Minnesota Urban Small Sites BMP Manual

Stormwater Best Management Practices for Cold Climates

Prepared for the Metropolitan Council by Barr Engineering Company

With guidance and support from:

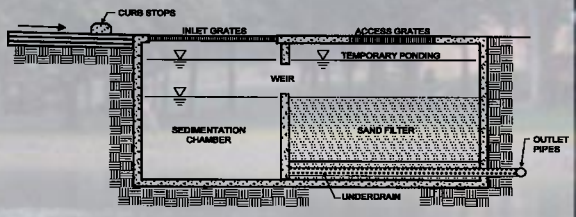
City of Minneapolis

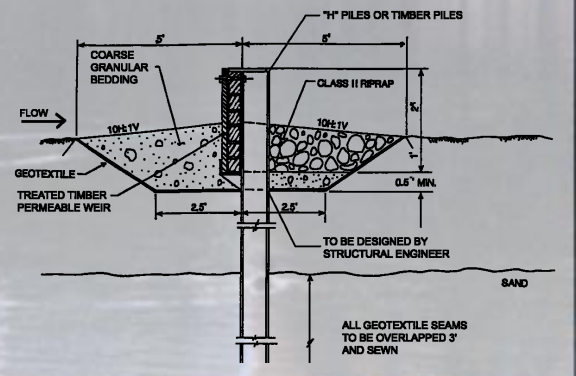
City of St. Paul

Minnehaha Creek Watershed District

Rice Creek Watershed District

Six Cities Watershed Management Organization





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Minnehaha Creek Watershed District, Excelsior

Rice Creek Watershed District, Arden Hills

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Tools for Design

The Metropolitan Council's Smart Growth initiative is expected to result in more concentrated, more compact development within the Twin Cities metropolitan area. The Council is eager to see that small-site urban development and redevelopment help continue the improvements in lake and river quality that have occurred over the past few decades.

These water quality improvements can be sustained only if site developers and regulators have the tools to design and implement stormwater management methods that are both effective and site-appropriate. Although the Metropolitan Council is charged with protecting and improving regional water quality, it will be the metropolitan cities and watershed management organizations (WMOs) that will be directly responsible for promoting methods to achieve water quality.

This *Urban Small Sites BMP Manual* provides tools to assist Twin Cities municipalities and WMOs in guiding site development and redevelopment. The manual focuses on runoff management for small (less than five-acre) sites, and takes into account the peculiarities of stormwater management in Minnesota's climate.

First, to help explain the importance of proper stormwater management, explanatory sections focus on stormwater hydrology, pollutants and cold climate concerns. Included in Chapter 2 are guides to help developers and regulators choose the best management practices (BMPs) that will be most appropriate for the specific needs of the site.

The centerpiece of the manual, Chapter 3, is a set of 40 concise and practical stand-alone BMP sections, each illustrating a technique that makes sense in an urban small-site, cold-climate setting. Each of the BMP sections provides:

- Definition and description of the BMP
- Discussion of the BMP's means of operation
- Diagrams and information to guide design and installation
- Listing of inspection and maintenance considerations
- References for more detailed information

The final chapter of the manual gives a description of the federal, state and local regulatory considerations that urban small site designers and developers should understand.

The final chapter of the manual describes the federal, state and local regulatory considerations that urban small site designers and developers should be aware of.

Additional information is provided in the manual's appendices, which include: regulatory information for the sponsoring agencies; local BMP installation examples and contacts; sources for model stormwater ordinances; and a source list of BMP manuals and other references.

Please note that design details and recommendations given in this manual are provided only for explanation and illustration of key concepts. Not all design details are shown, and site-specific professional judgement is always required. In addition, some of the BMPs included involve efforts that may by law require permits or design by a registered design professional. No implementation of the practices in this manual should be allowed without an appropriate and demonstrated level of professional competence.

Chapter 1
Factors in BMP Selection

Selection of appropriate methods for control of stormwater runoff requires an understanding of how rainfall, land management and pollutants on the ground interrelate. This chapter offers background information on hydrology (what happens to rainwater after it falls) and information on the most common surface water pollutants and their relationship to stormwater runoff. Cold-climate considerations for watershed management and the relationship between hydrology and watershed management are also discussed. Chapter 2 provides step-by-step guidance on selecting the best BMPs for a particular site.

Hydrology

Hydrology pertains to the movement of water. In the hydrologic cycle, rain or snow from clouds falls to the ground, and as water or snow melt: infiltrates or seeps into the ground, a process called percolation; is taken up by the trees and vegetation and is returned to the atmosphere through transpiration, or evaporation of water from all surfaces; or runs over the ground surface. Water that seeps into the ground travels underground until eventually reaching the groundwater table and possibly surface waters such as a lake, stream, or the ocean. This process, called groundwater recharge, helps maintain water flow in streams and wetlands and preserves water table levels that support drinking water supplies. The amount of recharge that occurs on a site is based on slope, soil type, vegetation and other cover, as well as precipitation and evapotranspiration rates. Sites with natural ground cover, such as forest, meadow, or shrubs, typically have greater recharge rates, less runoff, and higher transpiration than sites with pavement and buildings. The water that runs off the ground surface as overland flow is runoff. Through evaporation from surface waters, water is returned to the atmosphere, new clouds are formed, and the hydrologic cycle begins again (Fig. 1.1).

Introduction to Hydrologic Concepts

Stormwater runoff is a natural part of the hydrologic cycle. The volume and speed of runoff depends on the size of the storm (how much water falls in what amount of time) and the land features at the site. The size of the contributing drainage area, the slope of the land, the types of soils, and the surface conditions (such as woods or pavement) affect water movement. The contributing drainage area establishes the boundary limits for the movement of runoff - from the highest elevations to the lowest point. A watershed is a region that consists of one or more contributing drainage areas to a body of water.

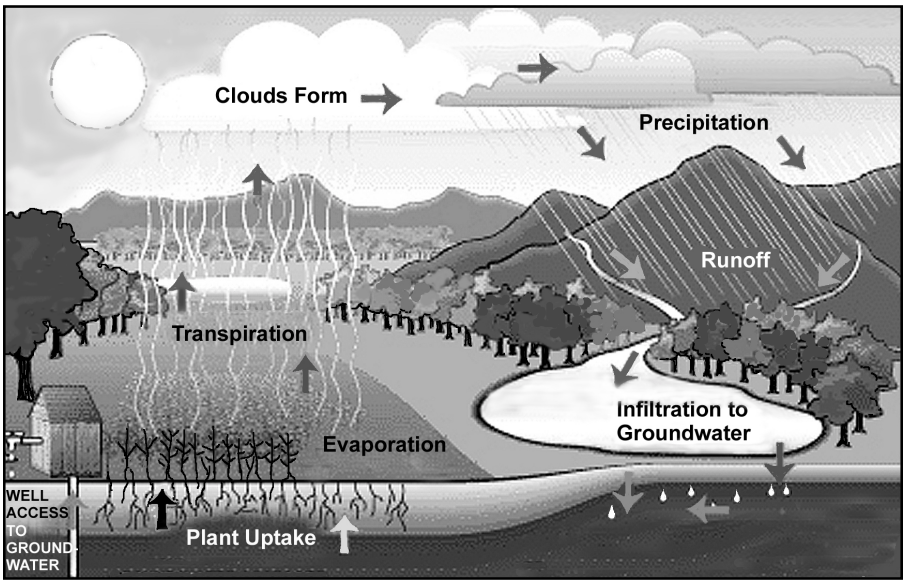


Figure 1.1: The Hydrologic Cycle
Adapted from US EPA, 2000

In a natural, undeveloped setting, the ground's surface often is pervious, meaning water can percolate down into the soil. In developed areas,

ground surfaces are often asphalt, concrete, and other materials that are impervious and prevent water from infiltrating into the soil. Water that cannot be absorbed into the ground becomes runoff. Water that falls during and immediately after a storm and flows over impervious surfaces or otherwise cannot be absorbed into the ground is called stormwater runoff.

Development - the construction of homes and other buildings, streets, parking lots, road gutters, storm sewers, paved channels and other man-made features - can alter the hydrology of the landscape and adversely affect water quality. Development changes land use and generally increases the amount of stormwater runoff from a site. Stormwater runoff can cause erosion and flooding. Development can change water flow and the percolation of water into the soil, which affects how much water can infiltrate into the ground to maintain water levels in streams, wetlands, and groundwater aquifers. Stormwater runoff also affects water quality, which can have adverse impacts on aquatic plants and animals. During development, vegetated and forested land with pervious surfaces are replaced by land uses with impervious surfaces. Impervious surfaces transform hydrology and impact aquatic habitats by changing the rate and volume of runoff and altering natural drainage features, including groundwater levels. Changes in water quantity begin with the initial site clearing and grading. Vegetation that intercepted rainfall and reduced runoff is removed. Natural depressions that provided temporary storage of rainfall are filled and graded. Soils are exposed and compacted resulting in

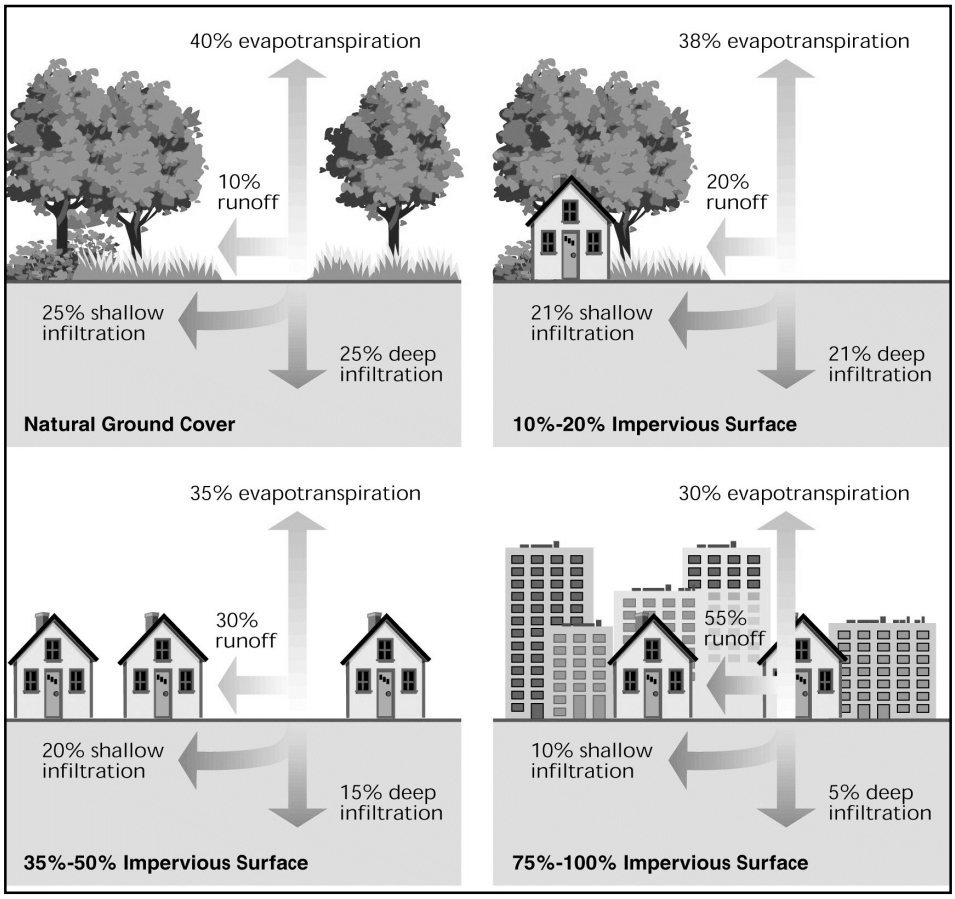
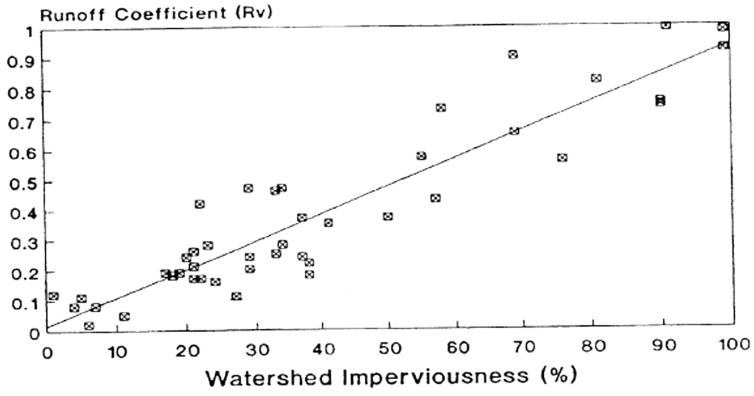


Figure 1.2: Relationship Between Impervious Cover and Surface Runoff

Source: Federal Interagency SRWG, 2000



The runoff coefficient (R_v) expresses the fraction of rainfall that is converted into runoff. The data points reflect over 35 monitoring stations in the U.S.

