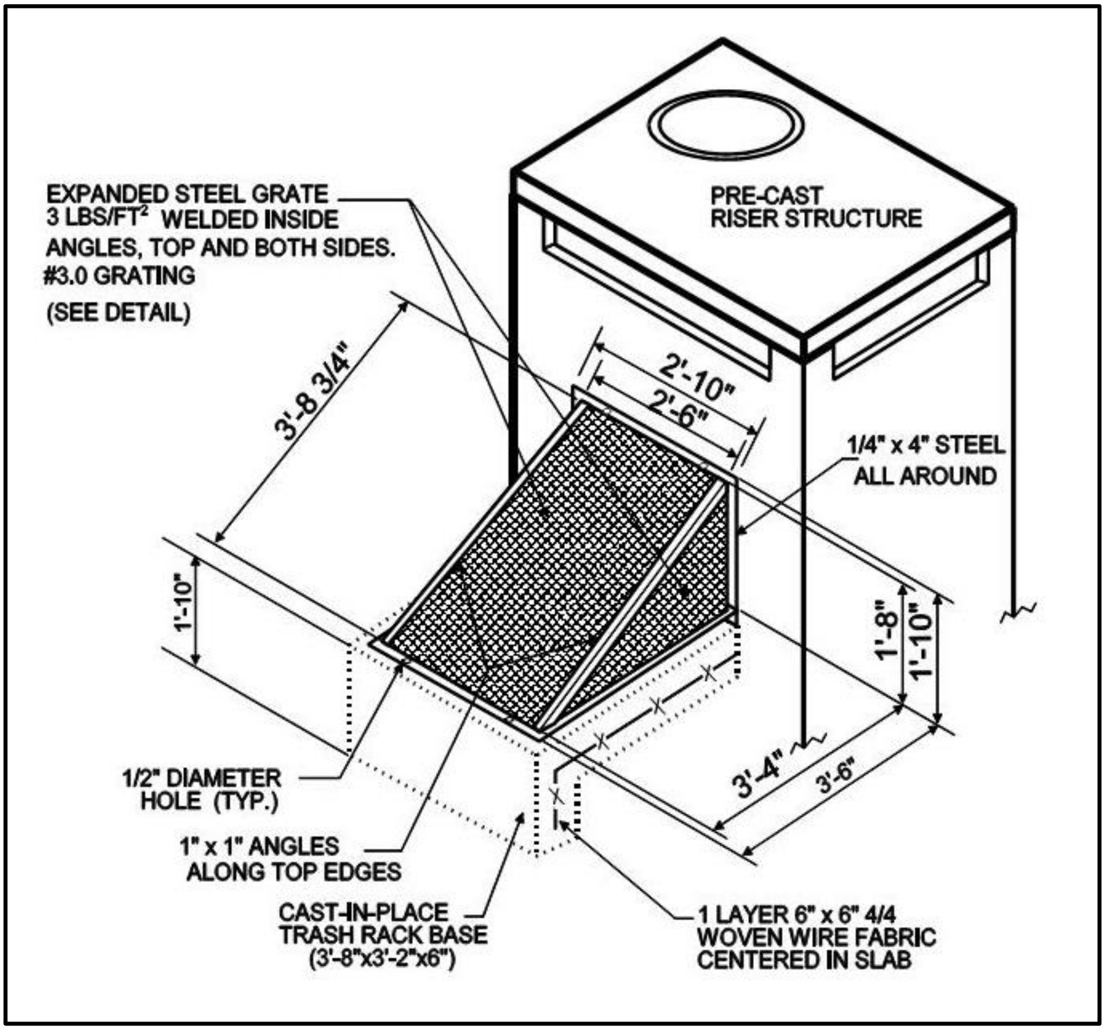
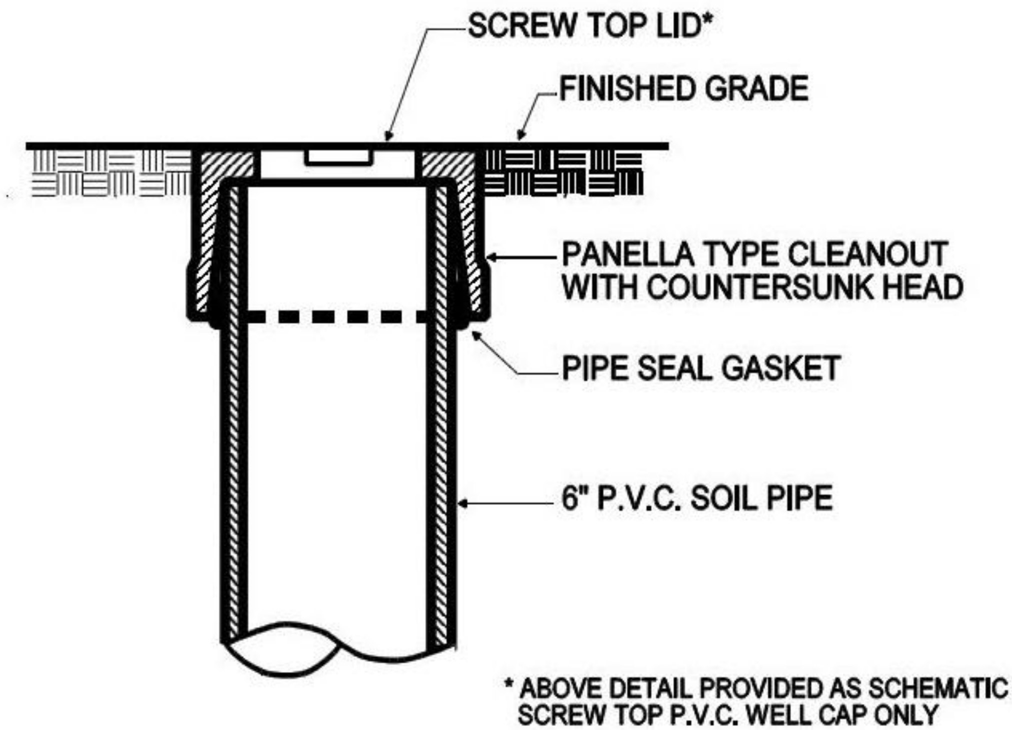


Figure C.3 Observation Well for Infiltration Practices



EACH OBSERVATION WELL / CLEANOUT SHALL INCLUDE THE FOLLOWING:

1. FOR AN UNDERGROUND FLUSH MOUNTED OBSERVATION WELL / CLEANOUT, PROVIDE A TUBE MADE OF NON-CORROSIVE MATERIAL, SCHEDULE 40 OR EQUAL, AT LEAST THREE FEET LONG WITH AN INSIDE DIAMETER OF AT LEAST 6 INCHES.

2. THE TUBE SHALL HAVE A FACTORY ATTACHED CAST IRON OR HIGH IMPACT PLASTIC COLLAR WITH RIBS TO PREVENT ROTATION WHEN REMOVING SCREW TOP LID. THE SCREW TOP LID SHALL BE CAST IRON OR HIGH OMPACT PLASTIC THAT WILL WITHSTAND ULTRA-VIOLET RAYS.

Figure C.4 On-Line Versus Off-Line Schematic

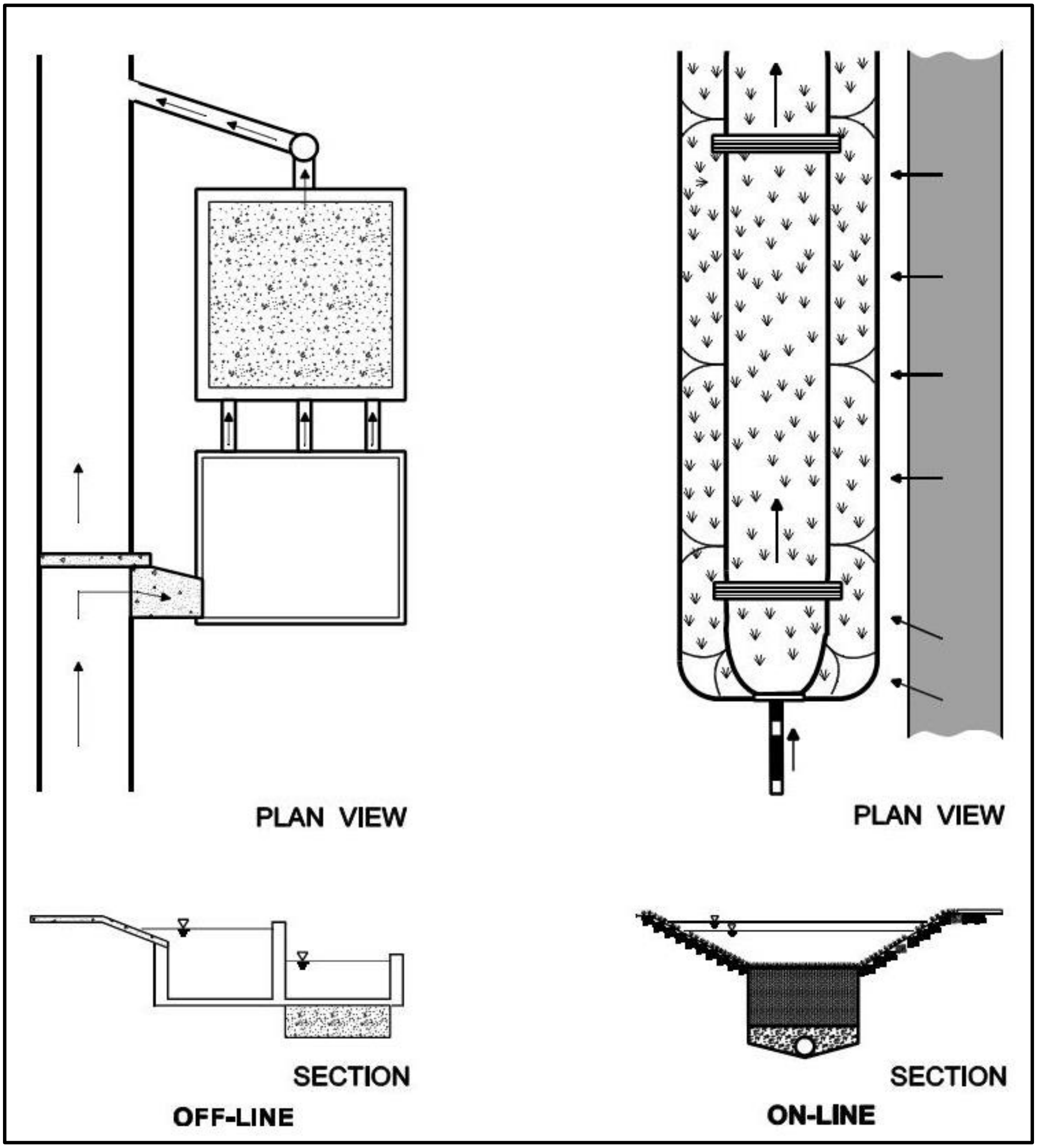


Figure C.5 Isolation Diversion Structure

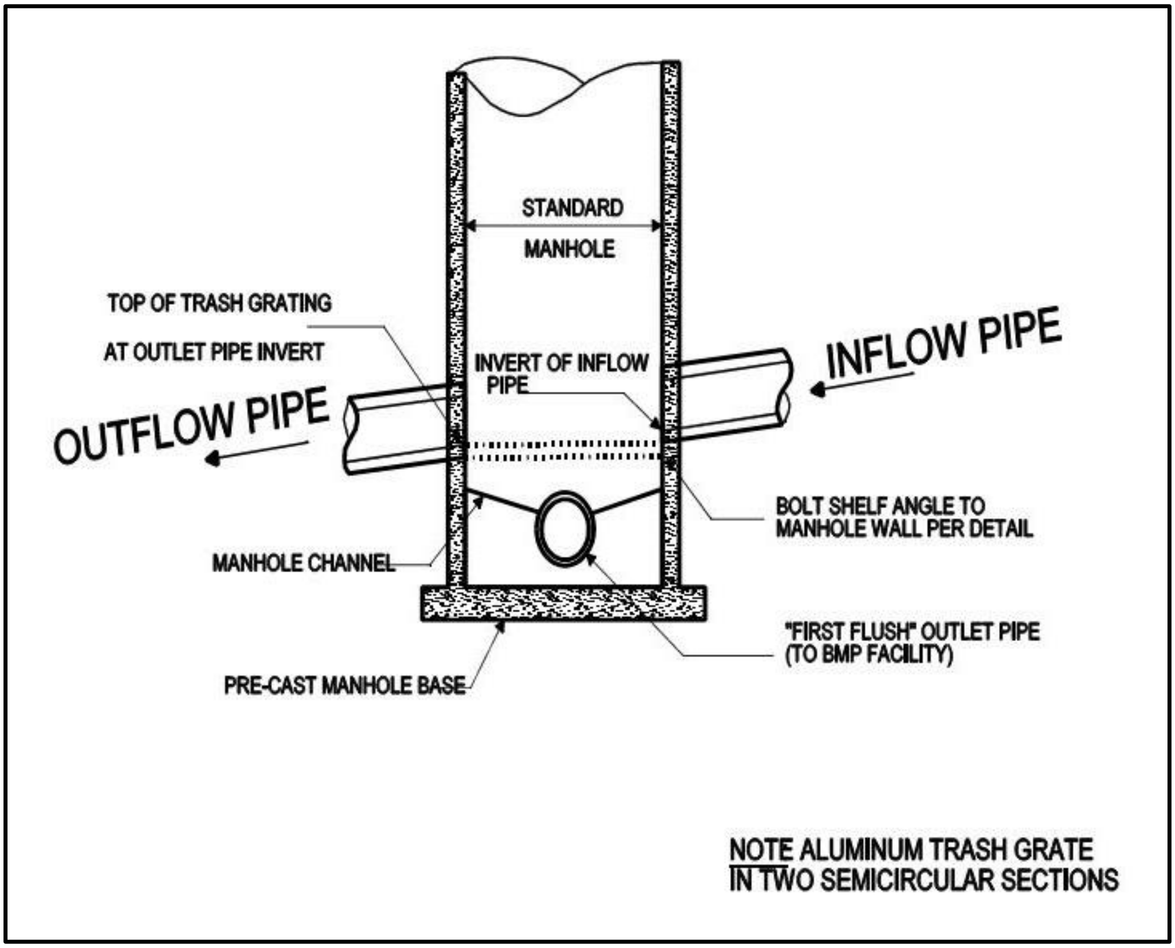


Figure C.6 Half Round CMP Hood

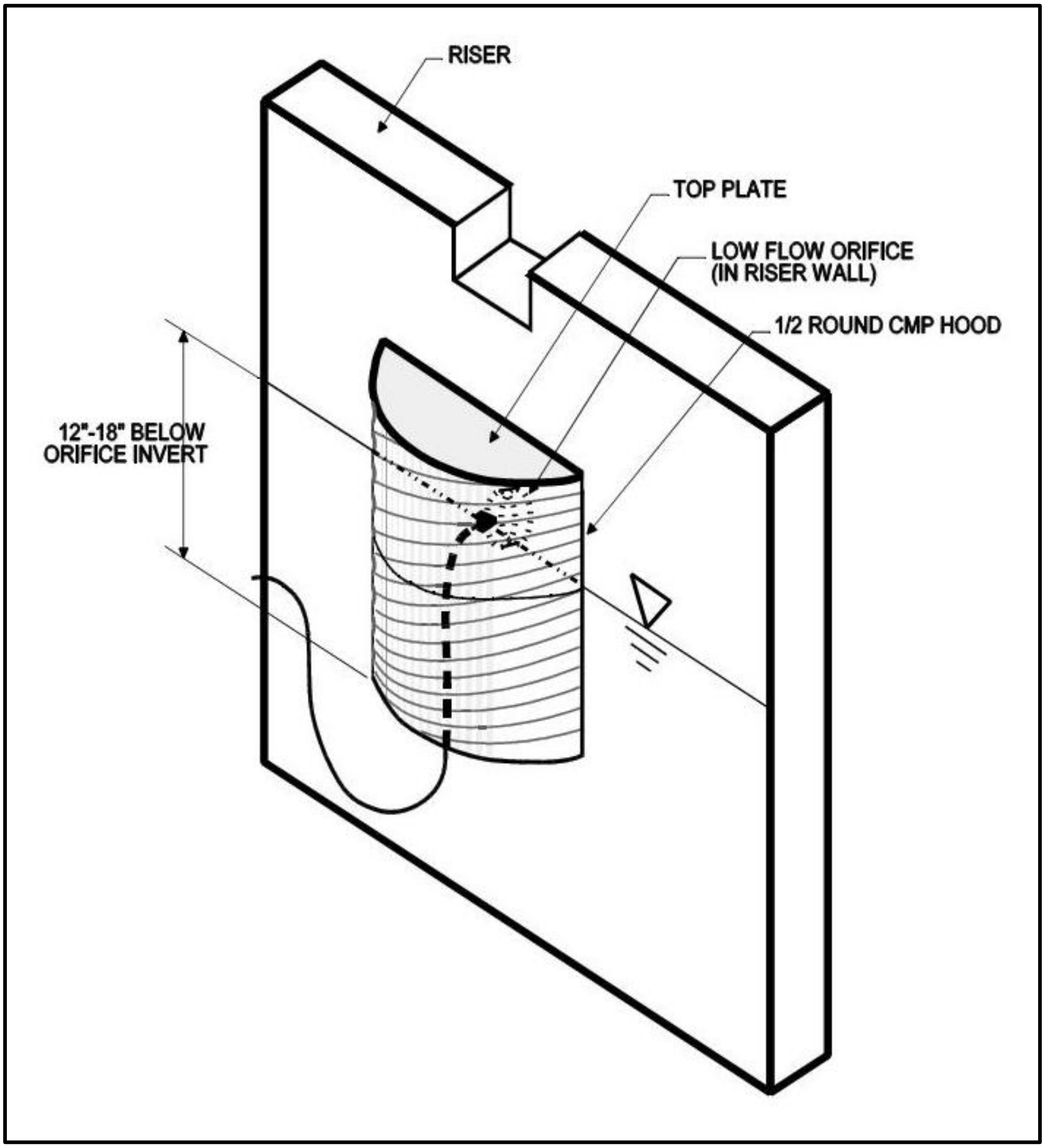


Figure C.7 Half Round CMP Weir

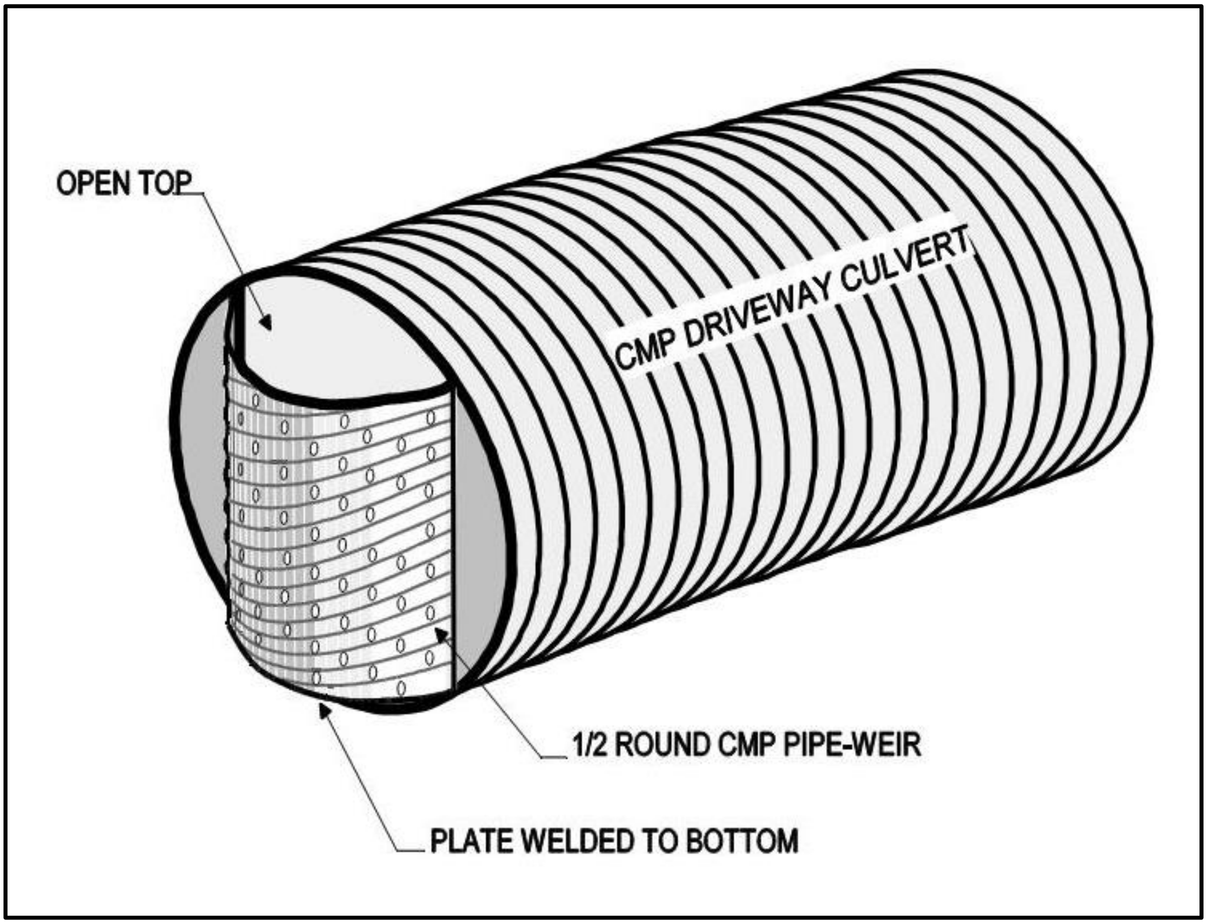


Figure C.8 Concrete Level Spreader

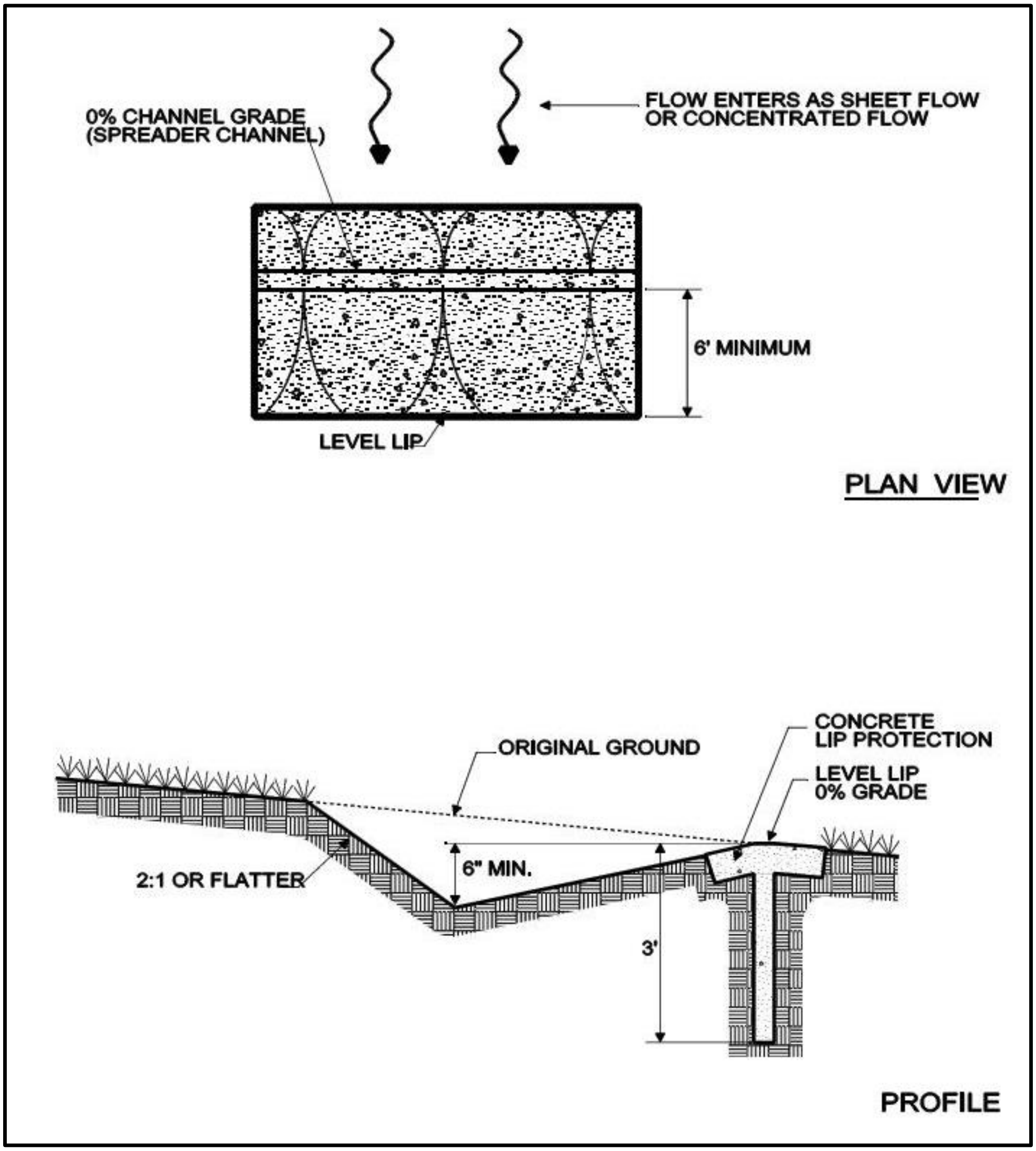


Figure C.9 Baffle Weir for Cold Climates

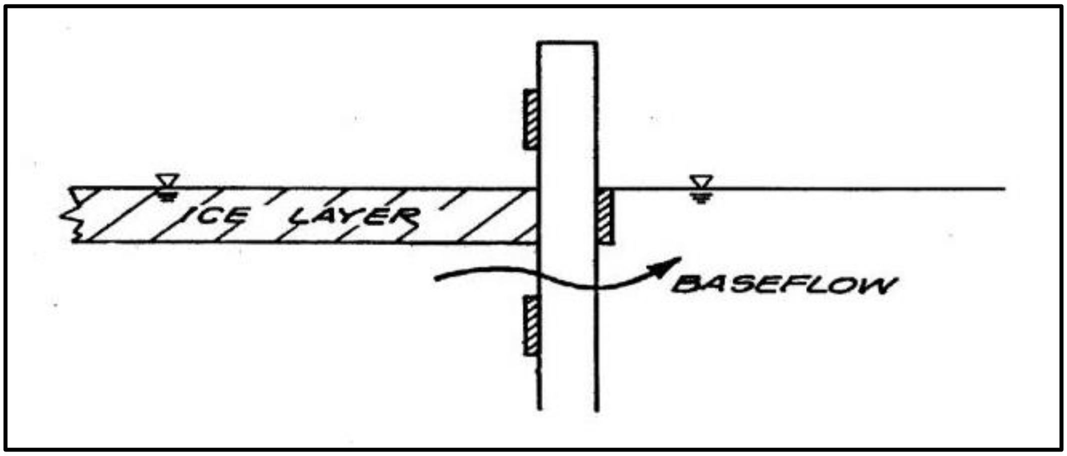


Figure C.10 Hooded Outlet with Hood Below Ice Layer

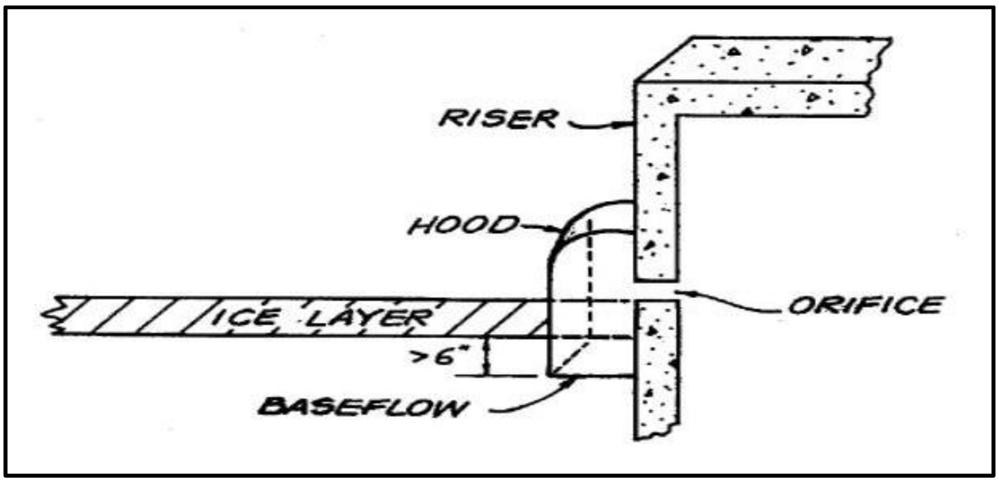


Figure C.11 Shallow Angle Trash Rack to Prevent Icing

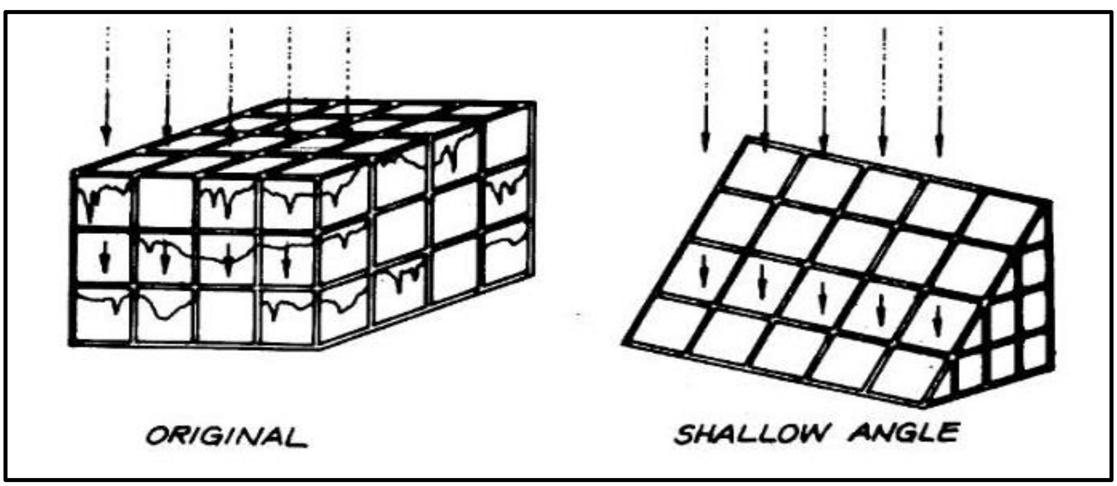
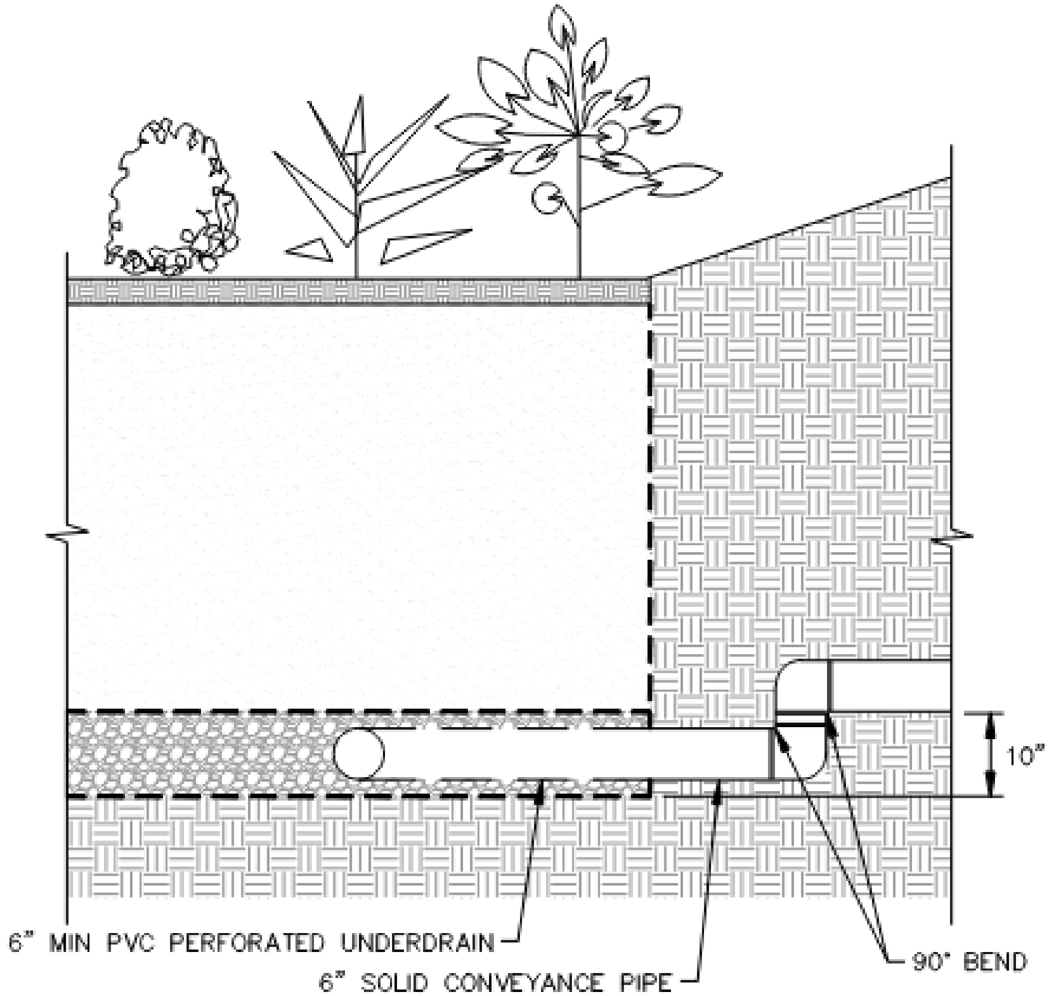


Figure C.12 Upturned Elbow



APPENDIX D

Infiltration Testing Requirements

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Appendix D: Testing Requirements for SMPs

General Notes Pertinent to All Testing

1. Refer to practice specific “Feasibility” sections, in **Chapter 5** & **Chapter 6**, for underlying soil infiltration rate requirements.
2. Number of required test pits/borings and permeability tests are based on the size of the proposed practice. Testing is done in two phases: Feasibility and Design Testing.
3. Testing shall be performed under the supervision of a qualified professional. This professional shall be either a registered Professional Engineer in the State of New York, or a Soil Scientist or Geologist that is licensed in the State of New York.

Feasibility Testing

Feasibility Testing is conducted to determine whether full-scale testing is necessary, and is meant to screen unsuitable sites, and reduce testing costs. Permeability testing and test pits/borings are not required at this stage. However, the designer or landowner may choose to skip Feasibility Testing, and proceed directly to Design Testing, per **Table D.1**.

Feasibility Testing requires, at minimum, one percolation within each proposed practice, or previous testing data, such as the following:

- Septic percolation testing on-site, within 200 ft of the proposed SMP location, and on the same contour.
- Previously written reporting on the site location as prepared by a registered professional engineer in the State of New York, soil scientist, or geologist licensed in the State of New York.
- NRCS County Soil Mapping showing an unsuitable soil group, such as a hydrologic group “D” soil, in a low-lying area, or a Marlboro Clay.