Figure 1.3: Relationship Between Impervious Cover and the Volumetric Runoff Coefficient

Source: Schueler, 1987 in Maryland, 1998

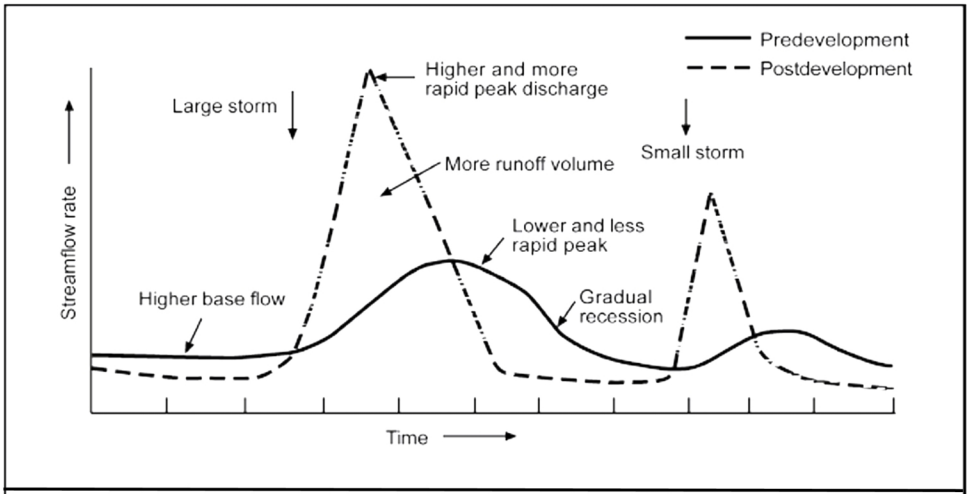


Figure 1.4: Changes in Stream Hydrology as a Result of Urbanization

Source: Schueler, 1992, in MPCA, 2000

increased sedimentation and decreased infiltration. Having lost much of its natural storage capacity, the cleared, graded site allows rainfall to rapidly become runoff. Once the development has been completed, the increase in impervious area (rooftops, roads, driveways, and parking lots) reduces the amount of rainfall that can be infiltrated, which increases the volume of runoff. Figure 1.2 shows the relationship of runoff, infiltration, and evaporation with varying degrees of impervious cover.

Figure 1.3 shows the increase in the volumetric runoff coefficient (Rv), which expresses the fraction of rainfall

volume that is converted into stormwater runoff, as a function of site imperviousness. 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 (Maryland, 1998, Schueler, 1994). The percentage of imperviousness in a watershed is a useful measure of land development impacts on streams and aquatic systems. Studies show that hydraulic and biological changes to streams occur when 10 to 20 percent of a watershed has impervious surfaces. Moreover, efforts to restore stream flow and water quality to pre-development conditions appear to be less successful when levels of impervious cover exceed 30 percent. (Massachusetts, 1997)

Drainage modifications also increase the velocity of runoff, which decreases the time required to convey it to the outlet of the watershed. Increased volume and increased velocity of runoff results in higher peak discharges and shorter times to reach peak discharge. This causes higher flows, flooding, erosion and adverse effects on habitat in natural streams. Figure 1.4 shows typical pre-development and post-development hydrographs for a watershed that is being developed for urban land uses. The areas below the hydrographs represent the volume of runoff. The increased volume of runoff after development is important because of the increased pollutant loading it can deliver as well as potential flooding and channel-erosion problems. Existing stream characteristics are a reflection of past conditions in the watershed. Under natural conditions and at bank-full capacity, studies have shown that streams can handle a flow approximately equal to the one-and-one-half- to two-year frequency peak discharge within their banks (Rosgen, 1994; Leopold et al., 1964). The frequency of bank-full events increases with urbanization, and might be expected to occur 2 to 8 times per year compared to less than once per year under natural conditions, causing the stream to enlarge its channel to reach a new equilibrium with the increased flows. In addition to regular flood damage, this condition causes previously stable channels to erode and widen. Much of the eroded material becomes bed load and can smother bottom-dwelling organisms. Sediment from streambank erosion eventually settles in streams, rivers and lakes, reducing their capacity and water quality. Base flow in streams is also affected by changes in hydrology from urbanization because a large part of base flow comes from shallow infiltration. Impervious cover reduces base flow, reducing the volume of water available for base flow in streams (MPCA, 2000). The problem may be further compounded by the installation of shallow ground water drainage systems to accommodate road or building construction. Lower recharge rates for groundwater in a watershed are generally reflected in lower stream base flows. Low rates of recharge also extend low flow durations; particularly during prolonged droughts. Typical alterations to the hydrologic regime as a result of development include, but are not limited to, increased runoff volume, imperviousness, flow frequency, duration, and peak runoff rate, reduced infiltration (groundwater recharge), modification of the flow pattern, faster time to peak (due to shorter time of concentration through storm drain systems), and loss of storage.

General Discussion of Design Hydrologic Events

Data for precipitation, including both snow and rain, are used in site planning and stormwater design. Precipitation occurs as a series of events characterized by different rainfall amount, intensity, and duration.

Frequency

Although precipitation events occur randomly, analysis of their distribution over a long period of time indicates that the frequency of occurrence of a given storm event follows a statistical pattern. This statistical analysis allows engineers and urban planners to further characterize storm events based on their frequency of occurrence or return period.

Storm events of specific sizes can be identified to support evaluation of designs. Storms with 2- and 10-year return periods are commonly used for subdivision, industrial, and commercial development design. The 1- and 2-year storm events are usually selected to protect receiving channels from sedimentation and erosion. The 5-

Table 1.1: Hydrologic Design Data

Metropolitan Area Precipitation Frequency Analysis: Comparison of TP40, Huff & Angel, Metropolitan Council and Skaggs-Low Estimate

	Return Period						
Event Duration	**1 Year**	**2 Years**	**5 Years**	**10 Years**	**25 Years**	**50 Years**	**100 Years**
30 Minutes							
TP40	0.70	1.10	1.45	1.65	1.90	2.10	2.40
Huff & Angel	0.82	0.98	1.20	1.37	1.61	1.81	2.02
Skaggs-Low Estimate		0.99	1.37	1.66	2.07	2.40	2.76
1 Hour							
TP40	1.15	1.40	1.80	2.10	2.40	2.70	3.00
Huff & Angel	1.04	1.25	1.52	1.73	2.04	2.29	2.57
Skaggs-Low Estimate		1.26	1.63	2.11	2.62	3.05	3.51
2 Hours							
TP40	1.40	1.65	2.20	2.50	2.75	3.20	3.50
Huff & Angel	1.29	1.54	1.87	2.14	2.52	2.83	3.17
Metropolitan Council						2.7	2.9
Skaggs-Low Estimate		1.55	2.01	2.60	3.24	3.76	4.33
3 Hours							
TP40	1.50	1.75	2.25	2.65	3.00	3.40	3.70
Huff & Angel	1.42	1.70	2.07	2.36	2.78	3.12	3.49
Skaggs-Low Estimate		1.71	2.22	2.87	3.57	4.15	4.78
6 Hours							
TP40	1.75	2.20	2.60	3.20	3.50	4.00	4.50
Huff & Angel	1.66	1.99	2.42	2.77	3.26	3.66	4.10
Metropolitan Council						3.8	4.1
Skaggs-Low Estimate		2.01	2.78	3.37	4.19	4.87	5.60
12 Hours							
TP40	2.00	2.50	3.20	3.60	4.25	4.60	5.25
Huff & Angel	1.93	2.31	2.81	3.21	3.78	4.25	4.75
Skaggs-Low Estimate		2.33	3.23	3.90	4.86	5.64	6.50
18 Hours							
TP40							
Huff & Angel	2.09	2.49	3.04	3.47	4.09	4.59	5.13
Skaggs-Low Estimate		2.51	3.49	4.22	5.25	6.10	7.02
24 Hours							
TP40	2.35	2.75	3.55	4.20	4.70	5.40	6.10
Huff & Angel	2.22	2.65	3.23	3.69	4.35	4.88	5.46
Metropolitan Council						4.5	4.9
Skaggs-Low Estimate		2.67	3.71	4.49	5.58	6.49	7.47

Sources: Hershfield (1961), Huff & Angel (1992), Vinha et al. (1995) and Skaggs (1998)

and 10-year storm events are selected for adequate flow conveyance design and minor flooding considerations. The 100-year event is used to define the limits of floodplains and for consideration of the impacts of major floods (Prince George's County, 1999).

One of the more confusing phrases used in meteorology and hydrology is "the 100-year storm." The phrase implies that an intense rainstorm dubbed as a 100-year event brings rainfall totals heretofore unseen for 100 years, and not to be experienced again for another century. This is a logical, but incorrect conclusion to draw from the phrase. A 100-year storm drops rainfall totals that had a one percent probability of occurring at that location that year. Encountering a 100-year storm on one day does not change the chances of observing the same amount of precipitation the very next day (Minnesota Climatology Working Group). Similarly, a "50-year-storm" has a two percent (1/50) chance of occuring in a given year, a "25-year storm" has a four percent (1/25) chance of occurring and a "ten-year storm," a ten percent (1/10) chance

Duration

The storm duration that is critical for a watershed depends on the watershed size, shape, and slope; the volume of storage available in the system; and the outlet capacity. The critical duration is determined by routing several different duration storms of a given frequency through the stormwater system and determining which duration event produces the greatest peak discharge and/or flood elevation. A small watershed with little available storage will have a critical storm of shorter duration than a large watershed with abundant storage. (Barr, 1991)

Hydrologic Events: Rainfall vs. Snowmelt

In many moderate climates, most of the runoff on an annual basis is generated by rainfall events that are distributed relatively evenly throughout the year. During rainfall events runoff occurs immediately, mostly from impervious surfaces. For snowfall, on the other hand, precipitation is stored during the year in the snowpack, and then released during snowmelt events, usually during the spring. The runoff from snowmelt is often increased because of saturated or frozen soils present during the spring melt, and nearly the entire watershed can contribute to runoff. This shift in the hydrologic cycle is important for BMP design because the critical runoff event may be this snowmelt event rather than the storm events typically used in sizing BMPs both for flooding and water quality.

Flows caused by rain-on-snow events can create significant flooding. These rain events fall on relatively impervious soils because of frozen conditions, and warm rains can cause rapid melting of the snowpack. (Center for Watershed Protection, 1997)

Table of Hydrologic Design Data

Several published studies have analyzed precipitation frequency distributions for various storm durations in the Twin Cities metropolitan area (Hershfield, 1961; Huff and Angel, 1992; Vinha et al., 1995; Skaggs, 1998). Precipitation frequency distribution information provides the basis for design of nearly all water drainage and storage projects throughout Minnesota.

Table 1.1 compares the Twin Cites metropolitan area precipitation estimates for various frequencies and storm durations, based on the latest editions of four published studies. Technical Publication No. 40 (TP40) utilized older hourly precipitation data from National Weather Service stations, which include approximately 20 stations in the Twin City metropolitan area, to develop frequency distributions (Hershfield, 1961). The Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992) utilized a longer period of record of precipitation data, which included just one National Weather Service station (the Minneapolis-St. Paul airport) in the Twin City

metropolitan area, to develop frequency distributions for nine regions in Minnesota (Section 6 data is shown in Table 1.1). The Metropolitan Council (Vinha et al., 1995) assembled rainfall frequency data from 23 National Weather Service stations in the vicinity of the Twin City metropolitan area. Six of these stations collected hourly precipitation data, while the rest collected data on a daily basis. Skaggs (1998) utilized data from the Minnesota high density precipitation network between 1958 and 1997 to develop low and high frequency distribution estimates for the Twin City metropolitan area.

The low estimates were intended to pertain to a 20 km by 20 km area while the high estimates were expected to occur *at some point* in the Twin Cities area. Table 1.1 only contains the low estimates from Skaggs (1998), as the high estimates are generally twice as high as the values shown for the other three studies. Hershfield (1961), Huff and Angel (1992), and Skaggs (1998) used standard inflation and deflation factors to transform daily precipitation values for maximum 24 hour and shorter durations, respectively. Skaggs (1998) utilized extreme value statistical distributions while the other three authors used graphical or empirical curve-fitting techniques to complete the rainfall frequency analyses. Table 1.1 shows that the low estimates from Skaggs (1998) are larger than estimates from the other three studies, with the differences increasing with increasing return period. Generally, the Metropolitan Council estimates (Vinha et al., 1995) are slightly lower than estimates from the other three studies.

Variability in Prescribed Hydrologic Design Events

Urbanization will increase the runoff volume from each storm event, thereby increasing the erosive force of the flows in the channel and can significantly upset the sediment load equilibrium that was established over many years. While the significance of large flood events should not be underestimated, the smaller flows with an approximately nine-month to two-year return period frequency can be very erosive. Often, these smaller flows have not been given sufficient consideration. Several states have developed policies regarding volume controls (Maryland, 1998) and erosive flow controls (Washington State Department of Ecology, 1992). Hydrologic studies need to look at flood, peak flow and total flow conditions, while keeping in mind that small-storm hydrology is a critical component for protection of property, water quality and habitat.

Rationale for Variability

Traditionally, the response of watersheds to urban development has been measured in terms of changes in the flow regime, with management efforts focused on the prevention of property damage from flooding as previously described. Stormwater management efforts historically followed the design storm concept described earlier and focused almost exclusively on runoff collection systems such as curbs and gutters, and pipe conveyance systems which discharged directly to receiving water bodies. Stormwater quantity (peak discharge rate) management was incorporated as BMPs to address concerns about downstream flooding and stream bank erosion. Typically these BMPs, usually ponds or detention basins were located at the lowest point of the site and at the end of the network of inlets and pipes.

Stormwater quantity controls have been set by states or local government agencies to prevent site and downstream flooding and erosion. A typical design criteria requires that "the post development peak discharge for a 2- and 10- year frequency storm event be maintained at a level equal to or less than the respective 2- and 10-year pre-development peak discharge rates, through the use of stormwater management structures that control the timing and rate of runoff." This requirement is based on the design storm concept described earlier under in this section. The selection of the 2-year return frequency storm is based on a belief that the 1.5- to 2-year storm dictates the shape and form of natural channels (Leopold, 1964; Leopold et al. 1968). The selection of the 10-year storm is based on consideration of possible property damage due to local flooding and stream bank erosion.