If Feasibility Testing results in a percolation rate of less than or equal to 20 min/inch, then it is probable that the infiltration rate is <u>sufficient</u> to support infiltration practices and Design Testing is required per **Table D.1**.

If Feasibility Testing results in a percolation rate greater than 20 min/inch, then it is probable that the infiltration rate is <u>insufficient</u> to support infiltration practices. The designer may choose to proceed with the design of non-infiltration practices or may choose to proceed with Design Testing. Non-infiltration practices may require infiltration testing to determine the need for an impermeable liner (see **Chapter 6**).

Feasibility Testing Requirements

a. Excavate each hole with vertical sides approximately 12 inches in diameter. The hole depth shall be at or as close to the projected bottom of practice as possible, with a 24-inch minimum depth. The sides of the percolation holes shall be scraped to remove smearing. Optional, place washed aggregate in the lower two inches of each test hole to reduce scouring and silting action when water is poured into the hole.

b. Presoak the test holes by periodically filling the hole with clean water and allowing the water to seep into the subgrade. This procedure shall be performed for at least four hours and shall begin one day before the test (except in clean coarse sand and gravel). After the water from the final presoaking has fully seeped into the subgrade, remove any sloughed soil from the bottom of the hole.

c. Pour clean water into the hole, with as little splashing as possible, to a depth of six inches above the bottom of the test hole.

d. Observe and record the time in minutes for the water to drop from the six-inch depth to the five-inch depth.

e. Repeat test a minimum of three times until the time for the water to drop from six inches to five inches, for two successive tests, is approximately equal. The longest time interval to drop one inch will be taken as the stabilized rate of percolation. If different results are obtained for multiple holes within the same proposed practice, the slowest stabilized rate shall be used for practice feasibility.

Design Testing Requirements

The goals of Design Testing are to establish detailed information about seasonal high water table conditions, boundary conditions such as bedrock, and physical characteristics of the soil to determine the suitability of the soil for a stormwater infiltration practice. Design Testing shall include test pits/borings and permeability tests, in accordance with **Table D.1**.

The soil profile recorded in each test pit/boring, and the infiltration rate recorded in each permeability test, shall be compared to the adjacent tests to confirm consistency. Where soil properties, infiltration rates, and/or depth to seasonal high water table or bedrock vary significantly, additional test pits/borings and/or permeability tests shall be conducted to resolve differences and accurately characterize the soils in the area of interest. If additional testing is not performed, then the more conservative value(s) shall be applied in the design.

Table D.1 Design Testing Summary Table

Area of Practice	# of Test Pits/Boring	# of Permeability Tests
< 2,500 sf	1	2
2,500 sf to < 5,000 sf	2	3
5,000 sf to < 7,500 sf	2	4
7,500 sf to 10,000 sf	2	5
> 10,000 sf	Add 1 test pit/boring for each additional 5,000 sf of practice Add 1 permeability test for each additional 2,500 sf of practice	
Linear Practice	1 test pit/boring for each 250 lineal feet of practice 1 permeability test for each 250 linear feet of practice	

Documentation

A legible site plan, drawn to an accurate scale, shall be provided and include all test locations, and SMP(s). All required documentation shall be included in the Stormwater Pollution Prevention Plan.

The documentation of soil profiles shall include a soil profile log prepared for each test pit/boring and a description of all soil horizons encountered according to the USDA textural classification. The soil profile log shall, at a minimum, include the following:

- Test number;
- Total depth of test;
- Depth and thickness of each soil horizon (each stratum) and depth to restrictive layer (if encountered);
- Appropriate textural class as shown on the USDA textural triangle;
- Soil moisture condition, using standard USDA classification terminology;
- Depth to seasonal high water table, either perched or regional; and
- Any observed seepage, saturation, or mottling.

Test Pit/Boring Requirements

a. Excavate a test pit or drill a boring to a depth of at least four feet below the proposed practice bottom, to the depth of bedrock, or to the seasonal high water table, whichever is less. Test pits should be of adequate size, depth, and construction to allow a person to enter and exit the pit and complete a soil profile description. If borings are drilled, continuous soil borings shall be taken using an auger, probe, or split-spoon sampler. Samples shall have a minimum two inch diameter. A minimum number of test pits and/or borings should be provided for each practice as designated in **Table D.1**.

b. Determine depth to seasonal high water table (if potentially within four feet below the base of the practice).

c. Determine USDA or USC System soil textures at the proposed bottom of practice and to four feet below the bottom of the practice.

d. Describe soil horizons and depth to bedrock (if within four feet of proposed bottom of practice).

e. The location of the test pit or boring shall correspond to the practice bottom; test pit/soil boring stakes shall be clearly labeled and left in the field for inspection and surveyed location.

Field Permeability Tests

Permeability tests shall be conducted at a depth of two feet below the bottom of the proposed SMP. Where stormwater practices are in proximity to fractured bedrock, the practice shall meet the separation requirements outlined in **Chapter 5** or **Chapter 6**.

For stormwater ponds and wetlands that do not provide a liner, the maximum allowable infiltration rate is 0.014 inch/hr (see **Chapter 6**). This can be proven with a permeability test that results in no measurable drop in water level over four hours.

Field Permeability Testing Requirements

a. Excavate to the proposed bottom depth of practice. Install casing (solid 4 to 6 inch diameter, 30 inch length) to a depth of 24 inches below proposed bottom of the practice. Remove all loose material from the casing.

b. Fill casing with clean water to a depth of 24 inches and allow to presoak for 24 hours.

c. 24 hours later, refill casing with another 24 inches of clean water and monitor water level (measure drop from the top of casing) for one hour. Repeat this procedure (filling the casing each time) a minimum of three additional times, until the permeability rate stabilizes. All results from permeability testing shall be reported.

d. Upon completion of the testing, the casings should be immediately pulled, and the test pit shall be backfilled.

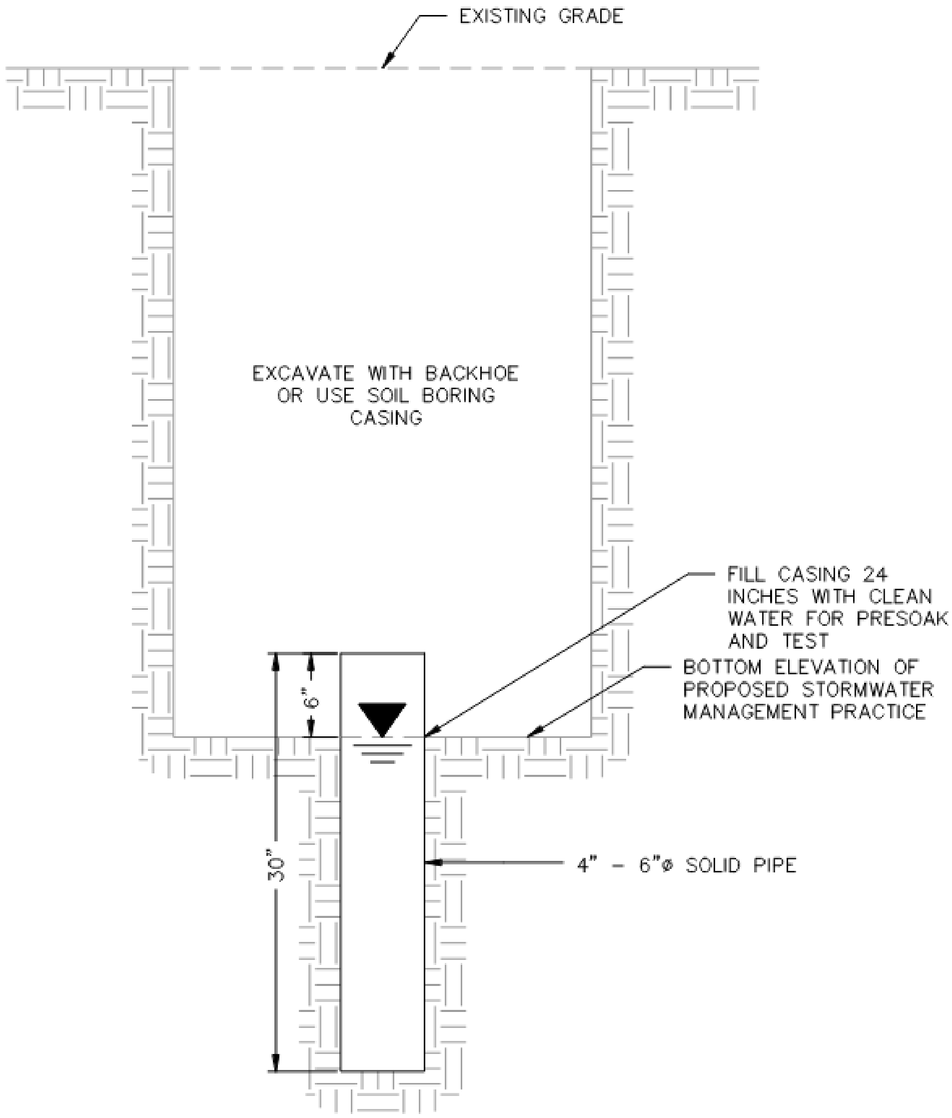

Figure D.1 Permeability Testing Requirements

Alternate: Laboratory Permeability Testing

a. The Ksat should be measured with test methods described in ASTM D2434 (Standard Test Method for Permeability of Granular Soils (Constant Head)) or ASTM D 5856 (Standard Test Methods for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction Mold Permeameter).

b. Apply a minimum factor of safety by dividing the representative Ksat by 2.0 and use the result as the design infiltration rate.

c. Once the fill is in place, the soil shall be field tested to confirm the design rate. To confirm the rate, run the field test in accordance with **Field Permeability Testing Requirements**.

APPENDIX E

Plan Review Checklists

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Appendix E: Plan Review Checklists

Example Checklist for Preliminary/Concept Stormwater Management Plan Preparation and Review

- Applicant information
- Name, legal address, and telephone number
- Common address and legal description of site
- Vicinity map
- Existing and proposed mapping and plans (recommended scale of 1″ = 50ft.) which illustrate at a minimum:
    - Existing and proposed topography (minimum of 2-ft contours recommended)
    - Perennial and intermittent streams
    - Mapping of predominant soils from USDA soil surveys
    - Boundaries of existing predominant vegetation and proposed limits of clearing
    - Location and boundaries of resource protection areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks)
    - Location of existing and proposed roads, buildings, and other structures
    - Existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
    - Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
    - Flow paths
    - Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
    - Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings
    - Preliminary location, size, and limits of disturbance of proposed stormwater treatment practices
- Hydrologic and hydraulic analysis including:
    - Existing condition analysis for runoff rates, volumes, and velocities presented showing methodologies used and supporting calculations
    - Proposed condition analysis for runoff rates, volumes, and velocities showing the methodologies used and supporting calculations
    - Preliminary analysis of potential downstream impact/effects of project, where necessary
    - Preliminary selection and rationale for structural stormwater management practices
    - Preliminary sizing calculations for stormwater treatment practices including contributing drainage area, storage, and outlet configuration
- Preliminary landscaping plans for stormwater treatment practices and any site reforestation or revegetation
- Preliminary erosion and sediment control plan that at a minimum meets the requirements outlined in local Erosion and Sediment Control guidelines
- Identification of preliminary waiver requests

Example Checklist for Final Stormwater Management Plan Preparation and Review

- Applicant information
- Name, legal address, and telephone number
- Common address and legal description of site
- Signature and stamp of registered engineer/surveyor and design/owner certification
- Vicinity map
- Existing and proposed mapping and plans (recommended scale of 1″ = 50ft or greater detail) which illustrate at a minimum:
  - Existing and proposed topography (minimum of 2-ft contours recommended)
  - Perennial and intermittent streams
  - Mapping of predominant soils from USDA soil surveys as well as location of any site-specific borehole investigations that may have been performed.
  - Boundaries of existing predominant vegetation and proposed limits of clearing
  - Location and boundaries of resource protection areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks)
  - Location of existing and proposed roads, buildings, and other structures
  - Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
  - Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
  - Flow paths
  - Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
  - Location and dimensions of proposed channel modifications, such as bridge or culvert crossings
  - Location, size, maintenance access, and limits of disturbance of proposed structural stormwater Management practices
- Representative cross-section and profile drawings and details of structural stormwater Management practices and conveyances (i.e., storm drains, open channels, swales, etc.) which include:
  - Existing and proposed structural elevations (e.g., invert of pipes, manholes, etc.)
  - Design water surface elevations
  - Structural details of outlet structures, embankments, spillways, stilling basins, grade control structures, conveyance channels, etc.
  - Logs of borehole investigations that may have been performed along with supporting geotechnical report.

- Hydrologic and hydraulic analysis for all structural components of stormwater system (e.g., storm drains, open channels, swales, Management practices, etc.) for applicable design storms including:
    - Existing condition analysis for times of concentration, runoff rates, volumes, velocities, and water surface elevations showing methodologies used and supporting calculations
    - Proposed condition analysis for times of concentration, runoff rates, volumes, velocities, water surface elevations, and routing showing the methodologies used and supporting calculations
    - Final sizing calculations for structural stormwater Management practices including, contributing drainage area, storage, and outlet configuration
    - Stage-discharge or outlet rating curves and inflow and outflow hydrographs for storage facilities (e.g., stormwater ponds and wetlands)
    - Final analysis of potential downstream impact/effects of project, where necessary
    - Dam breach analysis, where necessary
- Final landscaping plans for structural stormwater Management practices and any site reforestation or revegetation
- Structural calculations, where necessary
- Applicable construction specifications
- Erosion and sediment control plan that at a minimum meets the requirements of the local Erosion and Sediment Control Guidelines
- Sequence of construction
- Maintenance plan which will include:
    - Name, address, and phone number of responsible parties for maintenance.
    - Description of annual maintenance tasks
    - Description of applicable easements
    - Description of funding source
    - Minimum vegetative cover requirements
    - Access and safety issues
    - Testing and disposal of sediments that will likely be necessary
- Evidence of acquisition of all applicable local and non-local permits
- Evidence of acquisition of all necessary legal agreements (e.g., easements, covenants, land trusts)
- Waiver requests
- Review agency should have inspector’s checklist identifying potential features to be inspected on site visits

Appendix F: Construction Inspection Checklists

Stormwater/Wetland Pond Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Pre-Construction/Materials and Equipment		
Pre-construction meeting		
Pipe and appurtenances on-site prior to construction and dimensions checked		
1. Material (including protective coating, if specified)		
2. Diameter		
3. Dimensions of metal riser or pre-cast concrete outlet structure		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope		
6. Number and dimensions of prefabricated anti-seep collars		
7. Watertight connectors and gaskets		
8. Outlet drain valve		
Project benchmark near pond site		
Equipment for temporary de-watering		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
2. Subgrade Preparation		
Area beneath embankment stripped of all vegetation, topsoil, and organic matter		
3. Pipe Spillway Installation		
Method of installation detailed on plans		
A. Bed preparation		
Installation trench excavated with specified side slopes		
Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have defined steps before proceeding with installation)		
Invert at proper elevation and grade		
B. Pipe placement		
Metal / plastic pipe		
1. Watertight connectors and gaskets properly installed		
2. Anti-seep collars properly spaced and having watertight connections to pipe		
3. Backfill placed and tamped by hand under “haunches” of pipe		
4. Remaining backfill placed in max. 8” lifts using small power tamping equipment until 2 ft cover over pipe is reached		

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
3. Pipe Spillway Installation		
Concrete pipe		
1. Pipe set on blocks or concrete slab for pouring of low cradle		
2. Pipe installed with rubber gasket joints with no spalling in gasket interface area		
3. Excavation for lower half of anti-seep collar(s) with reinforcing steel set		
4. Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other approved waterproof sealant		
5. Low cradle and bottom half of anti-seep collar installed as monolithic pour and of an approved mix		
6. Upper half of anti-seep collar(s) formed with reinforcing steel set		
7. Concrete for collar of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
8. Forms stripped and collar inspected for honeycomb prior to backfilling. Parge if necessary.		
C. Backfilling		
Fill placed in maximum 8” lifts		
Backfill taken minimum 2 ft above top of anti-seep collar elevation before traversing with heavy equipment		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Riser / Outlet Structure Installation		
Riser located within embankment		
A. Metal riser		
Riser base excavated or formed on stable subgrade to design dimensions		
Set on blocks to design elevations and plumbed		
Reinforcing bars placed at right angles and projecting into sides of riser		
Concrete poured so as to fill inside of riser to invert of barrel		
B. Pre-cast concrete structure		
Dry and stable subgrade		
Riser base set to design elevation		
If more than one section, no spalling in gasket interface area; gasket or approved caulking material placed securely		
Watertight and structurally sound collar or gasket joint where structure connects to pipe spillway		
C. Poured concrete structure		
Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set		
Structure formed to design dimensions, with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
Forms stripped & inspected for “honeycomb” prior to backfilling; parge if necessary		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
5. Embankment Construction		
Fill material		
Compaction		
Embankment		
1. Fill placed in specified lifts and compacted with appropriate equipment		
2. Constructed to design cross-section, side slopes and top width		
3. Constructed to design elevation plus allowance for settlement		
6. Impounded Area Construction		
Excavated / graded to design contours and side slopes		
Inlet pipes have adequate outfall protection		
Forebay(s)		
Pond benches		
7. Earth Emergency Spillway Construction		
Spillway located in cut or structurally stabilized with riprap, gabions, concrete, etc.		
Excavated to proper cross-section, side slopes and bottom width		
Entrance channel, crest, and exit channel constructed to design grades and elevations		

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
8. Outlet Protection		
A. End section		
Securely in place and properly backfilled		
B. Endwall		
Footing excavated or formed on stable subgrade, to design dimensions and reinforcing steel set, if specified		
Endwall formed to design dimensions with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing, if necessary)		
Forms stripped and structure inspected for "honeycomb" prior to backfilling; parge if necessary		
C. Riprap apron / channel		
Apron / channel excavated to design cross-section with proper transition to existing ground		
Filter fabric in place		
Stone sized as per plan and uniformly place at the thickness specified		
9. Vegetative Stabilization		
Approved seed mixture or sod		
Proper surface preparation and required soil amendments		
Excelsior mat or other stabilization, as per plan		

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
10. Miscellaneous		
Drain for ponds having a permanent pool		
Trash rack / anti-vortex device secured to outlet structure		
Trash protection for low flow pipes, orifices, etc.		
Fencing (when required)		
Access road		
Set aside for clean-out maintenance		
11. Stormwater Wetlands		
Adequate water balance		
Variety of depth zones present		
Approved pondscaping plan in place Reinforcement budget for additional plantings		
Plants and materials ordered 6 months prior to construction		
Construction planned to allow for adequate planting and establishment of plant community (April-June planting window)		
Wetland buffer area preserved to maximum extent possible		

Comments:

Actions to be Taken:

Infiltration Trench Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock sufficient at depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Filter Fabric Placement		
Fabric specifications		
Placed on bottom, sides, and top		

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Aggregate Material		
Size as specified		
Clean / washed material		
Placed properly		
5. Observation Well		
Pipe size		
Removable cap / footplate		
Initial depth =______ft		
6. Final Inspection		
Pretreatment device in place		
Contributing watershed stabilized prior to flow diversion		
Outlet		

Comments:

Actions to be Taken:

Infiltration Basin Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Embankment		
Barrel		
Anti-seep collar or Filter diaphragm		
Fill material		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Final Excavation		
Drainage area stabilized		
Sediment removed from facility		
Basin floor tilled		
Facility stabilized		
5. Final Inspection		
Pretreatment device in place		
Inlets / outlets		
Contributing watershed stabilized before flow is routed to the facility		

Comments:

Actions to be Taken:

Sand Filter System Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Pre-construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Facility location staked out		
2. Excavation		
Size and location		
Side slopes stable		
Foundation cleared of debris		
If designed as exfilter, excavation does not compact subsoils		
Foundation area compacted		
3. Structural Components		
Dimensions and materials		
Forms adequately sized		
Concrete meets standards		
Prefabricated joints sealed		
Underdrains (size, materials)		

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Completed Facility Components		
24-hr water filled test		
Contributing area stabilized		
Filter material per specification		
Underdrains installed to grade		
Flow diversion structure properly installed		
Pretreatment devices properly installed		
Level overflow weirs, multiple orifices, distribution slots		
5. Final Inspection		
Dimensions		
Surface completely level		
Structural components		
Proper outlet		
Ensure that site is properly stabilized before flow is directed to the structure.		

Comments:

Actions to be Taken:

Bioretention Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
If designed as exfilter, soil testing for permeability		
Facility location staked out		
2. Excavation		
Size and location		
Lateral slopes completely level		
If designed as exfilter, ensure that excavation does not compact subsoils.		
Longitudinal slopes within design range		

Construction Sequence	Satisfactory / Unsatisfactory	Comments
3. Structural Components		
Stone diaphragm installed correctly		
Outlets installed correctly		
Underdrain		
Pretreatment devices installed		
Soil bed composition and texture		
4. Vegetation		
Complies with planting specs		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
5. Final Inspection		
Dimensions		
Proper stone diaphragm		
Proper outlet		
Soil/ filter bed permeability testing		
Effective stand of vegetation and stabilization		
Construction generated sediments removed		
Contributing watershed stabilized before flow is diverted to the practice		

Comments:

Actions to be Taken:

Open Channel System Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility location staked out		
2. Excavation		
Size and location		
Side slope stable		
Soil permeability		
Groundwater / bedrock		
Lateral slopes completely level		
Longitudinal slopes within design range		
Excavation does not compact subsoils		
3. Check dams		
Dimensions		
Spacing		
Materials		

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Structural Components		
Underdrain installed correctly		
Inflow installed correctly		
Pretreatment devices installed		
5. Vegetation		
Complies with planting specifications		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
6. Final inspection		
Dimensions		
Check dams		
Proper outlet		
Effective stand of vegetation and stabilization		
Contributing watershed stabilized before flow is routed to the facility		

Comments:

Actions to be Taken:

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APPENDIX G

Non-Erosive Velocities of Vegetated Channels

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Appendix G: Non-Erosive Velocities of Vegetated Channels

Velocity

Maximum velocities of flow in vegetated channels absent of permanent turf reinforcement matting shall not exceed the values shown in the following table:

Table L.1 Permissible Non-Erosive Velocities for Channels with Vegetative Lining

Channel Slope	Vegetative Lining	Maximum Velocity (ft/sec)
0-5%	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Serices lespedeza Annual lespedeza Small grains	2.5
5-10%	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Reed canarygrass Tall fescue Kentucky bluegrass	3

Source: Soil and Water Conservation Engineering, Schwab, *et al.*

[1] For highly erodible soils, maximum velocities should be decreased 25%. An erodibility factor (K) greater than 0.35 would indicate a highly erodible soil. Erodibility factors (K-factors) can be obtained from local NRCS offices.

For vegetated earth channels having permanent turf reinforcement matting, the maximum flow velocity shall not exceed 8 ft/sec. Turf reinforcement matting shall be a machine produced mat of nondegradable fibers or elements having a uniform thickness and distribution of weave throughout. Matting shall be installed per manufacturer's recommendations with appropriate fasteners as required.

Manning's n value

The roughness coefficient, n, varies with the type of vegetative cover and flow depth. At very shallow depths, where the vegetation height is equal to or greater than the flow depth, the n value should be approximately 0.15. This value is appropriate for flow depths up to 4" typically. For higher flow rates and flow depths, the n value decreases to a minimum of 0.03 for grass channels at a depth of approximately 12". The n value must be adjusted for varying flow depths between 4" and 12" (see **Figure L.1**).

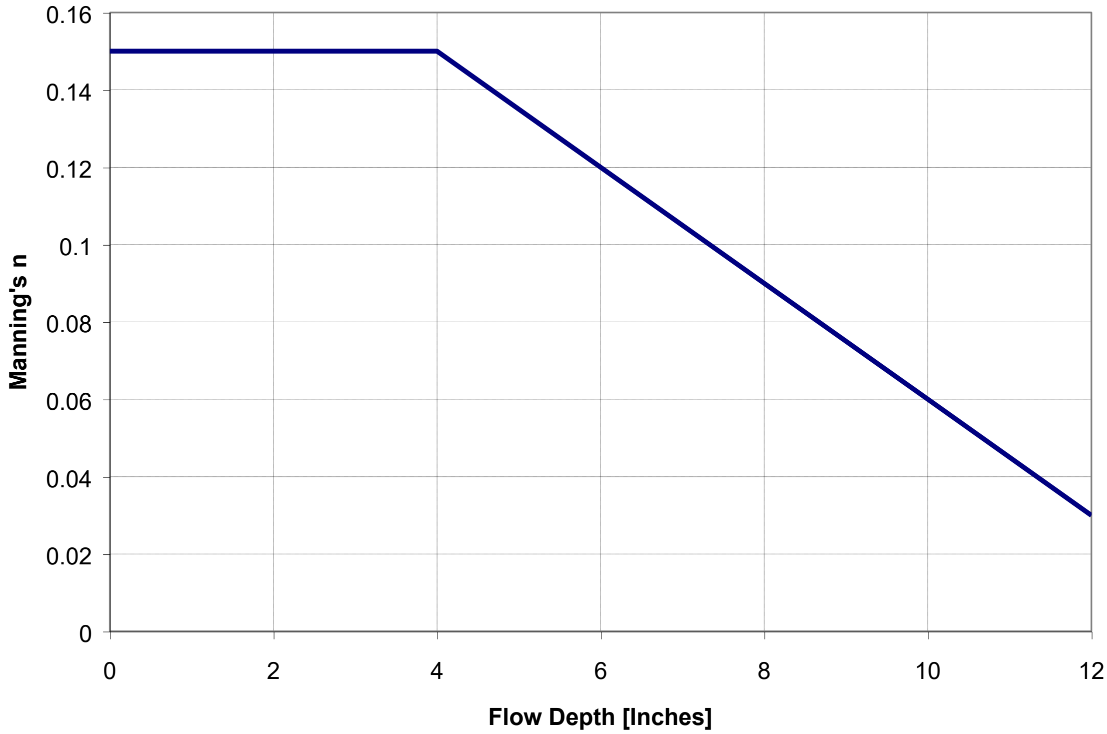

Figure L.1 Manning's n Value with Varying Flow Depth (Source: Claytor and Schueler, 1986)

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APPENDIX H

Cold Climate Sizing Criteria

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Appendix H: Cold Climate Sizing Criteria

Traditional SMP sizing criteria are based on the hydrology and climatic conditions of moderate climates. These criteria are not always applicable to cold climate regions due to snowmelt, rain-on-snow and frozen soils. This Appendix identifies methods to adjust water quality (**Section I.1**) sizing criteria for cold climates.

Section I.1 Water Quality Sizing Criteria

The water quality volume is the portion of the SMP reserved to treat stormwater either through detention, filtration, infiltration or biological activity. Base criteria developed for SMP sizing nationwide are based on rainfall events in moderate climates (e.g., Schueler, 1992). Designers may wish to increase the water quality volume of SMPs to account for the unique conditions in colder climates, particularly when the spring snowfall represents a significant portion of the total rainfall. Spring snowmelt, rain-on-snow and rain-on-frozen ground may warrant higher treatment volumes. It is important to note that **the base criteria required by a region must always be met**, regardless of calculations made for cold climate conditions.

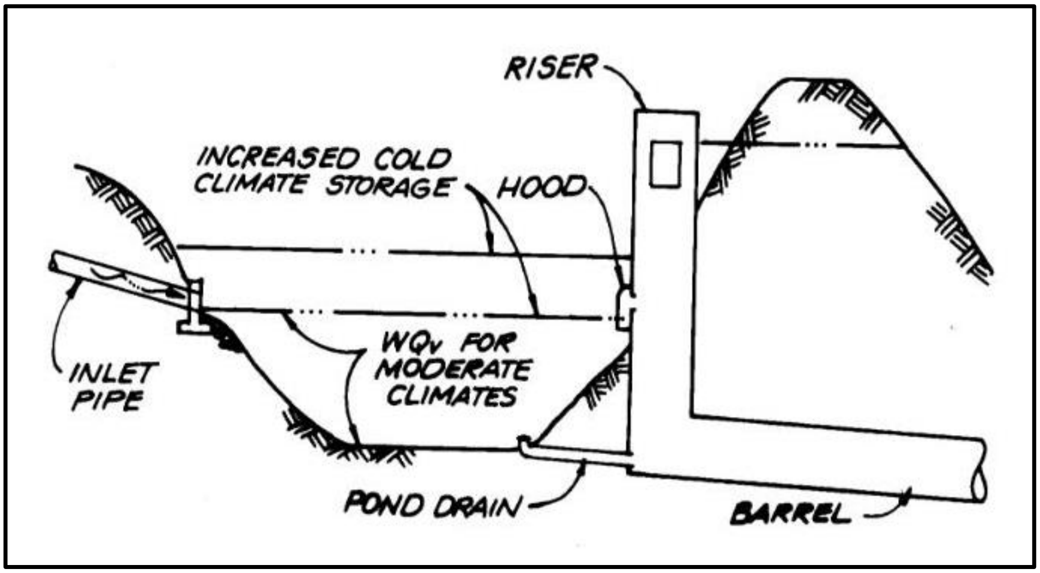

Figure I.1 Increased Water Quality Volume in Cold Climates

The goal of treating 90% of the annual pollutant load (Schueler, 1992), can be applied to snowmelt runoff and rain-on snow events. In the following conditions, cold climate sizing may be greater than base criteria sizing:

- Snowfall represents more than 10% of total annual precipitation. This value is chosen because, at least some portion of the spring snowmelt needs to be treated in order to treat 90% of annual runoff in these conditions. Using the rule of thumb that the moisture content of snowfall has about 10% moisture content, this rule can be simplified as:

  Oversize when average annual snowfall depth is greater than or equal to annual precipitation depth.

- The area is in a coastal or Great Lakes region with more than 3' of snow annually. In these regions, rain-on-snow events occur frequently enough to justify oversizing stormwater SMPs for water quality.

The following caveats apply to the sizing criteria presented in this section:

- These criteria are not appropriate for very deep snowpacks (i.e., greater than 4') because the volume to be treated would be infeasible, and often unnecessary.
- Snowmelt is a complicated process, with large annual variations. While the criteria presented here address the effects of snowmelt and rain-on-snow, several simplifying assumptions are made. Where local data or experience are available, more sophisticated methods should be substituted.

Section I.1.1 Water Quality Volume for Snowmelt

In order to treat 90% of annual runoff volume, sizing for snowmelt events needs to be completed in the context of the precipitation for the entire year. In relatively dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. On the other hand, in regions with high annual rainfall, storm events are more likely to carry the majority of pollutants annually. The sizing criteria for this section are based on three assumptions: 1) SMPs should be sized to treat the spring snowmelt event 2)Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture 3) No more than five percent of the annual runoff volume should bypass treatment during the spring snowmelt event and 4) SMPs can treat a snowmelt volume greater than their size.

- SMPs should be sized to treat the spring snowmelt runoff event

  Snowmelt occurs throughout the winter in small, low-flow events. These events have high concentrations of soluble pollutants such as chlorides and metals, because of "preferential elution" from the snowpack (Jeffries, 1988). Although these events have significant pollutant loads, the flows are very low intensity, and generally will not affect SMP sizing decisions.

  The spring snowmelt, on the other hand, is higher in suspended solids and hydrophobic elements, such as hydrocarbons, which can remain in the snowpack until the last five to ten percent of water leaves the snowpack (Marsalek, 1991). In addition, a large volume of runoff occurs over a comparatively short period of time (i.e., approximately two weeks). Most SMPs rely on settling to treat pollutants, and the pollutants carried in the spring snowmelt are more easily treated by these mechanisms. In addition, the large flow volume during this event may be the critical water quality design event in many cold regions.

- Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture

  Because of small snowmelt events that occur throughout the winter, losses through sublimation, and management practices such as hauling snow to other locations, the snowpack only contains a fraction of the moisture from the winter snowfall. Thus, the remaining moisture in the snowpack can be estimated by:

$$M=0.1 \cdot S_n - L_1 - L_2 - L_3 \qquad \textbf{(Equation I.1)}$$

Where M = Moisture in the Spring Snowpack (inches)

S_n = Annual Snowfall (inches)

L_1, L_2 and L_3 = Losses to Hauling, Sublimation and Winter Melt, respectively.

The volume of snow hauled off site can be determined based on available information on current plowing practices. In New York, sublimation to the atmosphere is not very important

The design examples in this section use a simple "rule of thumb" approach, to estimate winter snowmelt for simplicity (**Table I.1**). The method assumes that winter snowmelt is influenced primarily by temperature, as represented by the average daily temperature for January. One half of the snow (adjusted for plowing and sublimation) is assumed to melt during the winter in very cold regions (Average T_{max} <25°F) and two thirds is assumed to melt during the winter in moderately cold regions (Average T_{max} <35°F). Winter snowmelt can be estimated using several methods, such as the simple degree-day method, or through more complex continuous modeling efforts.

Table I.1 Winter Snowmelt*		
Adjusted Snowfall Moisture Equivalent	**Winter Snowmelt (January T_{max}<25°F)**	**Winter Snowmelt (January T_{max}<35°F)**
2"	1.0"	1.3"
4"	2.0"	2.7"
6"	3.0"	4.0"
8"	4.0"	5.3"
10"	5.0"	6.7"
12"	6.0"	8.0"

* Snowmelt occurring before the spring snowmelt event, based on the moisture content in the annual snowfall. The value in the first column is adjusted for losses due to sublimation and plowing off site.

Snowmelt is converted to runoff when the snowmelt rate exceeds the infiltration capacity of the soil. Although the rate of snowmelt is slow compared with rainfall events, snowmelt can cause significant runoff because of frozen soil conditions. The most important factors governing the volume of snowmelt runoff are the water content of the snowpack and the soil moisture content at the time the soil freezes (Granger et al., 1984). If the soil is relatively dry when it freezes, its permeability is retained. If, on the other hand, the soil is moist or saturated, the ice formed within the soil matrix acts as an impermeable layer, reducing infiltration. **Section I.1.3** outlines a methodology for computing snowmelt runoff based on this principle.

- *No more than 5% of the* ***annual runoff volume*** *should bypass treatment during spring snowmelt* In order to treat 90% of the annual runoff volume, at least some of the spring snowmelt, on average, will go un-treated. In addition, large storm events will bypass treatment during warmer months. Limiting the volume that bypasses treatment during the spring snowmelt to 5% of the annual runoff volume allows for these large storm events to pass through the facility untreated, while retaining the 90% treatment goal.

  The resulting equation is:

  $$Vol=(R_s-0.05Q)A/12 \qquad \textbf{(Equation I.2)}$$

  where Vol = Volume Treated (acre-ft)

  R_s = Snowmelt Runoff [See **Section I.1.3**]

  Q = Annual Runoff Volume (inches) [See **Section I.1.2**]

  A = Area (acres)

- *SMPs can treat a volume greater than their normal size.*

  Snowmelt occurs over a long period of time, compared to storm events. Thus, the SMP does not have to treat the entire water quality treatment volume computed over 24-hrs, but over a week or more. As a result, the necessary water quality volume in the structure will be lower than the treatment volume. For this manual, we have assumed a volume of ½ of the value of the computed treatment volume (Vol) calculated in equation I.2.