More recently, stormwater management efforts have recognized that runoff from urban areas was more polluted than runoff from undeveloped areas and was degrading the water quality of the receiving streams and other water bodies. Designers and modelers discovered that the design storm approach used for peak discharge control was not appropriate for water quality control issues, since water quality issues were related to the annual volume of runoff which consists of many small storms. For the most part this problem was addressed by modifying and improving traditional BMPs with extended detention, forebays, wetlands, permanent pools and numerous other design improvements to improve the pollutant removal effectiveness. Also the concept of controlling the "first flush" was introduced. A "first flush" event is defined as the first half inch of runoff from an impervious surface, and is expected to carry with it most of the pollutant load associated with stormwater. In terms of a typical storm hydrograph, the "first flush" represents a small portion of a storm's total discharge, but a larger percentage of the total loading for a particular contaminant.

Examples

Recognizing the need for BMP design that will protect and improve the integrity of unique water resources across Minnesota, watershed management organizations have developed different variations of design criteria with respect to hydrologic events. Some examples of the variability in hydrologic design requirements for these BMPs follow.

Design criteria from "Protecting Water Quality in Urban Areas" (MPCA, 2000), provides detailed recommendations for wet detention storage. Some of the key recommendations include the following:

- Outflow discharge should be no larger than 5.66 cfs per acre of basin area for the 1.25-inch event.
- Maximum treatment area velocity criteria for 2.4-, 2.8-, 4.0-, and 6.0-inch events.
- Discharges to erodible channels or streams should be limited to one-half the 2-year and the same as the 10-year and 100-year pre-urban rates.

The Minnehaha Creek Watershed District rules require water quality treatment and rate control for most development, and volume control for landlocked areas. For rate control, the rules specify that the rate of stormwater runoff must be restricted to the rate that existed before the development for runoff-producing events of critical duration with return frequencies of 1, 10, and 100 years in the subwatershed in which the site is located. Volume control is required when the receiving area of runoff is landlocked and not capable of handling the increased volume of runoff, in which case back-to-back 100-year runoff events will be used to analyze holding capacity and freeboard for the receiving area.

Check with the municipality or WMO in your project area for criteria.

Relationship of Hydrology and Watershed Management

Duration and Frequency Effects on the Runoff Hydrograph

A runoff hydrograph is a continuous plot of instantaneous discharge versus time. It results from a combination of physiographic and climatic conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, interflow, and ground water flow (Bedient and Huber, 1988). Important physiographic factors include size and shape of the drainage area, nature of the stream network, slope of the land and the main channel, storage detention in the watershed (Sherman, 1932), imperviousness, and soil types. Climatic factors that influence the hydrograph shape and volume of runoff include rainfall intensity and pattern,

areal distribution of rainfall over the basin, duration of the storm event (Bedient and Huber, 1988) and antecedent conditions.

Design Hydrograph and BMP Selection

Flow-Related Issues

Maintaining the preexisting hydrologic conditions is recommended in all cases, but especially for water bodies that are highly or moderately susceptible to stormwater impacts. The relationship between any storm event, no matter how small or how large, and runoff volumes must be thoroughly understood. Best management practices (BMPs) that address the full range of hydrologic conditions should be employed to minimize impacts.

Snow melt runoff events pose a problem in that a large volume of water occurs at the end of the winter when many impediments, such as frozen ground for infiltration basins or frozen permanent pools and clogged outlets for pond systems, may be at their worst. Thus, the effectiveness of these BMPs is often compromised during this critical runoff event. (CWP, 1997)

Pollutants of Concern

Stormwater runoff carries a variety of contaminants that affect water quality. These contaminants come from different residential, commercial, and industrial land uses within a watershed. People's daily activities leave pollutants, such as pesticides, fertilizers, animal wastes, sediments, nutrients and heavy metals, on the surface of the ground. Stormwater runoff carries the pollutants on the ground into nearby water bodies and waterways. As development increases and activities change and intensify, the concentrations and types of contaminants also increase. Although all land uses can affect water quality, in undeveloped areas natural processes can lessen the impacts of contaminants or even remove contaminants from runoff through infiltration and evaporation. Impervious areas reduce the opportunity for natural processes to treat stormwater. Therefore, stormwater runoff must be adequately controlled and treated to reduce pollutants before it is discharged to surface water, groundwater, or wetlands. A summary of the principal pollutants found in runoff, their sources, and related impacts is provided in Table 1.2.

Several mechanisms constitute the genesis of stormwater quality in urban areas, most notably buildup/washoff, erosion of solids and atmospheric deposition. In an impervious urban area, it is usually assumed that a supply of constituents is built up on the land surface during dry weather preceding a storm. Such a buildup may or may not be a function of time and factors such as traffic flow, dry fallout and street sweeping. With the storm the material is then washed off into the drainage system. The physics of the washoff may involve rainfall energy, as in some erosion calculations, or may be a function of bottom shear stress in the flow as in sediment transport theory. Most often, however, the magnitude of pollutant washoff or erosion is proportional to flow raised to some power. Therefore, longer antecedent dry periods, high rainfall intensity and runoff volumes result in higher pollutant loadings. A final source of pollutants is in the precipitation itself. Precipitation can contain surprisingly high concentrations of many constituents (Huber, 1981).

An evaluation of rainfall and pollutant runoff distributions for Milwaukee and Minneapolis-St. Paul show three distinct rainfall categories (Pitt, 1998):

- Common rains less than approximately 0.5 inch have relatively low pollutant discharges (less than 25 percent of the annual pollutant mass discharges from residential areas), but occur very often (on about 95 days a year in Minneapolis-St. Paul). These are key rains when evaluating runoff-associated water-quality violations, especially for bacteria and heavy metals. These pollutants in the storm water exceed water-quality standards for almost all rains.

AVAILABILITY OF POTENTIAL POLLUTANTS ON THE LAND SURFACE

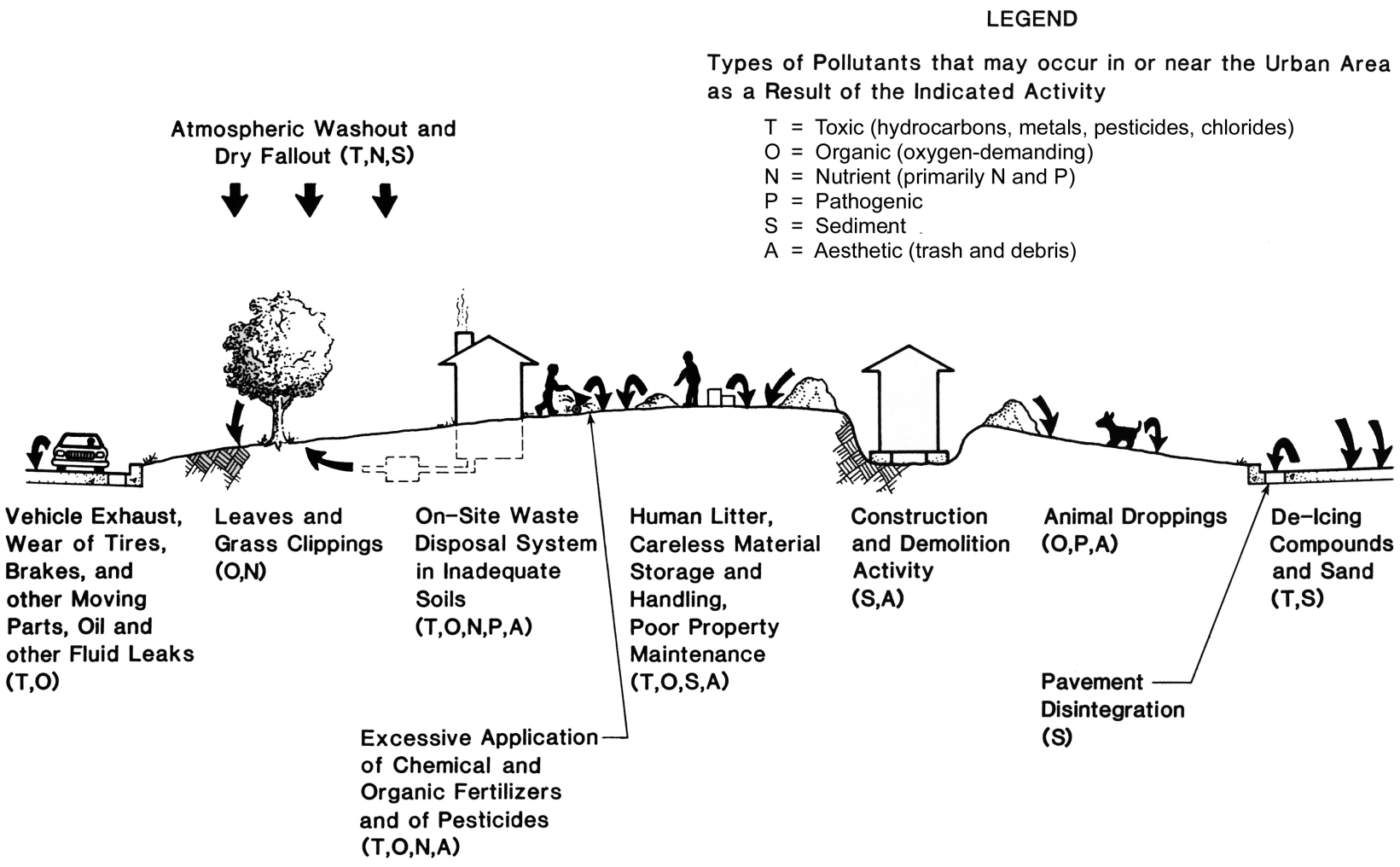


Figure 1-5
Source: Walesh, 1989

- Rains between 0.5 and 1.5 inches are responsible for about 75 percent of the annual runoff-pollutant mass discharges from residential areas, and are the key rains that need to be addressed when concerned with mass discharges of pollutants.
- Rains greater than 1.5 inches occur rarely (on only about two days a year in Minneapolis-St. Paul) and are needed for designing and evaluating storm drainage systems. However, these rains are only responsible for relatively small portions of the annual pollutant mass discharges. In Minnesota, more than 90% of the precipitation events are less than 1.0 inch. These rainfall events also account for the majority (about 65%) of the cumulative runoff quantity and proportionately large amounts of the pollutant loading associated with these rainfall events. The pollutant loading is more closely associated with total runoff volume than with peak runoff rates.

The spring melt event is important in terms of pollutant loading as well as hydrology. The snowpack has high pollutant concentrations because it represents the buildup of pollutants over an entire season. According to Oberts (1982) about 65% of sediment, organic, nutrient and lead loads can be attributed to the spring melt event. In addition, cyanide concentrations are high in snowmelt runoff because of cyanide added to salt to prevent clumping.

The rate of accumulation for polycyclic aromatic hydrocarbons (PAHs) is slightly elevated during the winter because of home heating, such as fireplaces, and the inefficiency of automobiles in cold weather. Chloride loadings are the highest in snowmelt events because of the use of sodium chloride and magnesium chloride as deicers. Much of the chloride melt occurs during the quick melting of snow on pavement throughout the winter season. Chlorides are also in plowed snow piles, and can be significant during the spring melt event (CWP, 1997).

Stormwater Pollutants

Urban stormwater runoff carries a variety of pollutants that affect water quality. These contaminants are generated through the activities in different residential, commercial, and industrial land developments within a watershed. During storm or snowmelt events, these pollutants quickly wash off and are carried to downstream waters. As development increases and activities change and intensify, the concentrations and types of contaminants increase accordingly.

The principal pollutants found in urban runoff are:

Nutrients

Urban runoff has elevated concentrations of both phosphorus and nitrogen, which can promote nuisance algal blooms in streams, rivers and lakes (known as eutrophication). In particular, excess phosphorus is known as a major factor in the decline of many of Minnesota's water bodies.

Sediments

Sources of sediment include particles washed off of impervious surfaces and the eroded from streambanks and construction sites. Both suspended and deposited sediments can have adverse effects on the aquatic life in streams, rivers and lakes. Sediments can also transport other, attached pollutants.

Organic Materials

Organic matter, such as grass clippings, leaves and seeds, carried with runoff during storm events, can cause an oxygen deficit in downstream waters. As organic matter decomposes, it consumes oxygen. Low levels of oxygen in water bodies can have an adverse effect on aquatic life.