  Thus,

  $$WQ_v = \tfrac{1}{2}\,Vol \qquad \textbf{(Equation I.3)}$$

Section I.1.2 Base Criteria/ Annual Runoff

The base criterion is the widely used, traditional water quality sizing rule. This criterion, originally developed for moderate climates, represents the minimum recommended water quality treatment volume. In this manual, the runoff from a one" rainfall event is used as the base criteria. The basis behind this sizing criteria is that approximately 90% of the storms are treated using this event. This value may vary nationwide, depending on local historical rainfall frequency distribution data. However, the one” storm is used as a simplifying assumption. The base criteria included in this manual is chosen because it incorporates impervious area in the sizing of urban SMPs, and modifications are used nationwide. The cold climate sizing modifications used in this manual may be applied to any base criteria, however.

- Runoff for rain events can be determined based on the Simple Method (Schueler, 1987).

$$r = p(.05+.9I) \quad \textbf{(Equation I.4)}$$

where r = Event Rainfall Runoff (inches)

p = Event Precipitation (inches)

I = Impervious Area Fraction

- Thus, the water quality volume for the base criteria can be determined by:

$$WQ_v = (0.05+.9I)\ A/12 \quad \textbf{(Equation I.5)}$$

where WQ_v =Water Quality Volume (acre-ft)

I= Impervious Fraction

A=Area (acres)

- The Simple Method can also be used to determine the annual runoff volume. An additional factor, P_j, is added because some storms do not cause runoff. Assume $P_j = 0.9$ (Schueler, 1987). Therefore, annual runoff volume from rain can be determined by:

$$R = 0.9\ P\ (0.05+.9I) \quad \textbf{(Equation I.6)}$$

where R = Annual Runoff (inches)

P = Annual Rainfall (inches)

Section I.1.3 Calculating the Snowmelt Runoff

To complete water quality sizing, it is necessary to calculate the snowmelt runoff. Several methods are available, including complex modeling measures. For the water quality volume, however, simpler sizing methods can be used since the total water quality volume, not peak flow, is critical. One method, modified from Granger et al. (1984) is proposed here. Other methods can be used, particularly those adjusted to local conditions.

According to Granger et al. (1984) the infiltration into pervious soils is primarily based on the saturation of the soils prior to freezing. While saturated soils allow relatively little snowmelt to infiltrate, dry soils have a high capacity for infiltration. Thus, infiltration volumes vary between wet, moderate and dry soil conditions (**Figure I.2**).

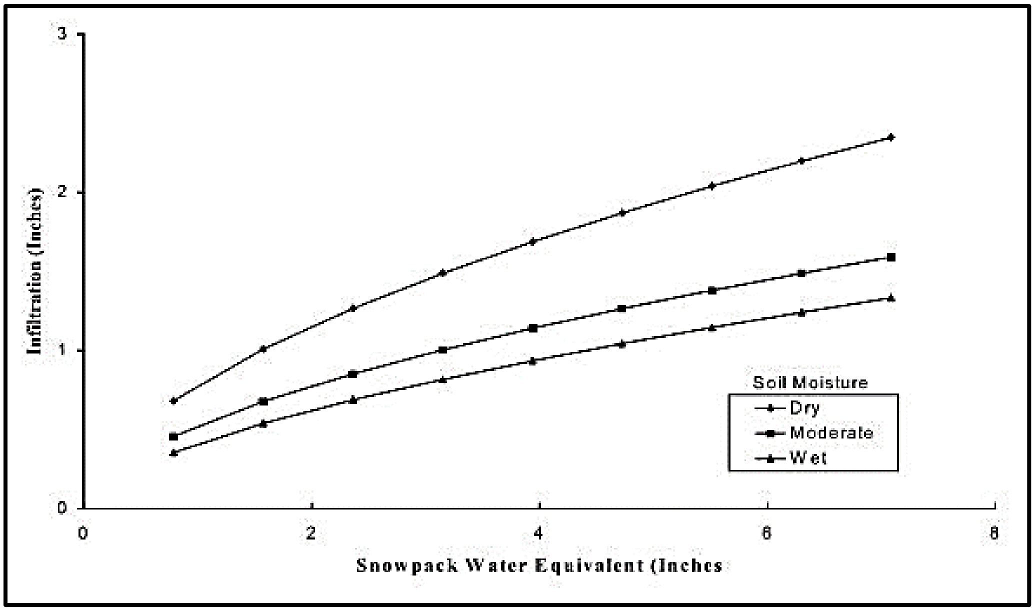

Figure I.2 Snowmelt Infiltration Based on Soil Moisture

Assume also that impervious area produces 100% runoff. The actual percent of snowmelt converted to runoff from impervious areas such as roads and sidewalks may be less than 100% due to snow removal, deposition storage and sublimation. However, stockpiled areas adjacent to paved surfaces often exhibit increased runoff rates because of the high moisture content in the stockpiled snow (Buttle and Xu, 1988). This increased contribution from pervious areas off-sets the reduced runoff rates from cleared roads and sidewalks.

- The resulting equation to calculate snowmelt runoff volume based on these assumptions is:

R_S = [runoff generated from the pervious areas] + [runoff from the impervious areas]

$$R_s = [(1 - I)(M - Inf)] + [(I)(1)(M)] \quad \textbf{(Equation I.7)}$$

where R_S = Snowmelt Runoff

I = Impervious Fraction

M = Snowmelt (inches)

Inf = Infiltration (inches)

Sizing Example 1: Snowpack Treatment

Scenario:

50 Acre Watershed

40% Impervious Area

Average Annual Snowfall= 5'=60"

Average Daily Maximum January Temperature= 20°

Average Annual Precipitation = 30"

20% of snowfall is hauled off site

Sublimation is not significant

Prewinter soil conditions: moderate moisture.

Step 1:

Determine if oversizing is necessary

Since the average annual precipitation is only ½ of average annual snowfall depth, oversizing is needed.

Step 2:

Determine the annual losses from sublimation and snow plowing.

Since snow hauled off site is about 20% of annual snowfall, the loss from snow hauling, L_1, can be estimated by:

$$L_1 = (0.2)(0.1)S_n$$

where L_1 = Water equivalent lost to hauling snow off site (inches)

S_n = Annual snowfall (inches)

0.1 = Factor to convert snowfall to water equivalent

Therefore, the loss to snow hauling is equal to:

$$L_1 = (0.2)(0.1)(60")$$

$$L_1 = 1.2"$$

Since sublimation is negligible, $L_2 = 0$

Step 3:

Determine the annual water equivalent loss from winter snowmelt events

Using the information in Step 2, the moisture equivalent in the snowpack remaining after hauling is equal to:

$$60"\cdot 0.1-1.2" = 4.8"$$

Substituting this value into **Table I.1**, and interpolating, find the volume lost to winter melt, L_3.

$$L_3 = 2.4"$$

Step 4:

Calculate the final snowpack water equivalent, M

$$M = 0.1\cdot S_n-L_1-L_2-L_3 \qquad \text{(\textbf{Equation I.1})}$$

$S_n = 60"$

$L_1 = 1.2"$

$L_1 = 0"$

$L_3 = 2.4"$

Therefore, M = 2.4"

Step 5:

Calculate the snowmelt runoff volume, R_s

$$R_s = (1-I)(M-Inf)+ I \cdot M \qquad (\textbf{Equation I.7})$$

M =2.4"

I =0.4

Inf =0.8" (From **Figure I.2**; assume average moisture)

Therefore, R_S = 1.9"

Step 6:

Determine the annual runoff volume, R

Use the Simple Method to calculate rainfall runoff:

$$R=0.9(0.05+0.9*I)P \qquad (\textbf{Equation I.6})$$

I=0.4

P=30"

Therefore, R=11"

Step 7:

Determine the runoff to be treated

Treatment, T should equal:

$$T= (R_s-0.05*R)\ A/12 \qquad (\textbf{Equation I.2})$$

R_s=1.9"

R =11"

A = 50 Acres

Therefore, T=5.6 acre-ft

Step 8:

Size the SMP

The volume treated by the base criteria would be:

$$WQ_v=(.05+.9*.4)(1'/12")(50 \text{ acres}) = 1.7 \text{ acre-ft} \qquad (\textbf{Equation I.5})$$

For cold climates:

$$WQ_v=1/2(T) = 2.8 \text{ acre-ft} \qquad (\textbf{Equation I.3})$$

The cold climate sizing criteria is larger and should be used to size the SMP.

I.1.4 Rain-on-Snow Events

For water quality volume, an analysis of rain-on-snow events is important in coastal regions. In non-coastal regions, rain-on-snow events may occur annually but are not statistically of sufficient volume to affect water quality sizing, especially after snowpack size is considered. In coastal regions, on the other hand, flooding and annual snowmelt are often driven by rain-on-snow events (Zuzel et al., 1983). Nearly 100% of the rain from rain-on-snow events and rain immediately following the spring melt is converted to runoff (Bengtsson, 1990). Although the small rainfall events typically used for SMP water quality do not produce a significant amount of snowmelt (ACOE, 1956), runoff produced by these events is high because of frozen and saturated ground under snow cover.

Many water quality volume sizing rules are based on treating a certain frequency rainfall event, such as treating the 1-year, 24- rainfall event. The rationale for treating 90% of the pollutant load (Schueler, 1992) can also be applied to rain-on-snow events, as shown in the following example.

Sizing Example 2: Rain-on-Snow

Step 1:

Develop a rain-on-snow data set.

Find all the rainfall events that occur during snowy months. Rainfall from December through April were included. Please note that precipitation data includes both rainfall and snowfall, and only data from days without snowfall should be included. Exclude non-runoff-producing events (less than 0.1"). Some of these events may not actually occur while snow is on the ground, but they represent a fairly accurate estimate of these events.

Step 2:

Calculate a runoff distribution for rain-on-snow events

Since rain-on-snow events contribute directly to runoff, the runoff distribution is the same as the precipitation distribution in **Figure I.3**.

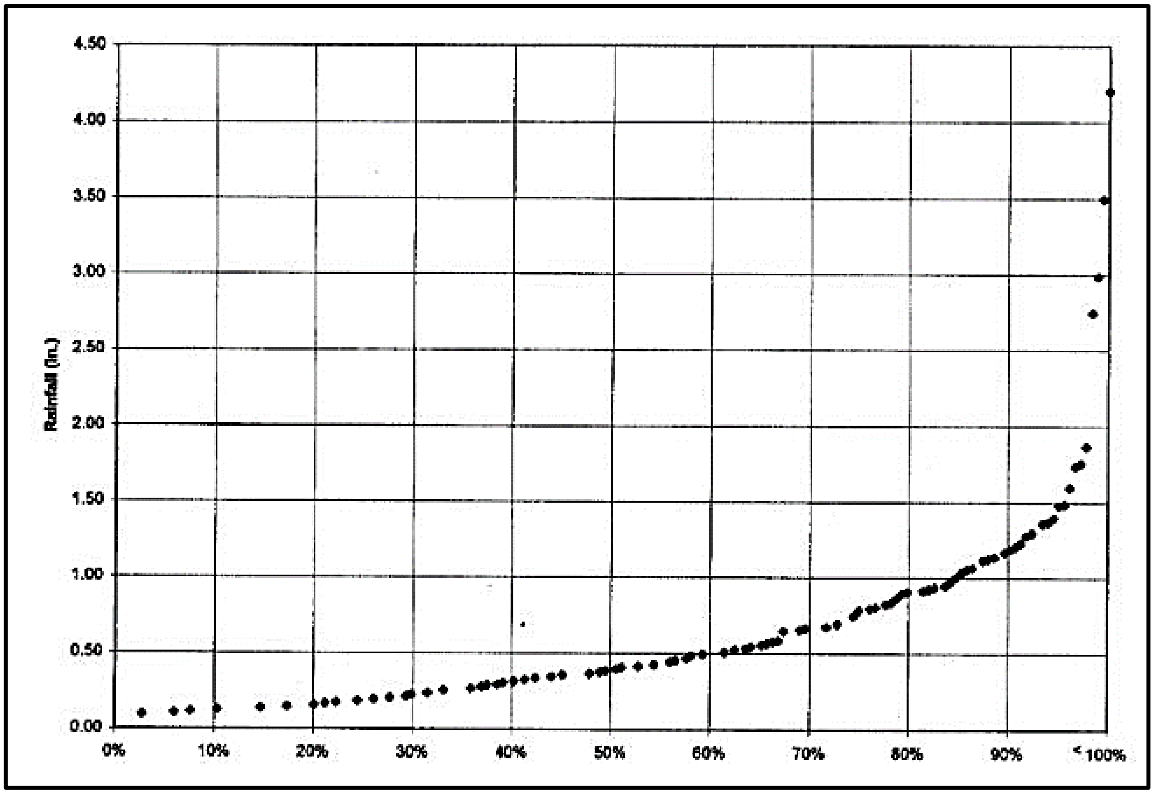

Figure I.3 Rainfall Distribution for Snowy Months

Step 3:

Calculate a rainfall distribution for non-snow months.

Develop a distribution of rainfall for months where snow is not normally on the ground. The rainfall distribution for May through November is included in **Figure I.4**.

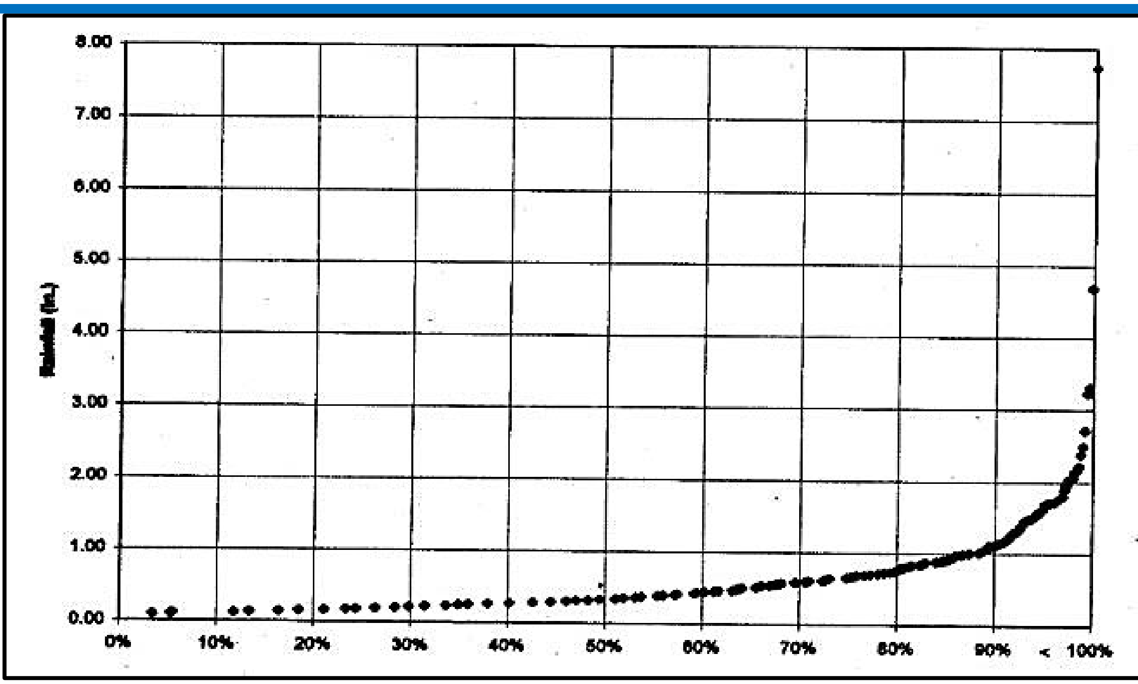

Figure I.4 Rainfall Distribution for Non-Snowy Months

Step 4:

Calculate the runoff distribution for non-snow months.

Use a standard method to convert rainfall to runoff, particularly methods that are calibrated to local conditions. For this example, use the Simple Method. Runoff is calculated as:

$$r = (0.05+0.9\ I)p \quad \textbf{(Equation I.4)}$$

For this example, I=0.3 (30% impervious area), so:

$r=0.32\ p$

The runoff distribution for non-snow months is calculated by multiplying the rainfall in **Figure I.4** by 0.32.

Step 5:

Combine the runoff distributions calculated in Steps 2 and 4 to produce an annual runoff distribution. The resulting runoff distribution (**Figure I.5**) will be used to calculate the water quality volume.

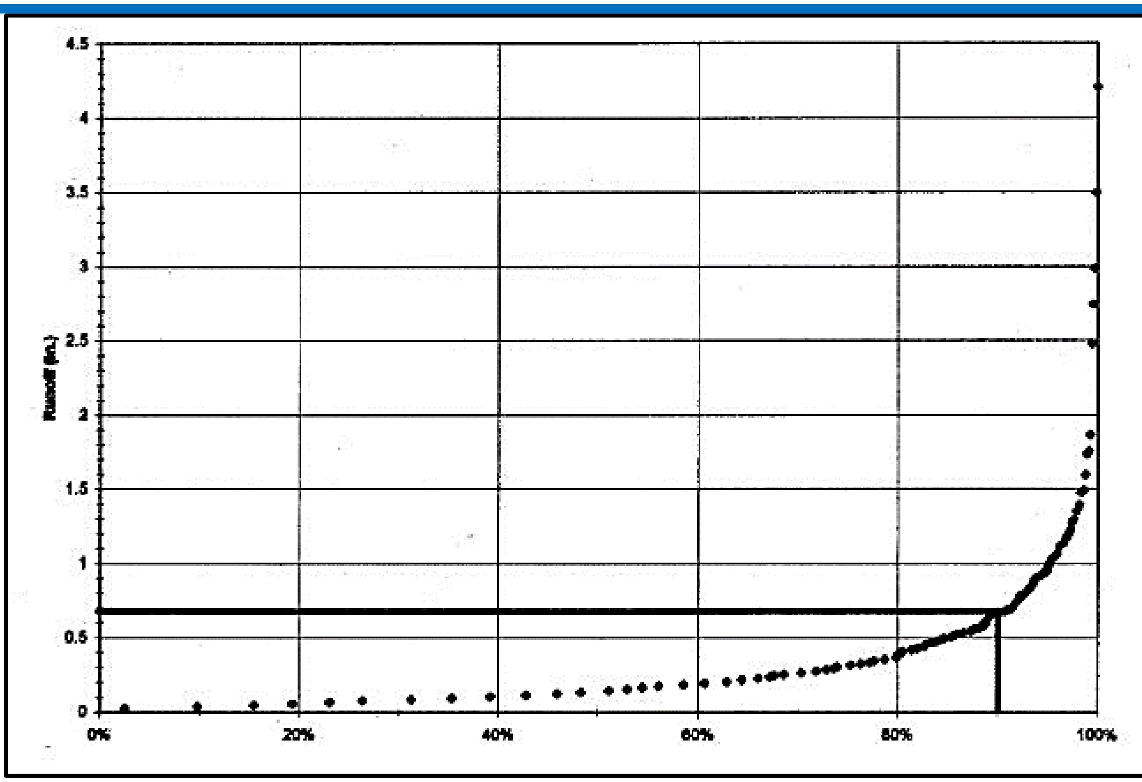

Figure I.5 Annual Runoff Distribution

Step 6:

Size the SMP.

In this case, use the 90% frequency runoff event (**Figure I.4**), or 0.65 watershed inches. This value is greater than the base criteria of 0.32 watershed inches (1" storm runoff). Therefore, the greater value is used.

WQv = (0.65”) (1 ft/12”) (50 acres) = 2.7 acre-ft

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APPENDIX I

Geomorphic Assessment

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Appendix I: Geomorphic Assessment

Distributed Runoff Control Methodology Pond Outlet Structure Design Example

The following design example illustrates a step-by-step methodology for the design of a weir for the control of instream erosion potential using a Stormwater Management (SWM) wet pond design based on the Distributed Runoff Control (DRC) approach. The DRC approach incorporates boundary material composition and its sensitivity to erosion (entrainment and transport) into the design protocol. The boundary materials are characterized at the point of maximum boundary shear stress on the bed and the point of secondary maximum boundary shear stress on the bank. By examining the channel at selected sites downstream of the SWM facility the DRC protocol provides a pseudo 3-dimensional assessment of the impact of development and the SWM facility on the receiving channel.

This design example involves 5 Steps as listed in **Table J.1**.

Table J.1 Overview of Key Steps in the DRC Design Approach
1) Determine the “stability” and “mode-of-adjustment” of the receiving channel
2) Complete a Diagnostic Geomorphic Survey of the receiving channel
3) Determine channel sensitivity to an alteration in the sediment-flow regime
4) Approximate the elevation-discharge curve for the pond.
5) Size the DRC weir

Step 1. Determine Channel “Stability” and “Mode-of-Adjustment”

Channel stability is determined using a Rapid Geomorphic Assessment (RGA) of the channel downstream of the outlet of the proposed Stormwater Management (SWM) pond. The RGA protocol involves the identification of the presence of in-stream features resulting from a variety of geomorphic processes to provide a semi-quantitative assessment of a stream's stability and mode-of-adjustment. The processes are represented by four Factors: aggradation (AF), widening (WF), downcutting (DF), and planimetric form adjustment (PF)). Each Factor is composed of 7 to 10 indices for which a “present” or “absent” response is required. The total number of “present” or “yes” responses is summed and divided by the total number of responses (both “yes” and “no”) to derive a value for each Factor. An index that is not relevant is not assigned a response. An example of an RGA Form is provided in **Table J.2**.

A Stability Index (SI) value is determined from the Factor values using the following equation:

$$SI = \frac{\{AF + DF + WF + PF\}}{m} \qquad \text{[Equation J.1]}$$

Where:

m = the number of Factors (typically 4 for alluvial streams).

Table J.2 Rapid Geomorphic Assessment Form					
FORM/ PROCESS	GEOMORPHIC INDICATOR		PRESENT		FACTOR VALUE
	No.	Description	No	Yes	
Evidence of Aggradation (AI)	1	Lobate bar	1		1/7=0.143
	2	Coarse material in riffles embedded		1	
	3	Siltation in pools	1		
	4	Medial bars	1		
	5	Accretion on point bars	1		
	6	Poor longitudinal sorting of bed materials	1		
	7	Deposition in the overbank zone	1		
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	-	-	2/6=0.333
	2	Exposed sanitary/storm sewer/pipeline/etc.	-	-	
	3	Elevated stormsewer outfall(s)	-	-	
	4	Undermined gabion baskets/concrete aprons/etc.	-	-	
	5	Scour pools d/s of culverts/stormsewer outlets	1		
	6	Cut face on bar forms	1		
	7	Head cutting due to knick point migration	1		
	8	Terrace cut through older bar material		1	
	9	Suspended armor layer visible in bank		1	
	10	Channel worn into undisturbed overburden/bedrock	1		
Evidence of Widening (WI)	1	Fallen/leaning trees/fence posts/etc.		1	3/10=0.30
	2	Occurrence of Large Organic Debris		1	
	3	Exposed tree roots		1	
	4	Basal scour on inside meander bends	1		
	5	Basal scour on both sides of channel through riffle	1		
	6	Gabion baskets/concrete walls/armor stone/etc. out flanked	1		
	7	Length of basal scour >50% through subject reach	1		
	8	Exposed length of previously buried pipe/cable/etc.	1		
	9	Fracture lines along top of bank	1		
	10	Exposed building foundation	1		
Evidence of Planimetric Form Adjustment (PI)	1	Formation of cute(s)	1		0/7=0
	2	Evolution of single thread channel to multiple channel	1		
	3	Evolution of pool-riffle form to low bed relief form	1		
	4	Cutoff channel(s)	1		
	5	Formation of island(s)	1		
	6	Thalweg alignment out of phase with meander geometry	1		
	7	Bar forms poorly formed/reworked/removed	1		
STABILITY INDEX (SI) = (AI+DI+WI+PI)/m				SI=	0.19

The Stability Index (SI) provides an indication of the stability of the creek channel at a given time based on the guidelines provided in **Table J.3**. The SI Value, however, does not differentiate between current and past disturbances.

Table J.3 Interpretation of the RGA Stability Index Value

Stability Index Value	Stability Class	Description
0.0<SI<0.25	Stable	Metrics describing channel form are within the expected range of variance (typically accepted as one standard deviation from the mean) for stable channels of similar type
0.25<SI<0.4	Transitional	Metrics are within the expected range of variance as defined above but with evidence of stress
0.4<SI<1.0	In Adjustment	Metrics are outside of the expected range of variance for channels of similar type.

The guidelines presented in **Table J.3** for the interpretation of the SI Value will vary with the field experience and the bias of the observer. The SI Values however, have been shown to be consistent between observers indicating that the protocol, once calibrated to the observer provides a reliable means of screening the channel for stability and mode-of-adjustment.

The RGA protocol is applied to channel segments of two meanders in length or the equivalent of 20 bankfull channel widths (the width of the channel at the geomorphically dominant discharge, recurrence interval of between 1 and 2 years or 1.5 years on average).

The segment chosen for application of the RGA assessment is selected to be representative of the morphology of the channel for some distance up and downstream of the surveyed segment. That is, the parameters defining channel cross-section and plan form (e.g. width, depth, meander wavelength, etc.) are within a consensual level of variance for this reach of channel. An acceptable level of variance is typically defined as within one standard deviation of the mean. These reaches are referred to as being of “like” morphology. Since the morphology of the channel will vary in the longitudinal direction with changes in flow, slope, physiography, etc., it will be necessary to re-apply the RGA protocol where the parameters characterizing the morphology of the channel have changed beyond the consensual level of variance from the previous survey reach. In this manner the channel is divided into a series of reaches of “like” morphology.

Having determined the length of the survey reach, the longitudinal profile can be plotted from topographic mapping as illustrated in **Figure J.1** (Topo). Examination of **Figure J.1** (topographic map data) suggests that the channel can be differentiated into three distinct reaches. In the first reach (length L=146 ft, the channel has an average slope of S=0.00385 ft/ft and a meander-pool-riffle morphology. In the middle reach (L≈356 ft; S≈0.0142 ft/ft) the channel has cascade morphology. The third reach (L≈258 ft; S≈0.00794 ft/ft) returns to the meander-pool-riffle form.

Land use through the study reach is homogeneous (forest) and there are no other features (e.g. bridges, dams, weirs, instream works, etc.) that would affect the hydraulic characteristics of the active channel. Consequently, a preliminary definition of “like” reaches includes the three morphologies described above.

A synoptic geomorphic survey was conducted through the subject reach with an RGA assessment completed for each of the three reaches of “like” morphology. The results of the RGA assessment for the first reach (Reach 1) are reported in **Table J.2** and **Table J.4**. Referring to **Table J.2**, the Stability Index (SI) value was found to be SI=0.19, which is less than 0.25, therefore the channel is considered to be “stable” (**Table J.3**).

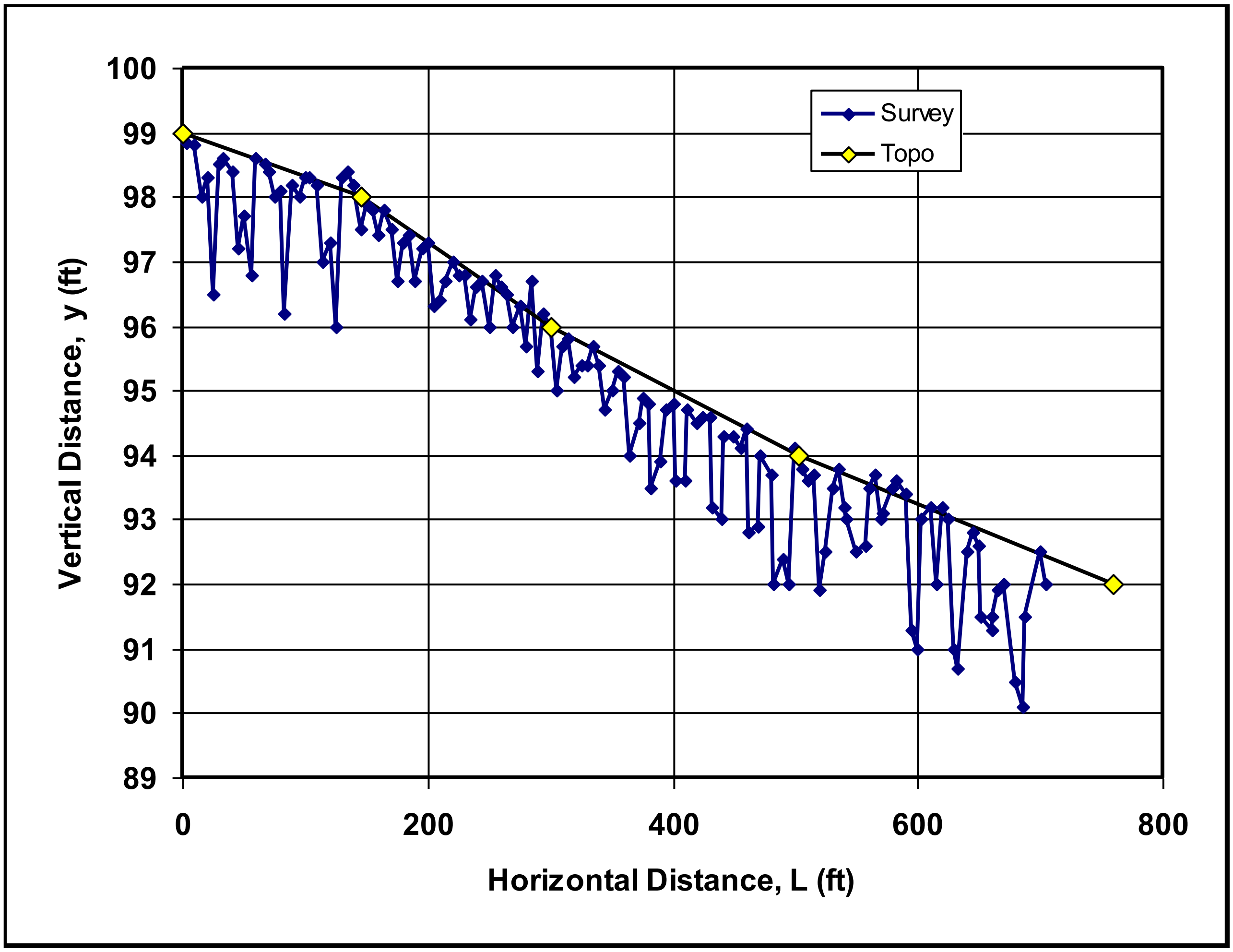

Figure J.1 Longitudinal Profile from Topographic Mapping and Field Survey of Channel Thalweg

Table J.4 Summary of Average Longitudinal Slope and Pool-Riffle Dimensions			
Parameter	**Reach 1**	**Reach 2**	**Reach 3**
Longitudinal Gradient, S_L (ft/ft)	0.00385	0.0142	0.00794
Riffle Length, LRIF (ft)	16	34	27
Pool Length, LPOL (ft)	37	10	18
Total Pool-Riffle Length, LTOT (ft)	53	44	45

Step 2. Diagnostic Geomorphic Survey

Following completion of the identification of reaches of "like" morphology and the synoptic survey to finalize the delineation of the "like" reaches, a diagnostic geomorphic survey is undertaken to characterize the morphological attributes of the channel. This information has two primary functions.

1. The optimization of the erosion control benefit of the pond; and,
2. The provision for establishing a baseline condition from which it is possible to assess the performance of the SWM measures.

A detailed diagnostic survey includes a collection of a comprehensive set of parameters to assess and evaluate stream geomorphic conditions. A complete survey is typically required when:

1. A post-construction monitoring program is mandated; and,
2. Data are required for the design and construction of instream works.

Only a partial diagnostic survey is needed where the above issues are not relevant to the project. The following lists those parameters required for the partial diagnostic survey:

1. In the absence of flow measurements, a field estimate of Manning's 'n' value is obtained for comparison with sediment computed estimates.
2. Detailed survey of the channel cross-section, including the floodplain, to determine hydraulic geometry metrics at a so called "Master cross-section" and the relative location of bank material strata.
3. The longitudinal profile of the bed along the channel thalweg and the water surface at the time of survey over a distance of one meander wavelength or 10 bankfull widths. These data are used to determine the longitudinal gradient of the channel from riffle crest to riffle crest and to determine the dimensions of the pool-riffle complex.
4. At least one estimate of bankfull depth (the depth of flow at the dominate discharge) at the Master cross-section and all ancillary cross-sections (3 alternative methods are described in this example for illustrative purposes).
5. Bed material characteristics based on pebble counts of the bed material at a riffle crossover. These data are collected to help assess roughness coefficients, bed material resistance, and provide an alternate method for the estimation of bankfull depth.
6. Soil pits in the banks to map bank stratigraphy and to determine bank material composition using soil consistency tests (stickiness, plasticity and firmness) or particle size analysis (percent silt clay) with Atterberg Limits (Plasticity Index) for each stratigraphic unit. These data are required to help assess historic degradation or aggradation patterns and determine bank material resistance.
7. Map riparian vegetation and root zone characteristics in the soil pits for assessment of the affect of root binding on bank material resistance.

The cross-section data and bank material characterization is completed at a Master cross-section within the representative segment of each "like" reach. The Master cross-section is typically located at a riffle crossover on a straight reach between meander bends. Ancillary cross-sections are located in the lower one third of the meander bends and riffle crossover points up and downstream of the Master cross-section. Data collected at the ancillary cross-sections includes a cross-section profile (typically 7 to 9 ordinates) and estimates of bankfull stage. The longitudinal profile is collected throughout the survey segment along with characterization of plan form geometry.

Design Case: Diagnostic Geomorphic Survey

The longitudinal survey of the channel along the thalweg is presented in **Figure J.1** ("Survey" data points). This profile more clearly demonstrates the differences between the three reaches as represented by slope and pool-riffle dimensions (**Table J.4**). Other parameter values derived from the geomorphic survey are summarized in **Table J.5**. These data are combined with the cross-section, soils and sediment data to generate values for key parameters as described in the following series of calculations.

The following calculations are required to determine the 3 different estimates of the dominant discharge.