Table 1-2

Stormwater Pollutant	Examples of Sources	Related Impacts
Nutrients: Nitrogen, Phosphorus	Animal waste, fertilizers, failing septic systems	Algal growth, reduced clarity, other problems associated with eutrophication (oxygen deficit, release of nutrients and metals from sediments)
Sediments: Suspended and Deposited	Construction sites, other disturbed and/or non-vegetated lands, eroding banks, road sanding	Increased turbidity, reduced clarity, lower dissolved oxygen, deposition of sediments, smothering of aquatic habitat including spawning sites, sediment and benthic toxicity
Organic Materials	Leaves, grass clippings	Oxygen deficit in receiving water body, fish kill.
Pathogens: Bacteria, Viruses	Animal waste, failing septic systems	Human health risks via drinking water supplies, contaminated swimming beaches
Hydrocarbons: Oil and Grease, PAHs (Napthalenes, Pyrenes)	Industrial processes; automobile wear, emissions & fluid leaks; waste oil.	Toxicity of water column and sediment, bioaccumulation in aquatic species and through food chain
Metals: Lead, Copper, Cadmium, Zinc, Mercury, Chromium, Aluminum, others	Industrial processes, normal wear of auto brake linings and tires, automobile emissions & fluid leaks, metal roofs	Toxicity of water column and sediment, bioaccumulation in aquatic species and through the food chain, fish kill
Pesticides: PCBs, Synthetic Chemicals	Pesticides (herbicides, insecticides, fungicides, rodenticides, etc.), industrial processes	Toxicity of water column and sediment, bioaccumulation in aquatic species and through the food chain, fish kill
Chlorides	Road salting and uncovered salt storage	Toxicity of water column and sediment
Trash and Debris	Litter washed through storm drain networks	Degradation of the beauty of surface waters, threat to wildlife

Pathogens
Pathogen concentrations in urban runoff (commonly quantified in terms of fecal coliform) frequently exceed public health standards for water contact recreation in urban areas. Pathogens in runoff can also lead to increased health risks in drinking water.

Hydrocarbons
Vehicles leak substances, including gasoline, oil and lubricants, that contain a wide variety of hydrocarbon compounds, some of which are toxic at low concentrations to aquatic organisms.

Metals
Metals are routinely found in stormwater runoff, and can be toxic to aquatic organisms. Metals can also accumulate sediments of streams, rivers and lakes and up the food chain of organisms.

Pesticides
Both currently used and recently banned insecticides and herbicides are sometimes detected in urban streams at levels that approach or exceed toxicity thresholds for aquatic organisms.

Chlorides
Salts that are applied to roads and parking lots during winter months accumulate in meltwater and are delivered to downstream water bodies at concentrations that many freshwater organisms cannot tolerate.

Trash and Debris
Considerable quantities of trash and debris are washed through storm drain networks, accumulating in downstream water bodies and diminishing their natural beauty.

These pollutants, their sources, and related impacts are summarized in Table 1-2 and Figure 1-5.

Cold Climate Considerations
Winter hydrologic conditions—ice, snow and snowmelt—present special considerations for runoff management. An extensive review of BMP selection and design in cold climates was performed by the Center for Watershed Protection (Stormwater BMP Design Supplement for Cold Climates, 1997). In this review, the major considerations for cold-climate snowmelt and stormwater management were identified as:

- Pipe Freezing
- Ice Formation on the Permanent Pool
- Reduced Biological Activity
- Reduced Oxygen Levels During Ice Cover
- Reduced Settling Velocities
- Frost Heave
- Reduced Infiltration
- Short Growing Season
- High Runoff Volumes During Spring Snowmelt
- High Pollutant Loading During Spring Snowmelt

- Snow Management
- Special Maintenance

Pipe Freezing

Most BMPs rely on some piping system at the inlet and outlet, Frozen pipes can crack due to ice expansion, creating a maintenance or replacement burden. In addition, frozen pipes reduce the treatment capability of BMPs (by restricting or completely blocking the inflow or outflow to the BMP) and can increase the potential for flooding.

Many authorities have recommendations for the sizing and location of inlets and outlets to avoid ice clogging and freezing (CWP, 1997).

Ice Formation on the Permanent Pool

In BMPs that have a permanent pool of water, ice formation causes two problems. First, the permanent pool's volume is reduced. Ice can take up as much as three feet of permanent pool space, often about half the depth and volume. Second, the intended movement of runoff through the pond is compromised. Specifically, runoff entering an ice-covered pond has two options, neither of which provides sufficient pollutant removal (Oberts, 1994). In one case, runoff is forced under the ice, causing scouring of bottom sediments. In the other case, runoff flows over the top of the ice, receiving very little treatment at all. The sediment that does settle on the top can easily be resuspended by subsequent runoff events.

Some authorities recommend that the permanent pool volume be increased by an amount equal to the expected volume of the ice cover (Ontario Ministry of the Environment, 1999) or that extended storage be incorporated into the pond's design. Another option is to increase the depth of the pond at the inlet and outlet, creating more room for ice to collapse. These features will usually result in designs that are robust enough to handle winter and spring runoff conditions.

Pond structures should be carefully selection to withstand ice conditions: Once ice begins to melt and break apart, ice movement can cause damage to structures in the pond. For example, standpipe outlets are particularly susceptible to ice damage.

Reduced Biological Activity

Many BMPs rely on biological mechanisms to help reduce pollutants, especially nutrients and organic matter. For example, wetland systems rely on plant uptake of nutrients and the activity of microbes at the soil/root zone interface to break down pollutants. In cold temperatures, microbial activity is sharply reduced when plants are dormant during longer winters, limiting these pollutant removal pathways.

Reduced Oxygen Levels in During Ice Cover

In cold regions, oxygen exchange between the air-water interface in ponds and lakes can be restricted by ice cover. In addition, warmer water sinks to the bottom during ice-cover because it is denser than the cool water near the surface. Thus, although biological activity is limited in cooler temperatures, most decomposition takes place at the bottom, sharply reducing oxygen concentrations in bottom sediments. In these anoxic conditions, nutrients and metals retained in the sediments can be released, reducing the BMP's treatment efficiency.

Reduced Settling Velocities

Settling is the most important removal mechanism in many BMPs. As water becomes cooler, its viscosity increases, reducing particle velocity. In fact, particle settling velocity is about 50% faster with water tempera-

tures at 68 degrees F than at 40 degrees F. This reduced settling velocity influences pollutant removal in any BMP that relies on settling.

Frost Heave

Frost heaving is a rising of the soil surface during cold periods. One of the sources of frost heaving is the expansion of pore water as it freezes under the ground's surface. An additional, and perhaps more important source is the formation of ice lenses, or layers of ice, below the soil surface. The primary risk associated with frost heave is the damage of structures such as pipes or concrete materials used to construct BMPs.

The CWPs Stormwater BMP Design Supplement for Cold Climates (CWP, 1997) addresses minimum depth of cover and backfilling practices to reduce the potential for pipe freezing and frost heave.

Reduced Infiltration

The rate of infiltration in frozen soils can be limited, especially when ice lenses form. As a result, BMPs that rely on infiltration to function may be ineffective when soil is frozen, which in cold climates can be a significant portion of the year. It is important to note, however, that some frozen soils can continue to infiltrate water year-round, depending on soil porosity and water content.

Short Growing Season

Vegetation is central to the proper functioning of some BMPs (wetlands and grass filter strips, for example). When the growing season is shortened, establishing and maintaining this vegetation is more difficult. During construction of a BMP system, the "envelope" for planting grass, wetland vegetation or other plant material is reduced. Also, the range of usable plants is more limited in cold climates than in more moderate climates. Finally, many plants are dormant during the winter months. This results in decreased efficiency for BMPs in which plants are used to help attenuate or filter runoff.

High Runoff Volumes During Spring Snowmelt

Ground freezing throughout the tributary watershed effectively increases the watershed's imperviousness which, in turn, increases the runoff volume that reaches BMPs. Runoff volume from spring snowmelt events can be very large, often the largest-volume event of the year. Another compounding problem is that this large volume of water occurs at the end of the winter when many impoundments may be at their worst, such as frozen ground for infiltration basins or frozen permanent pools and clogged outlets for pond systems. Thus the effectiveness of these BMPs is often compromised during this critical runoff event.

Designers may wish to increase the capacity of BMPs to account for the unique conditions in colder climates, particularly when the volume of 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.

Many regions have a goal to treat 90% of the annual runoff volume. Therefore, if snowfall represents more than 10% of the total precipitation in these regions, at least some portion of the spring snowmelt needs to be treated in order to meet the treatment goal. 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.

High Pollutant Loading During Spring Snowmelt

Snowmelt runoff events in cold climates may convey high concentrations of urban runoff pollutants to stormwater ponds and other receiving waters. Winter maintenance operations involve snow plowing, sanding,

and salting of roadways, parking lots, sidewalks and other impervious areas. Snow piles can build up over the winter months, generating concentrated releases of pollutants during spring snow melt conditions. Therefore, five months of winter pollutant accumulation may be available for rapid release in the spring. Typical pollutants found in snowmelt are:

- Sand (sediments)
- Salt (chlorides)
- PAHs
- Cyanide
- Trash and Debris

Sand

Large quantities of sand are applied to roadways during the winter months. By the end of winter, sand has accumulated onto streets and snow piles and will be carried with snowmelt to receiving water bodies if proper maintenance activities are not employed. Sediments (including sand) represent the largest volume of pollutants impacting receiving water bodies. The effect of sediments are discussed in the previous section of this report.

Salt (Chlorides)

Chloride loadings are the highest in snowmelt events because of the use of sodium chloride and magnesium chloride as deicers. In general, confirmed water quality impacts of chlorides are minimal; however, there is some current discussion on whether there should be more concern and research about the impact of chlorides transported into surface and ground waters.

It is estimated that most of the transport of deicing chemicals is caused by the concentrated runoff that can be created by inadequate storage facilities (MPCA, 2000). Also, because of the current concern over the movement of chlorides into the environment, any reduction in chloride runoff that can be achieved through the proper storage or reduced application rate is recommended.

The MPCA recommends the following practices when storing or using deicing chemicals (MPCA, 2000):

- Store compounds on sheltered (protected from precipitation and wind), impervious pads
- Watch the weather in anticipation of snow storm events, to estimate storm durations, temperatures, and conditions to better plan the amount of deicing chemical that will be needed
- Properly calibrate equipment so that the planned application is delivered
- Limit salt application on low-traffic areas and straight, level areas. Critical areas, such as intersections, hills or major roads, will need higher levels of service.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) in runoff from the snowpack can exceed drinking water standards. The rate of accumulation is slightly elevated during the winter because of home heating, such as fireplaces, and the inefficiency of automobiles in cold weather. In addition, these hydrophobic materials remain in the snowpack until the end of snowmelt, resulting in “shock” loadings.

Cyanide

Cyanide concentrations can be high in snowmelt runoff because of cyanide added to salt to prevent clumping.

Trash and Debris

Trash and debris usually accumulate in snow piles during snow plowing operations. During the winter, these materials can be blown off of snow piles. During snowmelt, they can be carried into receiving waters.

Snow Management

Proper management of snow, in terms of snow removal and storage, can prevent or minimize the major runoff and pollutant loading impacts. The following list outlines some recommendations for snow storage (MPCA, 2000):

- Plowed snow should not be directly discharged to lakes, streams or wetlands.
- Storage locations should be outside of direct drainage into surface waters.
- Plowed snow should be placed in pervious areas where it can slowly infiltrate.
- Snow should not be piled in wooded areas, around trees, or in vegetated buffer zones due to concerns about sediment and/or salt damage to vegetation.
- Snow piles should be monitored for debris that could be windblown.
- Sediments should be contained as snow melts, and removed from the snow storage areas every spring.

Special Maintenance

BMPs designed to function effectively in summer are often disrupted by winter and spring events. Inspection and maintenance during spring runoff should be a consistent feature of stormwater treatment systems in cold climates. In terms of the tributary watershed, intensive street and catch basin cleaning in early spring in anticipation of spring snowmelt events.

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Chapter 2 Selecting BMPs

Pollution Prevention BMPs

Design Phase

Replacing natural cover and soils with impervious surface leads to increased runoff, which adversely affects natural systems through flooding, channel erosion and increased pollutant loads. Research demonstrates a marked drop in fish, amphibian and insect species when the percentage of imperviousness in a watershed exceeds 10 to 15 percent. (Schueler, 1994.)

With careful site planning, developers and municipalities can reduce the amount of impervious area created by pavement and roofs and thus reduce the volume of runoff and associated pollutants requiring control. The Impervious Surface Reduction section of Chapter 3 of this manual includes details in these six areas:

- Cul-de-Sac Design
- Driveway Design
- Parking Lot Design
- Street Design
- Turf Pavers
- Green Rooftops

Construction Phase

Erosion and sediment control are critical to every construction project. Methods to prevent the export of sediments should be planned during the site design process. The most effective practices are presented in Chapter 3 under the following headings:

Construction Practices

- Vehicle Tracking Pads
- Grading
- Sequencing

Sediment Control

- Silt Fences
- Inlet Protection
- Temporary Sedimentation Basins/Traps
- Check Dams

Soil Erosion Control

- Mulch, Blankets and Mats
- Structural Methods
- Vegetative Methods

Questions to Ask Before Construction

- ***Will vehicles be entering and exiting the construction site with soil-laden tires?***

  If yes, implement Vehicle Tracking Pads.

- ***Will grading occur on site?***

  If so, try to minimize its extent – see the Grading BMP section. In addition, refer to the Sequencing and Silt Fence BMPs for other ways to erosion potential. When grading is complete, disturbed soil should be covered as soon as possible; see the Fabrics and Mulch, Blankets and Mats and Vegetative Methods sections.

- ***Will there be long slopes of disturbed soil?***

  If so, refer to the Structural Methods BMP section.

- ***Will a stormwater inlet be constructed on site?***

  If so Inlet Protection must be constructed.

- ***Will sediment loads be too large to be captured in a silt fence or is there a sensitive water body downstream?***

  If this is the case, employ Temporary Sedimentation Basins or Traps for extra protection.

- ***Will you be designing a swale or water diversion resulting in channelized or concentrated flow over disturbed soil?***

  To prevent excessive sediment transport, Check Dams could be constructed within the swale to capture the sediment. At minimum, erosion control blankets and/or mats will be necessary (Mulch, Blankets and Mats).

Post-Construction

After a project is built, cleanup practices and appropriate ongoing management are necessary to prevent contaminants from washing off the land and pavement and into water bodies. The Housekeeping portion of this manual describes these four basic areas of concern:

- Pavement Management
- Animal Management
- BMP Maintenance
- Landscape Design and Maintenance

See these sections in Chapter 3 for in-depth information on a variety of practices.

Source

1. Schueler, Thomas R. 1994. “The Importance of Imperviousness” in *Watershed Protection Techniques*. 1(3):100-111. Center for Watershed Protection, Ellicott City, MD.

Stormwater Treatment BMP Selection Matrix[1]

This section outlines a process for selecting the best stormwater treatment BMP or group of BMPs for a small site and provides factors to consider for their placement. The three-step process described below should be used to select which BMPs can best meet predetermined pollutant removal targets. This process guides the designer through three steps that progressively screen:

- Stormwater Treatment Suitability
- Physical Feasibility Factors
- Community and Environmental Factors

The Three-Step Process

Step ❶ Stormwater Treatment Suitability

Use the stormwater treatment matrix to answer the following question:

Can the BMP meet the stormwater rate, volume, and water quality treatment requirements mandated by local regulations at the site or are a combination of BMPs needed?

In this step, designers can screen the BMP list using the Step 1 matrix to determine if a particular BMP can meet the rate, volume, and water quality requirements they have identified. At the end of this step, the designer can reduce the BMP options to a manageable number and determine if a single BMP or a group of BMPs are needed to meet stormwater sizing criteria at the site.

Step ❷ Physical Feasibility Factors

Use the stormwater treatment matrix to answer the following question:

Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP?

In this step, the designer screens the BMP list using Step 2 matrix to determine if the soils, water table, drainage area, slope or head conditions present at their development site might limit the use of a particular BMP. In addition, the second matrix indicates whether a BMP is capable of treating hotspot runoff and provides comparative indexes on land consumption.

Step ❸ Community and Environmental Factors

Use the stormwater treatment matrix to answer the following question:

Do the remaining BMPs have any important community or environmental benefits or drawbacks that might influence the selection process?

In this step, the third matrix is used to compare the 16 stormwater treatment BMP options with regard to maintenance, community acceptance, habitat and cost.

[1]Adapted from the *Maryland Stormwater Design Manual*, Maryland Department of the Environment.

Step ❶ Stormwater Treatment Suitability Matrix

Runoff Hydrology

Rate Control

The matrix indicates the relative capacity of the BMP to provide rate control. If a particular BMP cannot meet the full rate control requirement it should not be necessarily eliminated from consideration, but it is an indication that more than one practice may be needed at a site (e.g., a bioretention area and a downstream stormwater wetland).

Volume Reduction

The matrix indicates the relative effectiveness in reducing the volume of stormwater runoff. Again, the fact that a particular BMP cannot fully meet the requirement does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at a site.

Water Quality

The four columns under the Water Quality heading are (1) TSS - Total Suspended Solids, (2) P & N - Phosphorus and Nitrogen, (3) Metals, and (4) Fecal Coliform. These columns indicate a particular BMP's expected benefits for each of the four constituents. A "primary" in a column indicates that this is a primary benefit of the BMP. A "secondary" indicates the BMP has some benefit but it is not the intended or primary benefit. A "minor" indicates there is little or no benefit using this BMP to control this constituent. It should be understood that a "primary" rating under the TSS column, for example, for wet vaults and a "primary" rating of TSS for an infiltration basin does not mean that the benefit or performance is the same or even similar. Rather it means that TSS removal is a primary benefit of each of these BMPs. It is not a comparison of BMP performance to one another.

Step ❶ Stormwater Treatment Suitability Matrix

BMP Family	BMP List	RUNOFF HYDROLOGY		WATER QUALITY BENEFIT			
		Rate Control	Volume Reduction	TSS	P & N	Metals	Fecal Coliform
Retention	Wet Pond	High	Low	Primary	Secondary	Secondary	Secondary
	Extended Storage Pond	High	Low	Primary	Secondary	Secondary	Secondary
	Wet Vaults	Medium	Low	Primary	Secondary	Secondary	Minor
Detention	Dry Pond	High	Low[1]	Secondary	Minor	Minor	Minor
	Oversized Pipes	High	Low	Minor	Minor	Minor	Minor
	Oil Grit/Separator	Low	Low	Secondary	Minor	Minor	Minor
	Dry Swale	Medium	Low[1]	Primary	Secondary	Primary	Minor
Infiltration	On-Lot Infiltration	Medium	High	Primary	Primary	Primary	Secondary
	Infiltration Basin	Medium	High	Primary	Primary	Primary	Secondary
	Infiltration Trench	Medium	High	Primary	Primary	Primary	Secondary
Wetland	Stormwater Wetland	High	Medium	Primary	Secondary	Secondary	Primary
	Wet Swale	Low	Low	Primary	Secondary	Secondary	Minor
Filtration	Surface Sand Filters	Low	Low[1]	Primary	Secondary	Primary	Secondary
	Underground Filters	Low	Low	Primary	Secondary	Primary	Secondary
	Bioretention	Medium	Medium	Primary	Primary	Primary	Secondary
	Filter Strips	Medium	Medium	Secondary	Minor	Minor	Minor

[1]May provide some volume reduction depending on permeability of native soil.

Step ❷ Physical Feasibility Factors Matrix

At this point, the designer has narrowed down the BMP list to a manageable size and can evaluate the remaining options given the actual physical conditions at a site. The six primary factors are:

Soils

The key soils evaluation factors are based on an initial investigation of the Natural Resources Conservation Service (NRCS) hydrologic soils groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Water Table

This column indicates the recommended minimum depth to the seasonally high water table from the bottom or floor of a BMP. The designer should check to see that local regulations do not require further restrictions, primarily with respect to infiltration and runoff from hot spots.

Drainage Area

This column indicates whether or not the BMP is considered suitable for small sites of 5 acres or less. The restrictions indicated for ponds and sometimes wetlands should not be considered inflexible limits and may be increased or decreased depending on water availability (baseflow or groundwater).

Head

This column provides an estimate of the elevation difference needed at a site (from the inflow to the outflow) to allow for gravity operation within the practice.

Area Requirements

This comparative index expresses the typical space or area requirements for the BMP. A "low" indicates that the BMP consumes a relatively small amount of land, whereas a "high" indicates the BMP may consume a relatively high fraction of land at a site. This factor is included in this early screening stage because many BMPs are severely constrained by land consumption.

The Ability to Accept Hotspot Runoff

This last column examines the capability of a BMP to treat runoff from hotspots. Hot spots are sites that produce exceptionally contaminated stormwater from surfaces such as vehicle salvage yards or industrial sites. A BMP that receives hotspot runoff may have design restrictions as noted, in addition to Local and State restrictions.

This does not imply that a single BMP would be adequate to treat an entire small site. Typically several BMPs, either the same type or different, will be required to adequately treat the runoff from a small site.

Step ❷ Physical Feasibility Factors Matrix

BMP Family	BMP List	Soil Considerations	Water Table[1]	Suitable for Site ≤ 5 acres	Head (feet)	Area Require-ments	Accepts Hotspot Runoff
Retention	Wet Pond	"A" soils may require pond liner	3 feet if hotspot or aquifer	Limited[4]	3 – 8	High	Varies[2]
	Extended Storage Pond	"B" soils may require testing		Limited	4 – 8	High	Varies[2]
	Wet Vaults	NA	NA	Yes	4 – 8	Low	Yes
Detention	Dry Pond	"A" soils may require pond liner "B" soils may require testing	3 feet if hotspot or aquifer	Yes	3 – 8	High	Varies[2]
	Oversized Pipes	NA	NA	Yes	5 – 10	Low	Yes
	Oil Grit/Separator	NA	NA	Yes	4 – 8	Low	Yes
	Dry Swale	Any soil type	3 feet	Yes	3 – 5	Med.	Yes[3]
Infiltration	On-Lot Infiltration	"A" and "B" soils preferred "C" soil difficult "D" soil not recommended	3 feet	Yes	1	Med.	No
	Infiltration Basin		3 feet	Yes	3 – 5	High	No
	Infiltration Trench		3 feet	Yes	2 – 4	Med.	No
Wetland	Stormwater Wetland	Any soil type if below water table	NA	Limited	2 – 6	High	Varies[2]
	Wet Swale	Any soil type if below water table	Below water table	Yes	3 – 5	Med.	No
Filtration	Surface Sand Filters	Any soil type	3 feet or 0 feet with liner	Yes	2 – 4	High	Yes[3]
	Underground Filters	NA	NA	Yes	4 – 8	Low	Yes
	Bioretention	Planting soil	3 feet	Yes	3 – 5	High	Yes[3]
	Filter Strips	Any soil type	3 feet	Yes	1	Med.	Yes

1 Recommended minimum elevation above water table. Check with state and local regulations.

2 Varies depending on type and concentration of contaminants in the runoff and depth to the water table.

3 Yes, but only if bottom of facility includes an impermeable liner that prevents infiltration of highly contaminated water into the groundwater.

4 Suitable only if a consistent source of water (such as groundwater) is available or if the pond is constructed with a liner or in clay soils.

Step ❸ Community and Environmental Factors Matrix

Maintenance

This column in the matrix assesses the relative maintenance effort needed for a BMP in terms of three criteria: frequency of inspection, scheduled maintenance and chronic maintenance problems (such as clogging). It should be noted that all BMPs require routine inspection and maintenance.

The amount of maintenance required is also a function of proper BMP selection, design, and construction. For this column, it was assumed that these steps were all completed properly.

Community Acceptance

This column in the matrix assesses community acceptance, as measured by three factors: market and preference surveys, reported nuisance problems, and visual orientation (e.g., is it prominently located or is it in a discreet underground location). It should be noted that a low rank can often be improved by a better landscaping plan.

Construction Cost

The BMPs are ranked according to their relative construction cost per impervious acre treated as determined from cost surveys and local experience.

Wildlife Habitat

BMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features and vegetative cover of the BMP and its buffer.

Step ❸ Community and Environmental Factors Matrix

BMP Family	BMP List	Maintenance	Community Acceptance	Cost (Relative to Drainage Area)	Wildlife Habitat
Retention	Wet Pond	Low	High	Low	Medium
	Extended Storage Pond	Low	Medium	Low	Medium
	Wet Vaults	High	High	High	None
Detention	Dry Pond	Medium	Medium	Low	Low
	Oversized Pipes	Low	High	High	None
	Oil Grit/Separator	High	High	High	None
	Dry Swale	Medium	High	Medium	Low
Infiltration	On-Lot Infiltration	Medium	Medium	Low	Medium
	Infiltration Basin	Medium	Medium	Medium	Medium
	Infiltration Trench	Medium	Medium	Medium	None
Wetland	Stormwater Wetland	Low	High	Medium	High
	Wet Swale	Medium	High	Low	Medium
Filtration	Surface Sand Filters	Medium	Medium	High	Low
	Underground Filters	High	High	High	None
	Bioretention	Medium	Medium	Medium	Medium
	Filter Strips	Low	High	Low	Medium

Chapter 3
Best Management Practices

The 40 best management practices (BMPs) presented in this chapter are organized into the two broad categories: Runoff Pollution Prevention and Stormwater Treatment. The names and page numbers of individual BMPs are listed immediately before each category, on pages 3-3 and 3-139.

Runoff Pollution Prevention

By far the most effective control of nonpoint source pollution is to prevent its release. This section of the manual discusses five families of runoff pollution prevention:

- Impervious Surface Reductions: Reducing the amount of hard surface.
- Housekeeping Techniques: Basic clean-up and management practices.
- Construction Practices: Ways to reduce opportunities for sediment release in stormwater.
- Soil Erosion Control: Techniques to prevent exposed soils from eroding.
- Sediment Control: Methods to catch sediment already suspended in stormwater.

Stormwater management begins with thoughtful design. Site planning that integrates comprehensive stormwater management from the outset is the most effective way to reduce and prevent pollution and flooding. Good site planning can also reduce the size and cost of structural solutions; when BMP stormwater structures are proposed only at the final stages of design and construction, the result is often unnecessarily large and costly facilities. Planning ahead can prevent the need for large structures.

Stormwater Treatment BMPs

A variety of BMPs are effective in filtering stormwater, reducing the speed at which it leaves a site, and reducing the volume of runoff. These three actions are critical to reducing nonpoint-source water pollution and protecting downstream water bodies.

This section of the manual presents six families of BMP practices:

- Infiltration Systems. Encourage stormwater to soak into the ground while filtering.
- Filtration Systems. Capture heavy metals, grease and oil, nutrients and sediment.
- Constructed Wetlands. Filter stormwater and reduce runoff rate while providing wildlife habitat.
- Retention Systems. Primarily designed to retain pollutants.
- Detention Systems. Primarily designed to reduce runoff rate.
- Alternative Outlet Designs. Primarily designed to regulate stormwater flow.