Estimate of Geomorphic Referenced Dominant Discharge

1. The longitudinal data are plotted to generate estimates of the channel gradient in order of priority as follows:
   - Water surface profile based on estimates of bankfull stage from the Master and ancillary cross-sections.
   - Bed slope (riffle crest to riffle crest), and
   - Water surface profile (dry weather flow at the time of the survey).
2. The pebble count data (length, width and breadth) are transformed into an equivalent diameter and used to generate a mass curve wherein cumulative percent finer by mass is plotted as a function of particle diameter;
3. The D_{50} and D_{84} particle size values (the particle diameter below which 50 and 84% of the particles are finer by mass, respectively) are determined from the mass curve;
4. Manning's roughness coefficient is estimated at bankfull stage using:
   - Standard field guides, and
   - Empirical relations such as: the Strickler (1923) and Limerinos (1970) equations.
5. The cross-section ordinates collected at the Master cross-section are plotted to produce a cross-section profile and a stage-area curve;
6. The stage-area curve is combined with the longitudinal gradient (S) and the estimate of Manning's roughness coefficient (n) to generate the stage-discharge curve for the cross-section using Manning's equation,

$$Q = \frac{1.49}{n} A R^{\left(\frac{2}{3}\right)} S^{\frac{1}{2}}$$ [**Equation J.2**]

in which Q represents the flow rate (cfs) at depth 'y' above the thalweg, 'A' is the cross-section area of the channel at depth 'y', 'R' represents the hydraulic radius at depth 'y' and 'S' is the longitudinal gradient of the channel (ft/ft). An example of a stage-discharge curve is provided in **Figure J.2**;

Table J.5 Summary of Hydraulic and Sediment Parameters

Reach No.	Rosgen Stream Type	Parameter: 2 Year Flow Q_{2YR} (cfs)	W/d Ratio	Width W_{BFL} (ft)	Depth d_{BFL} (ft)	Flow Q_{BFL} (cfs)	Base B (ft)	Wetted Perimeter P (ft)
1	C3	8.9	3.00	3.00	1.00	4.76	2.00	4.24
2	B3	9.54	3.23	2.75	0.85	5.10	1.90	3.80
3	C3	10.1	2.87	2.83	0.99	5.40	1.85	4.06

Reach No.	Parameter: Bed Material Mean Particle Size		Area A_{BFL} (ft^2)	Hydraulic Radius R (ft)	Slope S (ft/ft)	Velocity v (fps)	Riparian Vegetation Type
	D_{50} (in)	D_{84} (in)					
1	2.8	3.3	2.50	0.590	.00385	1.90	Woody
2	5.1	7.5	1.99	0.521	.0142	2.57	Woody
3	3.7	5.2	2.32	0.570	.00794	2.35	Woody

Reach No.	Parameter: Bank Material Composition						Critical Shear Stress		Depth of Stratigraphic Unit h (ft)	Excess Boundary Shear Stress τ_{CRT} (lbs/ft^2)	
	Soil Class		Soil Consistence Test				Bank (*) τ_{CRT} (lbs/ft^2)	Bed τ_{CRT} (lbs/ft^2)			
	Class	Unit No.	X1	X2	X3	SCORE				Bank	Bed
1	SiLm	1	1	2	1	4			0.36<h≤1.00		
	SiSa	2	0	0	1	1	0.120	0.548	0.10<h≤0.36	0.057	-0.334
	CoGr	3	N/a	N/a	N/a	N/a			0.0<h≤0.10		
2	CoBo	1	N/a	N/a	N/a	N/a	0.573	1.206	0.39<h≤0.85	-0.016	-0.526
	GrCo	2	N/a	N/a	N/a	N/a			0.0<h≤0.39		
3	SiLm	1	2	1	3	6			0.32<h≤0.99		
	SiCl	2	2	2	2	6	0.329	0.878	0.12<h≤0.32	0.03	-0.446
	SiCl	3	2	3	2	7			0.0<h≤0.12		

(*) Least resistant lower bank stratigraphic unit corresponding to the zone of secondary maximum boundary shear stress.

7. The dominant discharge (Q_{GEO}) is determined from the stage-discharge curve and field estimate of bankfull stage (d_{BFL}). For Reach 1 in this example, d_{BFL}=1.0 ft, consequently Q_{GEO}=4.76 cfs (**Figure J.2**). This procedure is repeated for each cross-section within the reach and the flow rate most common to all cross-sections is adopted as the geomorphic referenced estimate of the dominant discharge. If a wide disparity exists between estimates of (Q_{GEO}) than the determination of slope, Manning's 'n' value and the geomorphic indicators of bankfull stage are revisited to determine if a miss-interpretation of the data or an error in calculations has occurred.

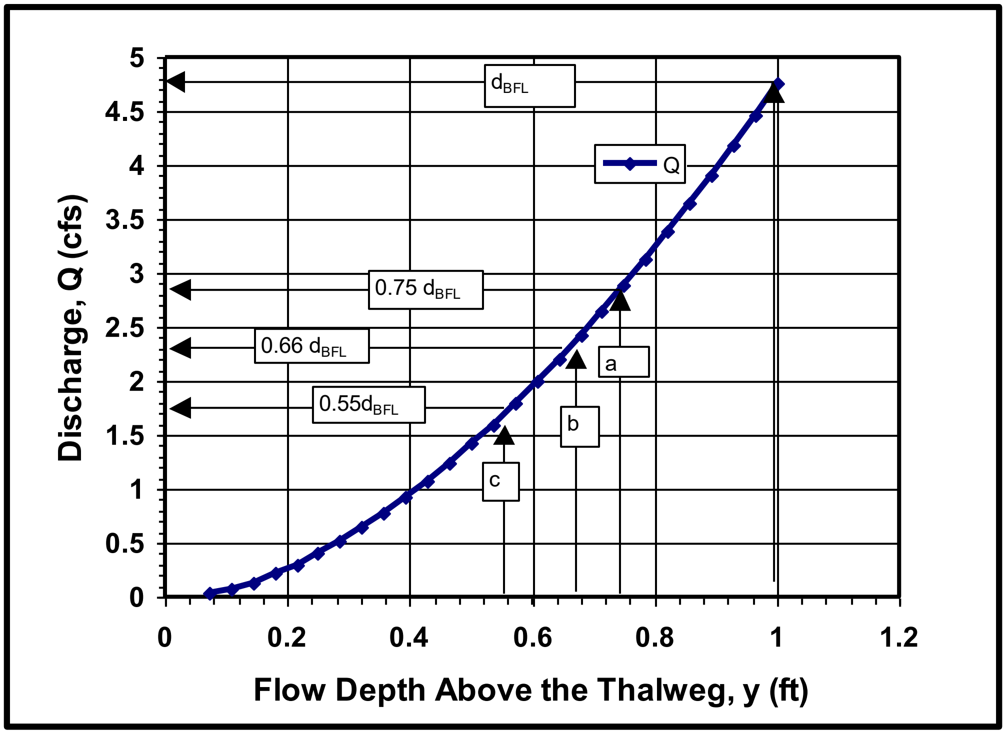

Figure J.2 Stage-Discharge Curve for Reach 1 Downstream of the Proposed Development

Estimate of Bed Material Critical Shear Stress

8. Critical shear stress is estimated for the Φ_{84} particle size value of the bed material using procedures such as:
   - The modified Shield's equation (Vanoni, 1977), or
   - Various empirical relations (from the literature) that express critical shear stress as a function of particle size, one such is **Equation J.3** proposed by Lane (1955)

$$(\tau_{CRT})_{BED} = 0.164\phi_{84} \quad \text{[Equation J.3]}$$

in which Φ_{84} is the particle size for which 84% of the materials are finer (inches) and τ_{CRT} represents the critical shear stress (lbs/ft^2). Applying, [**Equation J.3**] :

$$(\tau_{CRT})_{BED} = 0.164\Phi_{84} = 0.164\ (3.34\ \text{in}) = 0.548\ \text{lbs/ft}^2$$

at the Master cross-section (Reach 1);

Estimate of Instantaneous Bed Shear Stress

9. A stage-shear stress curve is generated for the Master cross-section using DuBoy's relation for average shear stress and a channel shape adjustment factor proposed by Lane (1955) as follows:

$$\tau_0 = k_b \rho g (d - d_P) S \quad \textbf{[Equation J.4]}$$

and,

$$k_b = 0.000547\left(\frac{B}{d}\right)^3 - 0.0121\left(\frac{B}{d}\right)^2 + 0.092\left(\frac{B}{d}\right) + 0.75 \quad \textbf{[Equation J.5]}$$

in which τ_0 represents the instantaneous boundary shear stress at point 'P' on the bed (lbs/ft s^2), k_b is a channel shape adjustment factor (dimensionless; Fig. J.3), Δ is the density of the sediment-water mixture being conveyed by the channel (62.4 lbs/ft^3), 'g' is acceleration due to gravity (32.2 ft/s^2), 'd' is the depth of the flow above the thalweg (ft), d_P is the depth of flow above the thalweg at point 'P' (ft), 'S' represents the longitudinal gradient of the flow at depth 'd' and 'B' is the bottom width of the channel (assuming a trapezoidal configuration). In this design case, a mapping of the isovels through the Master cross-section indicates that the point of maximum boundary shear stress occurs at the thalweg. Since the thalweg is the deepest part of the channel, the term d_P=0 in **Equation J.4**. A stage-shear stress curve for Reach 1 is illustrated in **Figure J.4**. Note that the units for ϑ_0 are reported in lbs/ft^2 to be consistent with the estimate of critical shear stress reported in **Task 8**. To obtain units of lbs/ft^2 remove 'g' from **Equation J.4**.

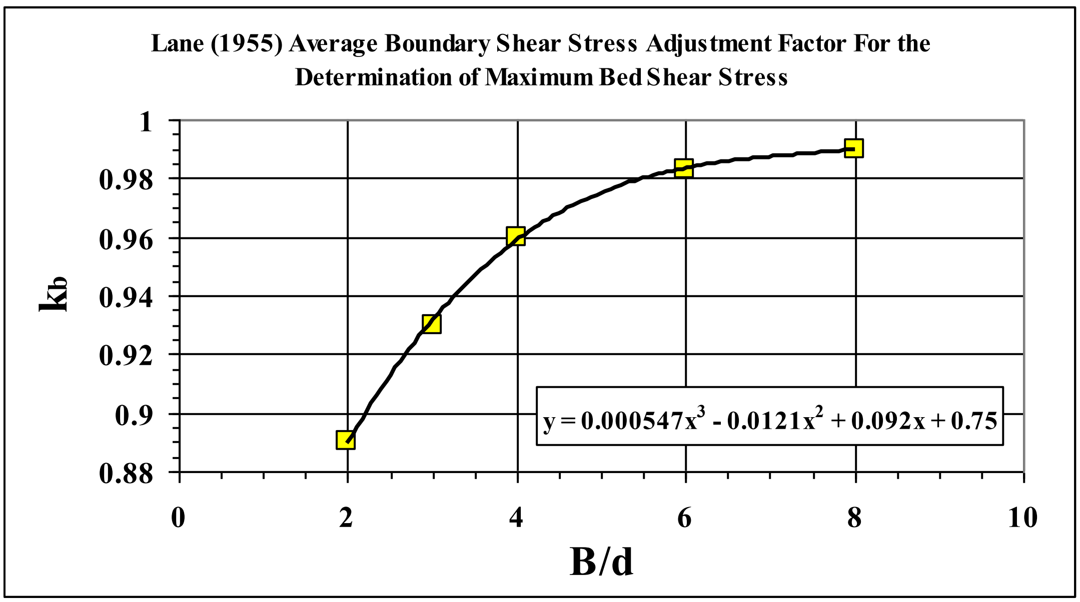

Figure J.3 Determination of kB for the Adjustment of Average Boundary Shear Stress for Variations in Channel Shape Assuming A Trapezoidal Channel Cross-Section Configuration

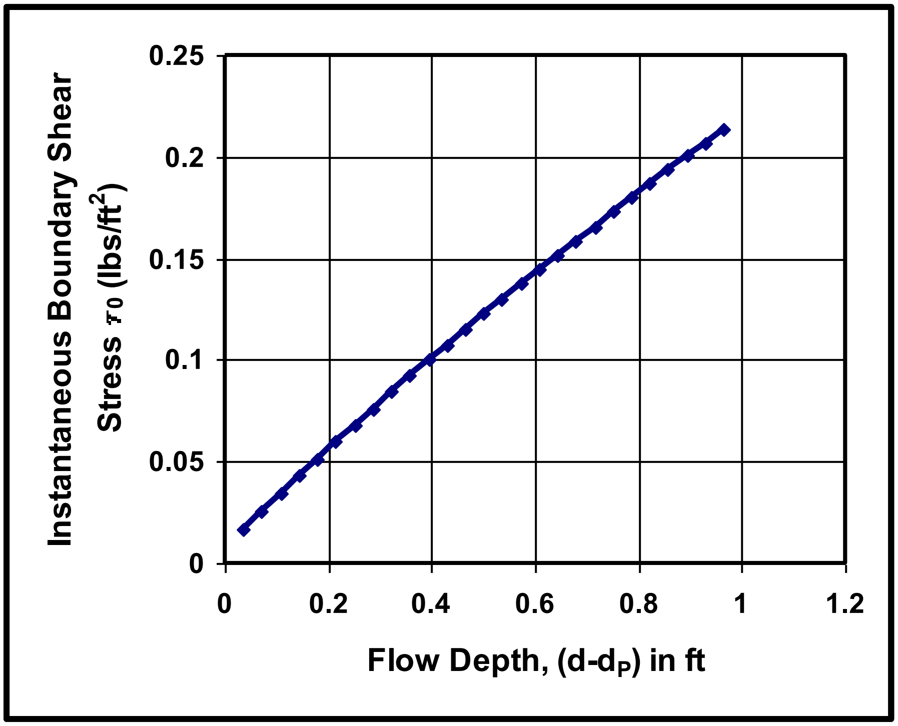

Figure J.4 Stage-Shear Stress Curve for Reach 1 (Master Cross-section): Bed Station.

Estimate the Sediment Referenced Dominant Discharge

10. The stage-shear stress curve is used to determine the depth of flow at which the boundary shear stress on the bed is equal to the critical shear stress of the N_{84} particle size fraction. This depth is transformed into an estimate of flow rate from the stage-discharge curve (**Task 5** above), providing a second, independent estimate of the dominant discharge (Q_{SED}). This calculation also provides a basis for determination of the sensitivity of the bed material to an alteration in the sediment-flow regime. This assessment is described in **Task 21** below;

Estimate the Flow Recurrence Interval of the Referenced Dominant Discharge

11. A flow time series is generated using:
    - Flow gauge data if available, or
    - A continuous hydrologic model to generate a synthetic flow time series of 6 to 13 years in length.
12. The flow time series is used to derive a flood frequency curve from which a third independent estimate of the dominant discharge (Q_{RI}) is determined as the flow having a recurrence interval between 1 and 2 years (average RI=1.5 years);

Finalize the Estimate of Dominant Discharge

13. The three estimates of dominant discharge are compared for consistency. If consistent (e.g. the range is equal to or less than 20% of the mean), then the mean value of the dominant discharge can be accepted with a higher degree of confidence

Step 3. Determine the Sensitivity of the Boundary Materials

Sensitivity of the Bed Material

14. Using the stage-shear stress relationship developed in **Task 9** and the estimate of flow depth (d_{BFL}, **Task 10**) from the dominant discharge (**Task 13**), determine the boundary shear stress $(\tau_0)_{BED}$ being applied to the bed at point 'P' at the dominant discharge. Point 'P' is located on the bed within the zone of maximum boundary shear stress. In this example the value of maximum instantaneous boundary shear stress at a depth of d_{BFL}= 1.0 ft was found to be $(\tau_0)_{BED}$ = 0.214 lbs/ft^2 at the Master cross-section in Reach 1 (**Figure J.4**). Similarly, for Reaches 2 and 3 the maximum value of instantaneous boundary shear stress was found to be $(\tau_0)_{BED}$ = 0.680 and 0.432 lbs/ft^2 respectively.

15. Compute the value of $(\tau_e)_{BED}$ for the Master cross-section knowing $(\tau_0)_{BED}$ and $(\tau_{CRT})_{BED}$ as,

$$(\tau_e)_{BED} = (\tau_0 - \tau_{CRT})_{BED} \qquad \text{[Equation J.6]}$$

in which $(\tau_e)_{BED}$ represents the effective boundary shears stress, τ_0 is the instantaneous boundary shear stress at the dominant discharge and τ_{CRT} is the critical shear stress of the bed material at point 'P'.

16. Repeat the bed shear stress analysis for all Master cross-sections in all reaches of "like" morphology.

17. Compare the value of $(\tau_e)_{BED}$ for all Master cross-sections through the study reach and select the Master cross-section for which the value of $(\tau_e)_{BED}$ is greatest. The reach represented by the Master cross-section having the highest value of $(\tau_e)_{BED}$ is referred to as the "Control Reach".

    In this example, effective boundary shear stress on the bed was found to range from between -0.526 and -0.334 (**Table J.5**). The negative values infer that the channel bed is armored and the bed material is mobile under flood flow events in excess of the dominant discharge. However, of the three Master cross-sections the value of $(\tau_e)_{BED}$ was greatest for Reach 1, consequently, Reach 1 was identified as the "Control Reach".

Sensitivity of the Bank Material

18. The bank material for the "Control Reach" is classified according to soil type for each stratigraphic unit using:
    - Soil consistency tests; or
    - Particle size analysis and Atterberg Limits.

      In this example the bank materials were mapped and differentiated into stratigraphic units as summarized for the three reaches in **Table J.5**. The soil consistency test results determined using standard soil classification guidelines (as quantified by MacRae, 1991)), are summarized below and reported in **Table J.5**.
        - Assign a value for the stickiness of the material, e.g. not sticky, (X1=0) to extremely sticky (X1=4),
        - Assign a value for the plasticity of the material, e.g. not plastic (X2=0) to extremely plastic (X2=4),
        - Assign a value for the firmness of the material, e.g. loose, no structure (X3=0) to stiff (X4=4).
    - Sum the consistency test values,

$$SCORE = \sum_{i=1}^{3} x_i \qquad \text{[Equation J.7]}$$

in which SCORE represents the sum of the values assigned for stickiness, plasticity and firmness.

19. Construct stage-shear stress curves for selected bank stations approximated by $0.25d_{BFL}$, $0.33d_{BFL}$, $0.4d_{BFL}$. More than one bank station may be required in a stratigraphic unit depending upon the thickness of the unit. The curves may be approximated as follows:

$$\tau_0 = k_S(\rho g(d - d_P)S)$$ **[Equation J.8]**

in which k_S is a correction factor for points on the channel bank determined as a function of channel shape (see **Equation J.9**, **Figure J.5**), 'd' is the depth of flow (ft), Δ is the density of water (62.4 lbs/ft^3), 'g' is acceleration due to gravity (32.2 ft/s^2) and d_P is the depth of flow at the elevation of the boundary station (ft).

$$k_S = 0.7236\left(\frac{B}{d}\right)^{0.0241}$$ **[Equation J.9]**

in which B is the channel bottom (ft) width and 'd' is the depth of flow (ft). Note, to obtain units of lbs/ft^2 remove the constant 'g' from **Equation J.8**.

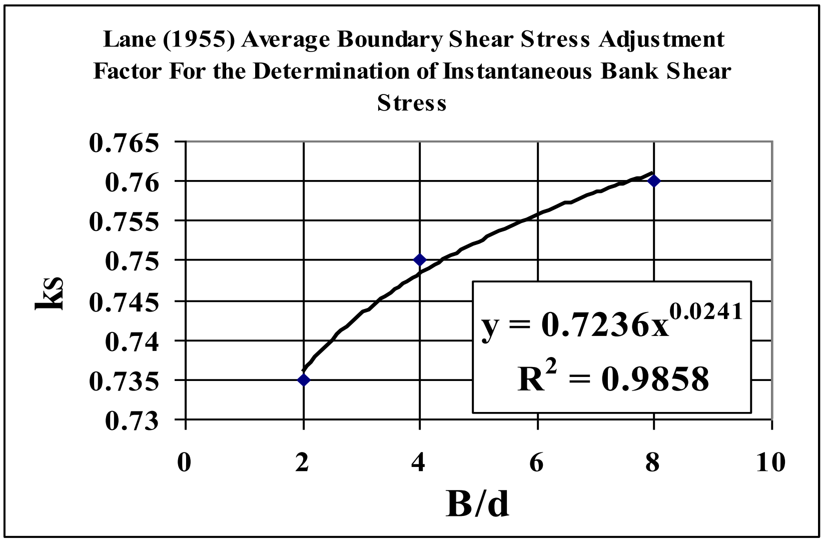

Figure J.5 Adjustment Factor kS for Bank Shear Stress for Channels Approximating a Trapezoidal Shape

20. Estimate the critical shear stress (ϑ_{CRT}) within each stratigraphic unit using available empirical relationships. These relations are typically based on percent silt and clay content, degree of compaction, particle size (Vanoni, 1977) or the SCORE value (MacRae, 1991);

21. Compute the excess boundary shear stress for each bank station at a flow depth of between 0.6 and 0.75 ft by reading the boundary shear stress off the stage-shear stress curve for each boundary station and subtracting the critical shear stress as described in DuBoy's relation,

$$(\tau_e)_{BNK} = (\tau_0 - \tau_{CRT})_{BNK}$$ **[Equation J.10]**

in which $(\tau_e)_{BNK}$ represents the excess boundary shear stress (lbs/ft^2) at the selected boundary station (P), τ_0 is the instantaneous boundary shear stress (lbs/ft^2) at any specified depth of flow at point P and τ_{CRT} represent the critical shear stress (lbs/ft^2) of the boundary material at point P.

22. Compare the estimates of excess boundary shear stress $(\tau_e)_{BNK}$ at each bank station and select that station having the highest value of $(\tau_e)_{BNK}$ as the bank station controlling bank response (controlling stratigraphic unit) to a change in the flow regime. Using the guidelines presented in **Table J.6** determine channel sensitivity to an alteration in the sediment-flow regime and the corresponding Over Control (OC) curve and Inflection Point

Table J.6 General Guidelines for the Application of the DRC Approach Based on Bank Material Sensitivity Using SCORE Values

BANK SENSITIVITY		BED SENSITIVITY				DRC PARAMETERS	
Excess Shear Stress $(\tau_e)_{BED}$	Sensitivity Class	Excess Shear Stress $(\tau_e)_{BNK}$	Bank Resistance		Sensitivity Class	Over Control Multiplier R_{OC}	Inflection Point
			Soil Class	SCORE			
<0	L	<0	Very Stiff	N/a	L	1.0 –0.9	a
		≈0	Stiff	10-12	ML	0.9 - 0.7	a
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
≈0	ML	<0	N/a			0.9 - 0.7	a
		≈0	Stiff	10-12	ML	0.9 - 0.7	a
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
	M	<0	N/a			0.7 - 0.5	b
		≈0	Stiff	N/a		0.7 - 0.5	b
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
	H	N/a				0.5 - 0.2	c
>0	H	N/a				0.5 - 0.2	c

The multiplier (R_{OC}) in **Table J.6** is used in the following manner:

- The 2 year peak flow attenuation technique is used to derive the stage-discharge curve for the erosion control component of the SWM pond.
- A multiplier of unity is equivalent to the traditional 2-year peak flow attenuation approach.
- The multiplier is used to adjust the 2-year stage-discharge curve to account for differences in the erodability of the boundary materials. The adjustment is performed by multiplying each ordinate of the stage-discharge curve by R_{OC}. For stiff materials, the multiplier approaches unity ($R_{OC} \rightarrow 1.0$). For very sensitive materials, the multiplier is between 0.2 and 0.3, which is equivalent to 80%OC to 70%OC respectively.

Bank materials may be grouped according to the SCORE value if the soil consistency tests apply (i.e. fine-grained material with few stones). For coarse-grained materials, resistance can be determined from observation of bank erosion following a high flow event. As an alternative the resistance of the coarse-grained stratigraphic unit can be inferred from bank form and shear stress distribution through comparison with adjoining strata of fine-grained material.

Finally, relations expressing critical shear stress as a function of particle size are available in the literature. Many of these relations were derived from flume experiments using disturbed material that has been re-compacted. These relations tend to underestimate the resistance of the material as it is observed in the field. Consequently, these relations should be employed with caution or corrected to account for root binding, imbrication, compaction and structurization.

Step 4. Approximate the Elevation-Discharge Curve for the DRC Pond.

The DRC outflow control structure can be constructed as set of pipes or nested weirs. This design example is for a nested, sharp crested weir.

Determine the stage-discharge curve for the flow rate having a recurrence interval of 2 years for the baseline land use condition. For this example, the baseline condition is the reforested land use scenario. The flow having a recurrence interval 2 years was determined previously as between 8.9 and 10.1 cfs for Reaches 1 through 3 respectively (**Table J.5**).

Construct the 2 year stage-discharge curve using an equation for sharp crested weirs with end contractions:

$$Q = C_e L_e h_e^{\left(\frac{3}{2}\right)} \qquad \text{[Equation J.11]}$$

in which, 'Q' represents the rate of flow (cfs), 'C_e' is the effective weir coefficient (C=3.19, Brater and King, 1982), L_e is the effective length of the weir (ft) and 'h_e' is the effective depth of flow above the weir crest (ft). Set the invert of the weir at 628.0 ft. The terms L_e, C_e and h_e are adjusted to account for losses due to end contractions (Brater and King, 1982). In this illustration it is assumed that the stage-volume curve has already been derived and that the approximate head at Q_{BFL}=8.9 cfs is h=2.25 ft.

Re-arranging **Equation J.11** and solving for 'L_e' at $Q=(Q_{2YR})_{PRE}$=8.9 cfs yields,

$$L_e = \frac{Q}{C_e h_e^{\left(\frac{3}{2}\right)}} = \frac{8.9}{3.19(2.25)^{\left(\frac{3}{2}\right)}} = 0.83\text{ft} \qquad \text{[Equation J.12]}$$

Compute the stage-discharge curve for the 2-year weir using **Equation J.11** as illustrated in **Figure J.6** (Q_{2YR}, curve AB. This stage-discharge curve represents the rating curve for the 2-year post- to pre-development peak flow attenuation approach.

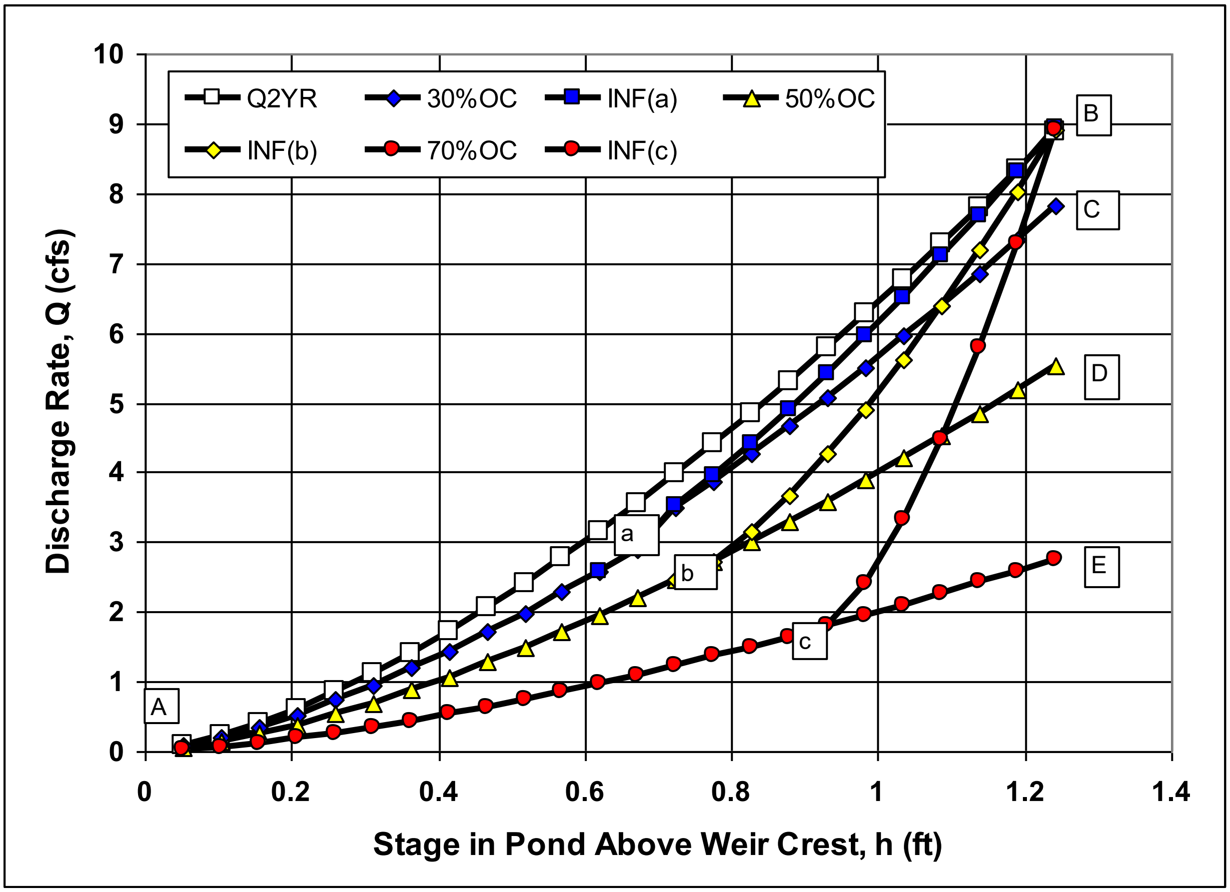

Figure J.6 The 2 Year Peak Flow Attenuation and DRC Rating Curves for 30%OC, 50%OC and 70%OC

Construct the DRC stage-discharge curve as follows:

- Determine the level of OC control and the inflection point from **Table J.6**.
  - Since $(\tau_e)_{BED}<0$ (**Table J.5**) then the bed is classified as "Low" sensitivity (shaded boxes in the first two columns of **Table J.6**);
  - The value of $(\tau_e)_{BNK}>0$ consequently, Row 3 of Column 3 (shaded box in **Table J.6**) was selected;
  - The bank material was classified as soft (SCORE=1), consequently, the 4th Row of Column 4 was chosen providing a range of R_{OC} between 0.5 and 0.2 with an inflection point at "c". In this case R_{OC}=0.3 was selected in accordance with the guidelines in **Table J.6**. Note: 70%OC means that the multiplier for the 2 year curve is R_{OC}=0.3
  - The 70%OC curve (designated as curve AE in **Figure J.6**) is created by multiplying the ordinance of the 2 year stage-discharge curve (Q_{2YR} in **Figure J.6**) by the multiplier R_{OC}=0.3.
  - The inflection point (c) is determined using the guidelines provided in **Table J.7**.

Table J.7 Guidelines For Determination of the Flow Rate for the DRC Curve Inflection Point (Reach 1)					
Inflection Point	Ratio of Inflection Point Depth to Bankfull Depth d_i/d_{BFL} (dim)	Bankfull Depth d_{BFL} (ft)	Inflection Point Depth d_i (ft)	Dominant Discharge Q_{BFL} (cfs)	Flow Rate at Inflection Point Q_i (cfs)
a	.75	1.0	.75	4.76	2.88
b	.67		.67		2.30
c	.55		.55		1.74

The point d_c=0.55 ft, d_{BFL}=1.0 ft, characterize the Control Reach, consequently the ratio,

$$\frac{d_c}{d_{BFL}} = \frac{0.55\,ft}{1.0\,ft} = 0.55$$ **[Equation J.12]**

- The flow rate at d_c/d_{BFL}=0.55 was estimated from **Figure J.6** to be Q_c=1.74 cfs.
- Point (c) can be located on curve AE at a flow corresponding to Q_c=1.74 cfs.

- The DRC stage-discharge curve follows the curve A(c)B in **Figure J.6**. For the purpose of illustration, the stage-discharge curves for 30%OC (inflection point (a)) and 50%OC (inflection point (b)) are also provided in **Figure J.6**.

Step 5. Sizing the DRC Weir

After establishing the DRC stage-discharge curve the next step is to size the DRC weir. This is done using a nested weir configuration as illustrated in **Figure J.7**. The equation for the nested weir can be approximated from **Equation J.14** for sharp crested weirs as,

$$Q = \left(C_e L_e h_e^{\left(\frac{3}{2}\right)} \right)_{INSET} + \left(C_e (L_e^* - L_e)(h_e^* - h_e)^{\left(\frac{3}{2}\right)} \right)$$ **[Equation J.14]**

in which Q represents the discharge from the nested weir, 'C_e' is a coefficient (3.19) adjusted to account for end contractions, L_e is the length of the inset weir, h_e represents the height of the inset weir where $0 \le h_e \le h_2$ (h_2 represents the total height of the nested weir) and h_e^* is the depth of flow through the nested weir above the inset weir ($h_e \le h_e^* \le h_2$).

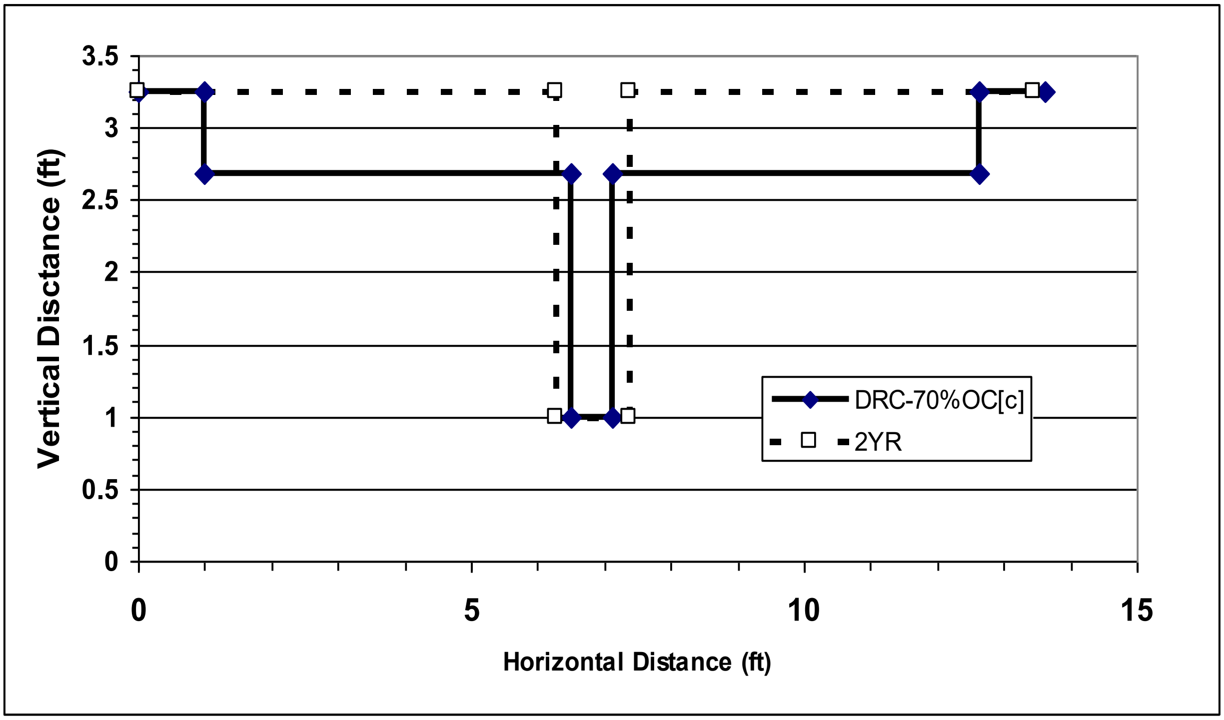

Figure J.7 Comparison of the 70% OC DRC Weir with Inflection Point at [c] and the Traditional 2-year Peak Flow Attenuation Weir

Solving **Equation J.14** for results in the dimensions and flow values reported in **Table J.8**.

Table J.8 Summary of Dimensions and Flow Characteristics for a Nested DRC Weir: Reach 1

Parameter	DRC Weir			2 Year Weir
	Inflection Point (a)	Inflection Point (b)	Inflection Point (c)	
L_e (ft)	1.77	1.00	0.62	N/A
h_e (ft)	0.67	0.78	0.93	
Q_i at h_e (cfs)	2.89	2.21	1.74	
L_e^* (ft)	0.80	4.32	11.0	0.83
h_2 (ft)	2.25			
Q at h_2 (cfs)	8.94			

Parameters in **Table J.8** are defined in the preceding text.

Note: the weir dimensions for DRC stage discharge curves 30%OC (inflection point 'a') and 50%OC (inflection point 'b') are provided for comparison with the selected option (inflection point 'c').