Runoff Pollution Prevention

Impervious Surface Reduction

Street Design 3-5
Cul-de-Sac Design 3-9
Driveway Design 3-13
Parking Lot Design 3-17
Turf Pavers 3-23
Green Rooftops 3-29

Housekeeping

Pavement Management 3-35
BMP Maintenance 3-41
Landscape Design and Maintenance 3-47
Animal Management 3-51

Construction Practices

Grading 3-55
Sequencing 3-63
Vehicle Tracking Pads 3-69

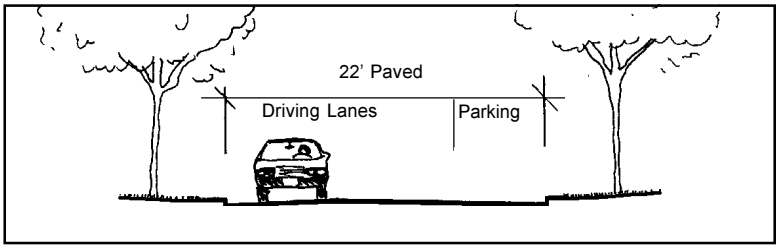
Soil Erosion Control

Mulch, Blankets and Mats 3-75
Vegetative Methods 3-85
Structural Methods 3-93

Sediment Control

Silt Fences 3-105
Inlet Protection 3-113
Temporary Sedimentation Basins/Traps 3-121
Check Dams 3-131

Street Design



Description

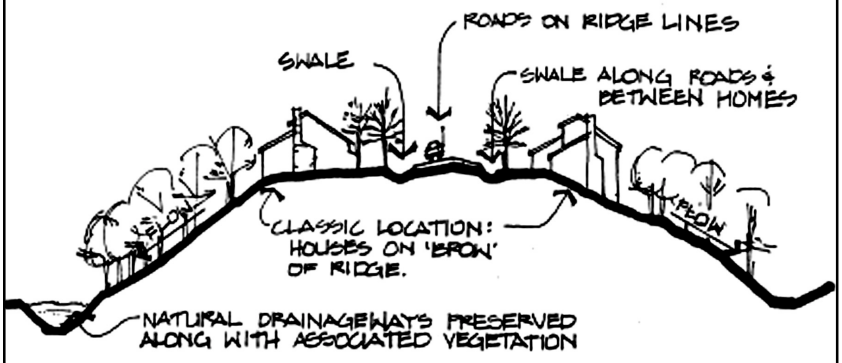
Street design offers numerous opportunities to reduce impervious surfaces and thus decrease runoff and associated stormwater management requirements. Areas of opportunity include the siting of streets, street width and drainage design.

Siting Streets

In new developments, road siting and street network layout are important considerations. To maximize stormwater filtration and infiltration, municipalities should aim to preserve natural drainage patterns whenever possible and avoid locating streets (and other impervious surfaces) in low areas or on highly permeable soils.

For example, locate roads on ridge lines, allowing water to drain naturally downhill. (See Fig. 1.) Whenever possible, choose sites with the least permeable soils for roads.

While designers must consider development character and context when designing a street system, they also should be aware that the



Place roads along ridge lines. Keep construction area away from low areas and valley flow lines.

Figure 1
Source: MPCA, 2000

Purpose

Water Quantity

Flow attenuation ◧

Runoff volume reduction ■

Water Quality

Pollution prevention

Soil erosion □

Sediment control ◧

Nutrient loading ◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Street Design

type of network selected affects the total amount of pavement. A typical grid system, for example, results in approximately 20,800 lineal feet of pavement, while a scheme of "loops and lollipops" (cul-de-sacs) results in 15,300 lineal feet of pavement. (See Fig. 2.)

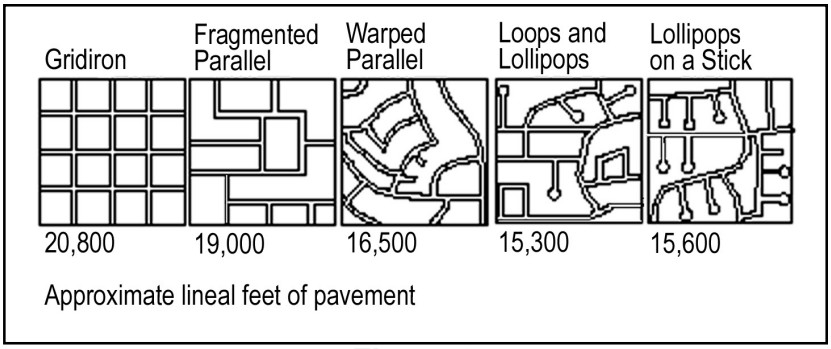


Figure 2

Source: Prince George's County, 2000 (adapted from ULI, 1980)

Design Width

Many residential streets are wider than necessary. They should be designed with the minimum pavement width that will support the area's traffic volume; on-street parking needs; and emergency, maintenance and service vehicles.

A simple way to narrow a suburban residential street is to provide for one parking lane rather than two. In especially low traffic areas, sidewalks may be restricted to one side of street or, in certain situations, eliminated.

Street Drainage

While curb-and-gutter is often considered the "standard" in road design, it tends to amplify stormwater volume and velocity while discouraging infiltration and groundwater recharge. Curbless road design, such as the so-called "rural residential section," encourages infiltration via roadside swales. (See Fig. 3.) On low-traffic streets without curbs, grass shoulders can serve as an occasional parking lane, allowing a narrower paved area.

Advantages

- Thoughtful siting and design of streets helps achieve stormwater control "at the source," which means less runoff requiring management, less stormwater infrastructure, and less impact on downstream water bodies.
- Reducing paving lowers development and maintenance costs.
- Forgoing curb-and-gutter in favor of a rural residential section results in major cost savings.
- Rural-section streets can incorporate attractive "rain garden" plantings in low areas adjacent the roadway, when soils permit.
- Narrower streets tend to slow traffic and create a more pedestrian-friendly environment.
- Reducing pavement lessens the urban heat island effect—the increase in air temperature that occurs when highly developed areas are exposed to the sun.

Limitations

- Local ordinances may preclude narrowed or curbless street design.
- Cities' desire to design roads to accommodate future growth may impede innovations.

Street Design

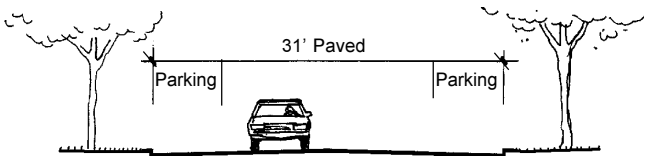
- Roadside swales are difficult to accommodate in single family residential developments with net densities above 8 units per acre.
- Good drainage for road subgrade must be provided when using roadside infiltration methods.
- Soil and topography may limit street siting opportunities.

Requirements

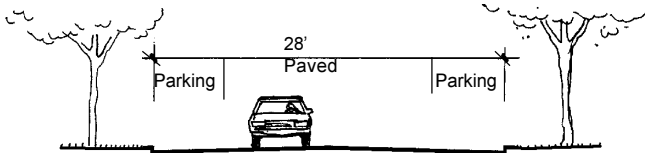
Design

- Design residential streets with the minimum pavement width necessary to support: the traffic volume; on-street parking needs; and emergency, maintenance, and service vehicles.
- Use shallow, grassed roadside swales (rural residential cross-section) instead of curb and gutter when net densities are 6 to 8 units per acre or less.
- Swales to catch road runoff should be sloped no more than 3:1 (See Lot Level Infiltration and Rain Gardens.)

Modest Street Widths, Two-Side Parking

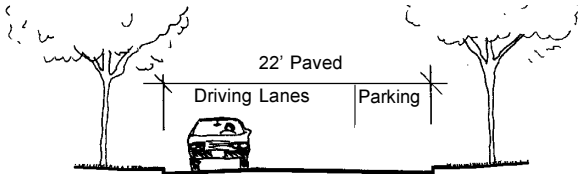


Standard width for residential collector streets, with parking on both sides. Dimension Source: Maple Grove, Minnesota.

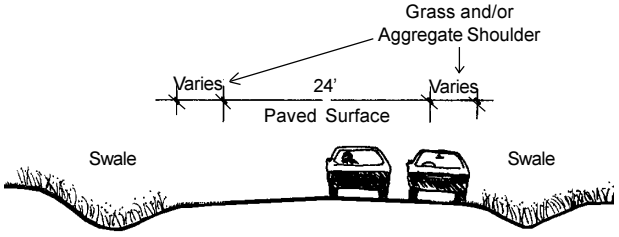


Standard width for residential minor streets, with parking on both sides. Dimension Source: Eden Prairie, Minn.

Other Alternatives



Allowing parking on only one side can further reduce the width of low-volume residential streets. Dimension Source: Robert Engstrom Companies (Fields of St. Croix, Lake Elmo, Minn.).



Crowned, curbless road drains to roadside swales. Grass shoulders function as occasional parking lanes. Dimension Source: Afton, Minn.

Figure 3

Source: Valley Branch Watershed District, 2000

Street Design

Requirements

Design (continued)

- Limit sidewalks to one side on roads with less than 400 Average Daily Traffic (ADT) (or 200 ADT for cul-de-sacs).
- Resist designing for distant future growth.

Construction

- Take care not to compact adjacent, permeable soils during road construction.
- Protect swales and other infiltration areas from sediment influx during construction, or remove sediment after construction is complete.
- For subgrade drainage options, see Lot Level Infiltration BMP.

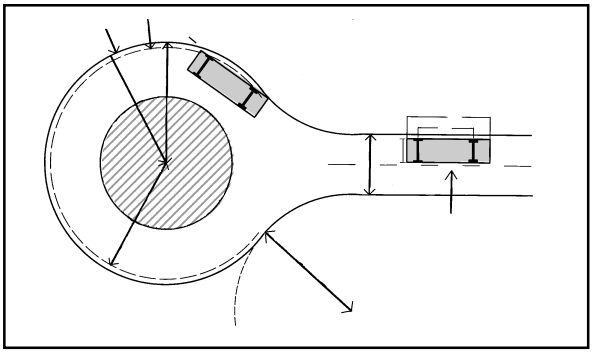
Maintenance

- Swales planted with perennials grasses and wildflowers rather than turfgrass must be weeded at least monthly during the first two to three years. After that, weeding once or twice a growing season may suffice.
- Swales will need periodic sediment removal to maintain volume and filtering ability (see Rain Garden BMP).

Sources

1. Massachusetts Department of Environmental Protection. 1997. *Stormwater Management: Vol. 2.* Boston.
2. Minnesota Pollution Control Agency. 2000. *Protecting Water Quality in Urban Areas. St*. Paul.
3. Prince George's County Department of Environmental Resources, Programs and Planning Division. 2000. *Low-Impact Development Design Strategies. Largo*, MD.
4. Schueler, Tom. 1995. *Site Planning for Urban Stream Protection. Center* for Watershed Protection, Silver Spring, MD.
5. Valley Branch Watershed District. 2000. *Alternative Stormwater Best Management Practices Guidebook.* Lake Elmo, MN.

Cul-de-Sac Design



Description

Careful cul-de-sac design can greatly reduce the amount of impervious surface in subdivisions. To do this, cul-de-sacs (also called turnarounds or dead-ends) should use the smallest practical radius. A 40-foot turning radius will accommodate turning of most emergency, service, and maintenance vehicles, while a 30-foot radius will require the largest of these vehicles to make one backing movement in order to turn around.

Simply changing the radius from 40 feet to 30 feet can reduce the impervious coverage by about 50 percent (Schueler, 1995).

Additionally, a landscaped island can be created in the center of the cul-de-sac, where driving does not occur. This island can be designed as a depression to accept stormwater runoff from the surrounding pavement, thus furthering infiltration. A flat apron curb will stabilize roadway pavement and allow for runoff to flow into the cul-de-sac's open center.

A T-shaped (or hammerhead) turnaround reduces impervious surface even further—yielding a paved area less than half that of a 30-foot radius turnaround. Since vehicles need to make a three-point turn to drive out, T-shaped turnarounds are most appropriate on streets with ten or fewer homes.

Advantages

- Cul-de-sac designs like those suggested here result in less stormwater runoff requiring management and less impact on downstream water bodies.
- Planted cul-de-sac islands are attractive amenities
- Less paving can lower development costs

Purpose

Water Quantity

Flow attenuation ◧

Runoff volume reduction ■

Water Quality

Pollution prevention

Soil erosion □

Sediment control ◧

Nutrient loading ◧

■ Primary design benefit

◧ Secondary design benefit

□ Little or no design benefit

Cul-de Sac Design

- Reducing pavement lessens the urban heat island effect—the increase in air temperature that can occur when highly developed areas are exposed to the sun.
- Reducing pavement can help reduce the increased runoff temperature commonly associated with impervious cover.

Limitations

- City ordinances may not accommodate small radii cul-de-sacs, due to accommodations for emergency vehicles. (Some older vehicles require very large turning radii.)
- Hammerhead turnarounds require vehicles to make a three-point-turn to drive out.
- In first two to three years, planted islands require more maintenance than paving.

Design

- If traffic volume is low (10 or fewer homes), consider a T-shaped turnaround. A dimension of 20 by 60 feet will accommodate most vehicles. (See Fig. 4)
- Design circular cul-de-sacs with a radius of 30 feet or less whenever possible. (See Fig. 2)
- Include an unpaved, depressed island, using whatever radius will allow a 20-foot-wide road. (See Fig. 3)
- To make turning easier, the pavement at rear of center island may be wider. (See Fig. 2)
- In the island, plant attractive, low-maintenance perennials or shrubs appropriate for the soil and moisture conditions.

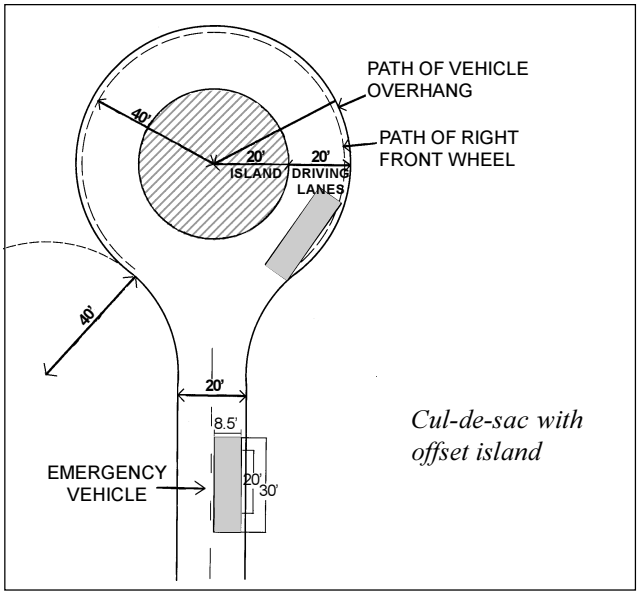
Construction

- During paving, care should be taken to avoid compacting soil in center island. Should compaction occur, it may be necessary to rip or till soils to a depth of 2 feet.
- Choose plants that will thrive when rainfall is high, as well as during droughts without watering. See On-Lot Infiltration BMP for plant list.

Maintenance

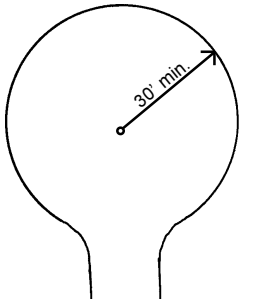
- Cul-de-sac island planting areas must be weeded monthly during the first two to three years. After that, weeding once or twice a growing season may suffice.

Cul-de-Sac Design

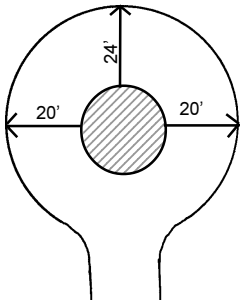


Cul-de-sac with offset island

Figure 1

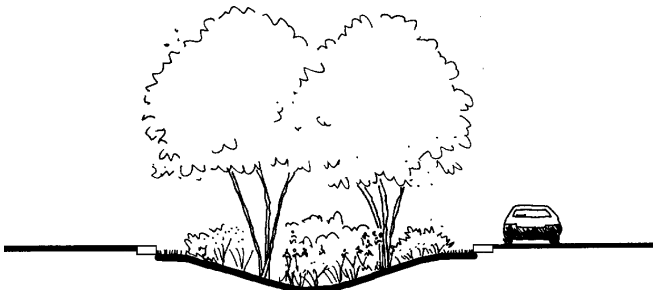


A 30' radius will accommodate most vehicles and reduce pavement



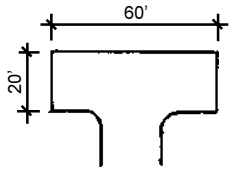
An island can be placed to allow wider lanes in rear, making turning easier.

Figure 2



Cul-de-sac infiltration island accepts stormwater from surrounding pavement. Note flat curb.

Figure 3



T-shaped turnaround

Figure 4

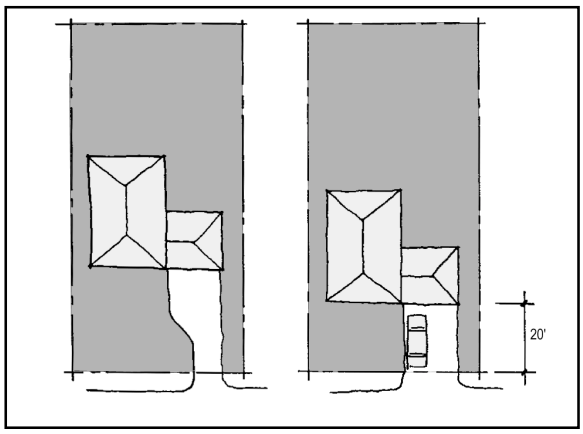
Sources: Adapted from Schueler, 1995, and ASCE, 1990.

Cul-de Sac Design

Sources

1. American Society of Civil Engineers, National Association of Home Builders and Urban Land Institute. 1990. *Residential Streets.* Washington, D.C.
2. Harris, Charles W. and Nicholas T. Dines. 1988. *Time-Saver Standards for Landscape Architecture.* McGraw-Hill, New York.
3. Schueler, Tom. 1995. *Site Planning for Urban Stream Protection.* Center for Watershed Protection, Silver Spring, MD.
4. Valley Branch Watershed District. 2000. *Alternative Stormwater Best Management Practices Guidebook.* Lake Elmo, MN.

Driveway Design



Description

Driveway design is a relatively simple way to reduce stormwater runoff by limiting impervious surface. In addition, alternative driveway grading schemes and materials can help reduce runoff.

Pavement Reduction

Impervious surfaces in housing developments can be reduced by 1) changing building setback codes and thus shortening driveways, 2) reducing driveway widths, and 3) implementing alternative driveway layouts.

1. Driveways are shortened when codes allow buildings to be placed closer to the street. Side setback codes can also be changed to allow developers to design a single driveway between two dwellings. This can then branch into two driveways closer to the garages. (See Figs. 1 and 3)
2. New houses commonly have two- or three-stall garages with driveway widths ranging from 24 to 36 feet. An alternative is to design driveways full-width, deep enough for one car, in front of the garage, then narrowed to a single lane where they meet the street. (See Fig. 2)
3. Other design alternatives include concrete wheel track driveways, which are unpaved in the center. These are commonly found in old neighborhoods, such as Crocus Hill in St. Paul. Residents there can attest to their ease of maintenance, both in mowing and snow removal.

Grading and Materials

Many driveways can be graded to drain toward front and side yards, rather then directly into the street. (See Lot-Level Infiltration BMP.)

Purpose

Water Quantity

Flow attenuation	◧
Runoff volume reduction	■

Water Quality

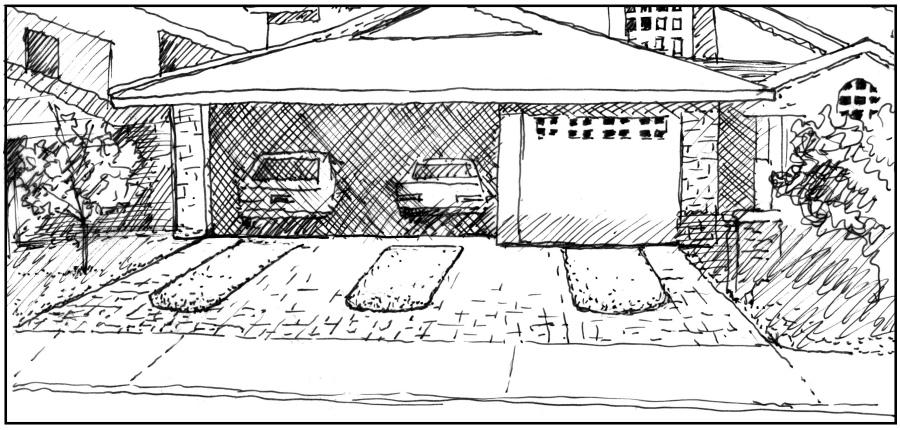
Pollution prevention

Soil erosion	□
Sediment control	◧
Nutrient loading	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Driveway Design

When site conditions permit, pervious surfacing such as dry-set pavers can be used. Turf pavers may be appropriate in front of a third garage or for driveway overflow parking in summer. (See Turf Pavers BMP.)



Wheel-track driveway variation. The turf "islands" may be strengthened by using grass pavers or soil amendments (see Turf Pavers BMP).

Advantages

- Reducing impervious surface reduces runoff and thus minimizes the need for stormwater treatment.
- Less paved surface means lower costs for development and driveway maintenance.
- Areas requiring snow removal are reduced.
- Oils and other vehicle-related pollutants are prevented from directly entering the stormwater system and downstream water bodies.

Limitations

- Setback ordinances can be hard to change.
- Small lot size and tight soils can create difficulties in establishing on-site infiltration areas.

Requirements

Design

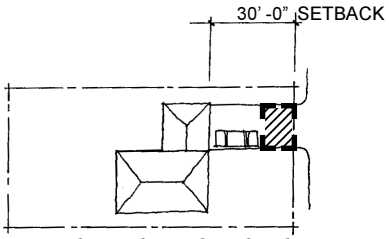
- Reduce front yard setback to 20 feet from the property line. This is more than sufficient to allow a vehicle to park without encroaching on public right-of-way. (Fig. 1)
- For long driveways, narrow the driveway to one lane as it approaches the street. (Fig. 2)
- Use turf pavers for temporary overflow parking along driveways.
- Grade driveways to drain into yard instead of street.
- Especially if driveway is graded to drain into yard, plant areas adjacent driveway to help slow runoff and encourage infiltration.
- To ensure drainage, dry-set pavers require a sand setting bed, 1 to 1-1/4 inches deep, atop a 6- to 12-inch compacted granular base (depth depends on permeability of soil) which is placed over the compacted subgrade. Lateral support may be provided by extending base beyond the pavement edge and/or by installing a rigid edging. If a edging is employed, be sure drainage is provided along an unrestrained edge.

Driveway Design

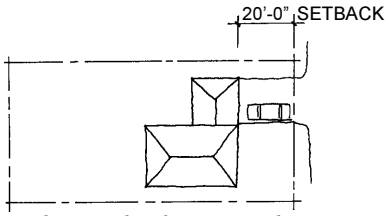
- Design wheel-track driveways for various vehicle sizes—a central grass strip 3.5 feet wide or narrower and two paved tracks, one foot each or wider. (See example drawing on previous page.)

Construction

- During paving, care should be taken to avoid compacting soil in areas that will receive runoff. Should compaction occur, soils may be ripped or tilled to a depth of 2' before being replanted.

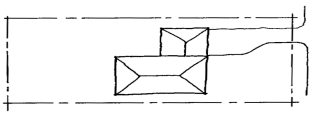


Typical residential setback creates excess driveway paving.



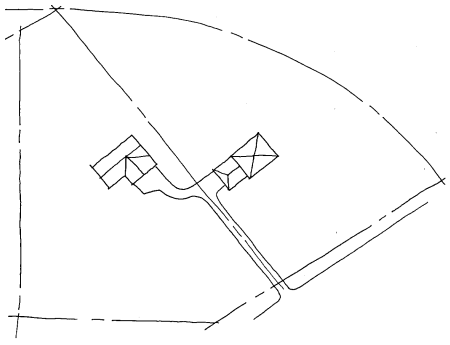
Reduce setback to provide one car length in driveway.

Figure 1



For longer driveways, taper pavement to one lane at the street.

Figure 2



Shared driveways can eliminate the need for two long driveways.

Figure 3

Source: Valley Branch Watershed District, 2000

Driveway Design

Sources

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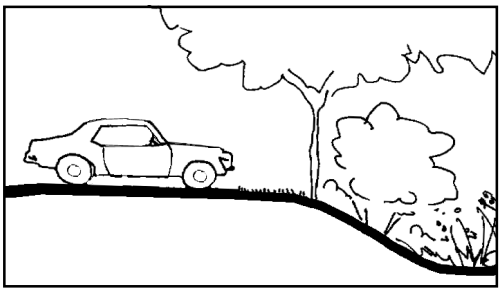
Parking Lot Design



Description

Two main strategies can help reduce runoff volume or provide water quality benefits in parking lots: reducing paved surface area and incorporating plants and infiltration swales into designs.

Reduced Paved Surface

Pavement reduction can be accomplished in three main ways:

- *Changing municipal codes to reduce parking requirements.* To avoid excessive paving, codes should set a minimum *and* maximum number of spaces a development can provide. Parking demand ratios should be based on site-specific parking generation studies.
- *Reducing stall dimensions*. This can be accomplished by creating dedicated compact car spaces and then offering spillover parking areas with pervious surfaces. Determine the most space-efficient design for the site, which may be angle parking (to reduce driving lane width) or conventional stalls.
- *Promoting shared parking lots*. Allow shared lots between businesses with peak parking demand at different times of the day or week. For example, a restaurant that requires parking primarily evenings and weekends could share parking with an office building with weekday parking needs.

Planting Strategies.

Vegetation is an effective and attractive way to reduce runoff, and smaller parking lots free up more space for landscaping.

Leaves, stems and branches intercept rainwater, which then evaporates. A significant amount of stormwater can evaporate from beds of tall grasses, wildflowers, shrubs, and trees. Furthermore, deep-rooted prairie plants create channels that help encourage infiltration (see Figure 1). They also hold up to a half-inch of stormwater on their leaves and in the thatch they create.

Purpose

Water Quantity

Flow attenuation	◧
Runoff volume reduction	■

Water Quality

Pollution prevention

Soil erosion	□
Sediment control	◧
Nutrient loading	◧

Pollutant removal *(only if runoff is directed into planted swales)*

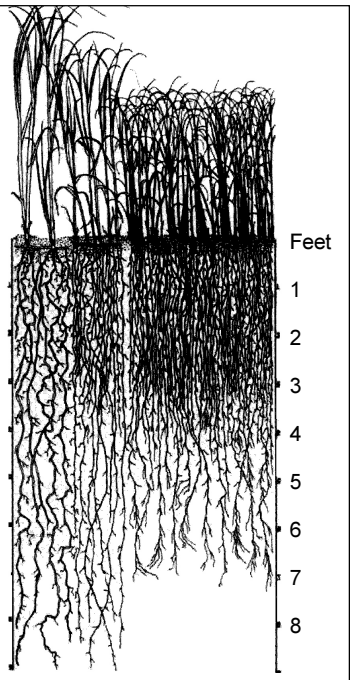
Total suspended sediment (TSS)	◧
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	◧
Floatables	◧
Oil and grease	◧

Other

Fecal coliform	□
Biochemical oxygen demand (BOD)	□

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Parking Lot Design



Deep-rooted native plants, especially grasses, help encourage infiltration.

Figure 1

Shallow-rooted turf grass is not nearly so effective; substitute deep-rooted perennial plantings for sod wherever possible.

Even if extensive perennial planting is not possible, include trees to canopy paved areas. In addition to intercepting rainwater, the summer shade they provide helps to reduce the urban heat island effect and make parking lots more pleasant places to be.

Infiltration

Planted areas can also be designed specifically to accept runoff of parking areas (as shown in Figures 2, 3 and 4), providing temporary storage and on-site infiltration. See Rain Garden information in On-Lot Infiltration BMP.

Advantages

- Reducing parking surface reduces the need for stormwater runoff management.
- Less paving means lower development and maintenance costs.
- Grasses, wildflowers, shrubs and trees hold water that is then evaporated, reducing runoff.
- Channels created by deep roots encourage infiltration.
- Shade from trees helps reduce the urban heat island effect and make the area more comfortable for people.
- Planting native vegetation creates wildlife habitat.
- A variety of vegetation creates a more interesting and aesthetically pleasing environment.
- Trees shade impermeable surfaces, keeping stormwater cool and reducing urban heat island effect.

Limitations

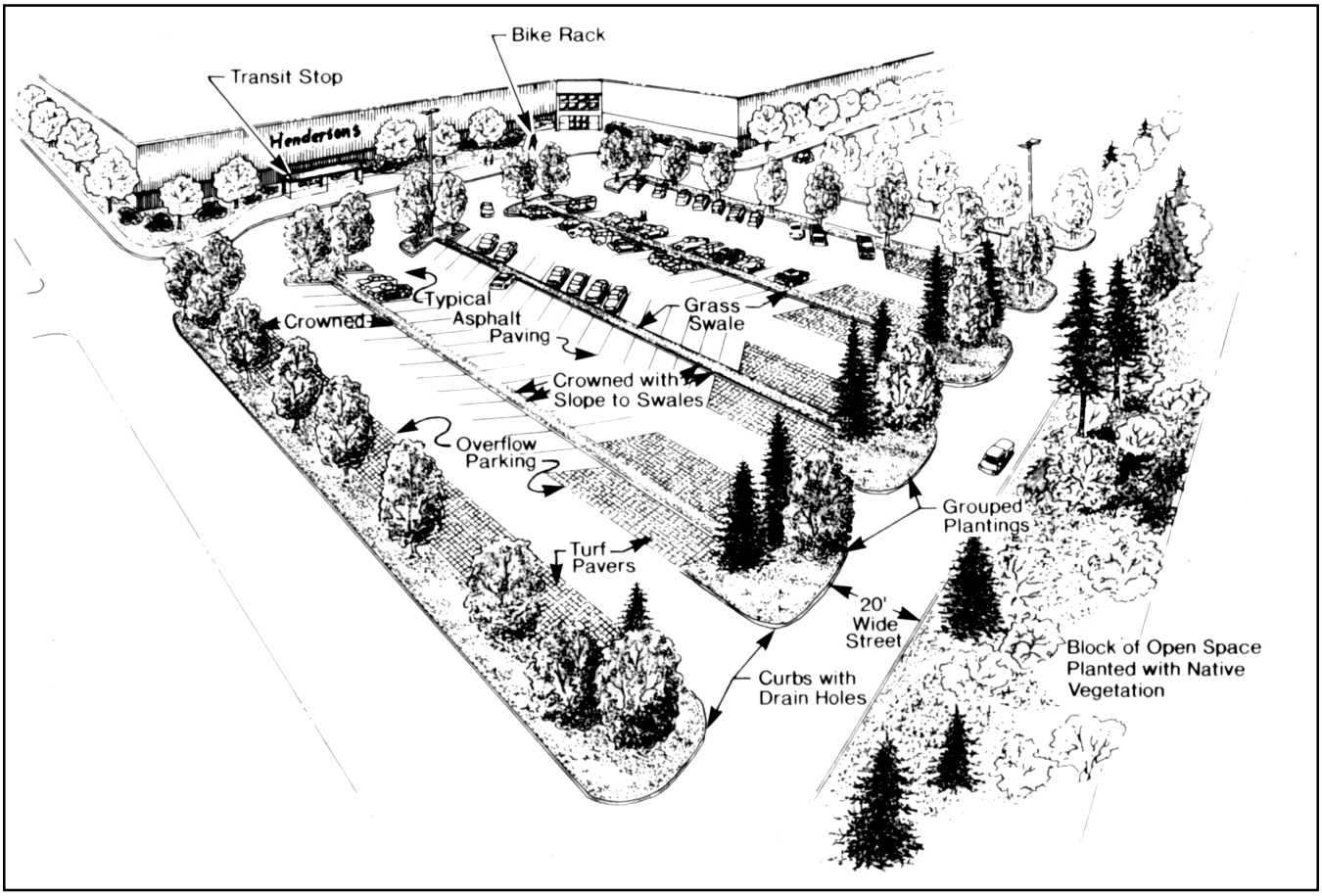
- Municipalities may have firm parking requirement that do not encourage innovation.
- Space allocated for parking lot in a given development may not be sufficient to include significant planted areas.
- Soil type may limit infiltration and/or planting success.

Land Use	"Better Site Design" Parking Ratio
Single family home	2 spaces or less per dwelling unit (driveway spaces count)
Professional offices	3.0 spaces or less per 1,000 $ft.^2$ gross floor area
Retail	4.0 - 4.5 spaces or less per 1,000 ft^2 gross floor area

Table 1

Source: Adapted from CWP, 2000.

Parking Lot Design



Source: Robert W. Droll, ASLA, in Wells 1994.

Requirements

Design

- Revise outdated, overly generous parking ratio requirements. (See Table 1.)
- Use minimum stall dimensions.
- Use the most space-efficient stall configuration for the site (See Turf Pavers BMP).
- In larger commercial parking lots, design 30 percent of the spaces for compact cars only.
- Use pervious surfacing in summer spillover parking areas.
- If soils are suitable, drain parking lot runoff into infiltration islands using curb cuts or flat curbs.
- If soils are unsuitable, excavate to a depth of 3 feet and fill with a planting soil mix.
- Plant native or vigorous nonnative perennials rather than turfgrass over as much of non-paved surfaces as possible. See Plant List on following page.

Parking Lot Design

- Aim to have canopy trees at maturity cover at least 50 percent of paved surfaces. Since tree height and spread will generally be smaller than normal in parking lot growing conditions, compensate by planting more trees closer together.
- Irrigation systems are usually necessary for parking lot island plantings, unless sufficient runoff is directed into them..

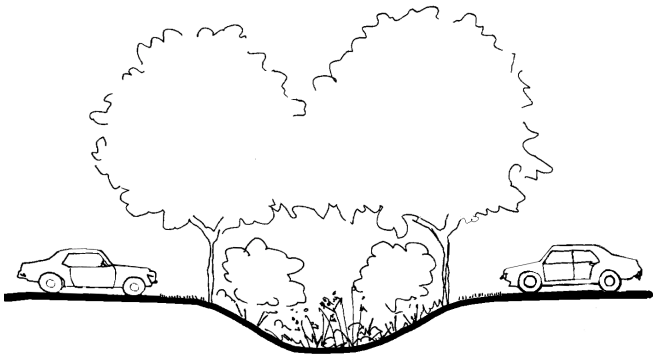
Requirements

Construction

- To avoid compaction, do not drive on planting areas during construction.
- After construction, loosen soils in planting areas to a depth of 24 inches, to a maximum compaction of 85 percent standard proctor density. Till the upper 10 inches of soil.

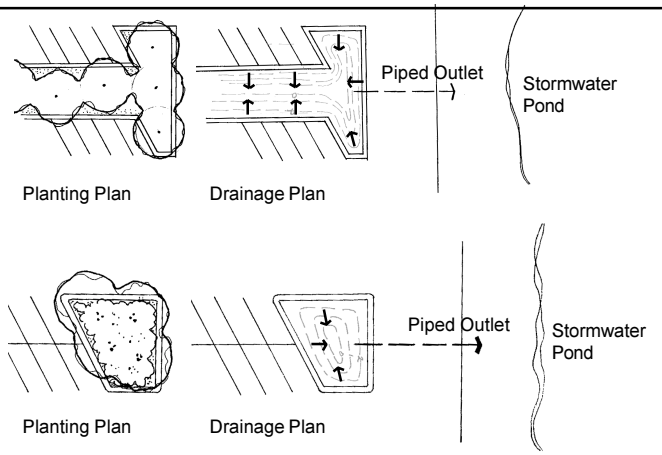
Maintenance

- Planted areas must be weeded monthly during the first two to three years. After that, weeding once or twice a growing season may suffice.
- Regular watering will be necessary during dry spells. Limit irrigation to a maximum of two inches per week.
- During winter plowing, push street snow away from swales whenever possible in order to avoid accumulation of road sand.



Infiltration island within parking lot.

Figure 3
Source: VBWD, 2000



Two alternative designs for parking lot infiltration islands. Parking lot sheet flow is directed to depressed islands, overflow drains to stormwater pond.

Figure 4
Source: VBWD, 2000

Rainwater Gardens Plant List

Source: Fred Rozumalski, Barr Engineering

Mesic-Dry Soils (Sunny)

Native		***Non-Native***	
Butterfly Flower	*Asclepias tuberosa*	Yarrow 'Coronation Gold'	*Achillea 'Coronation Gold'*
Purple Prairie Clover	*Dalea purpureum*	Feather Reed Grass 'Karl Foerster'	*Calamogrostis 'Karl Foerster'*
Purple Coneflower	*Echinacea purpurea*	Daylily	*Hemerocallis spp.*
Bee balm	*Monarda fistulosa*	Blazingstar 'Kobold'	*Liatris 'Kobold'*
Little Bluestem	*Schizachyrium scoparium*	Silverfeather Grass	*Miscanthus sinensis*
Spiderwort	*Tradescantia bracteata*	Garden Phlox	*Phlox paniculata*
		Black-Eyed Susan 'Goldsturm'	*Rudbeckia fulgida 'Goldsturm'*

Mesic-Dry Soils (Shady)

Native		***Non-Native***	
Wild Columbine	*Aquilegia canadensis*	White Comfrey	*Symphytum grandiflorum*
Wild Geranium	*Geranium maculatum*	Tufted Hair Grass	*Deschamsia caespitosa*
Obedient Plant	*Physostegia virginiana*	Bigroot Geranium	*Geranium macrorrhizum*
Jacob's Ladder	*Polemonium reptans*	Daylily	*Hemerocalis spp.*
Solomon's Seal	*Polygonatum biflorum*	Hosta 'Royal Standard'	*Hosta 'Royal Standard'*
Zig Zag Goldenrod	*Solidago flexicaulis*	Tigerlily	*Lilium tigrinum*
Canada Violet	*Viola canadensis*		
Culver's Root	*Veronicastrum virginium*		

Wet Soil (Sunny)

Native		***Non-Native***	
Giant Hyssop	*Agastache foeniculum*	Joe-Pye 'Gateway'	*Eupatorium purpurescens 'Gateway'*
Canada Anemone	*Anemone canadensis*	Daylily	*Hemerocalis spp.*
Marsh Milkweed	*Asclepias incarnata*	Siberian Iris	*Iris sibirica*
New England Aster	*Aster novae-angliae*	Tigerlily	*Lilium tigrinum*
Turtlehead	*Chelone glabra*	Switchgrass 'Heavy Metal'	*Panicum virgatum 'Heavy Metal'*
Joe-Pye Weed	*Eupatorium maculatum*		
Obedient Plant	*Physostesia virginianum*		
Boneset	*Eupatorium perfoliatum*		
Queen of the Prairie	*Filpendula rubra*		
Blueflag Iris	*Iris versicolor*		
Great Blue Lobelia	*Lobelia siphilitica*		
Switchgrass	*Panicum virgatum*		
Mountain Mint	*Pycnanthemum virginianum*		
Tall Meadow Rue	*Thalictrum dasycarpum*		
Culvers Root	*Veronicastrum virginicum*		
Golden Alexander	*Zizia aurea*		

-list continued on next page-

Parking Lot Design

Plant List (continued)

Wet Soils (Shady)

Native		*Non-Native*	
Cardinal Flower	*Lobelia cardinalis*	Pink Turtlehead	*Chelone layonii*
Ostrich Fern	*Matteuccia struthiopteris*	Daylily	*Hemerocalis spp.*
Virginia Bluebells	*Mertensia virginica*	Obedient Plant	*Physostegia virginiana*
Sensitive Fern	*Onoclea sensibilis*		

Shrubs (Sunny)

Black Chokeberry	*Aronia melanocarpa*
Red-Osier Dogwood	*Cornus sericia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens 'Annabelle'*
Pussy Willow	*Salix discolor*
High Bush Cranberry	*Viburnum trilobum*

Shrubs (Shady)

Black Chokeberry	*Aronia melanocarpa 'alata'*
Red-Osier Dogwood	*Cornus serecia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens 'Annabelle'*

Trees (consider soils when making selections)

Autumn Blaze Maple	*Acer x freemanii 'Jeffersred'*
Black Ash	*Fraxinus nigra 'Fallgold'*
Seedless Green Ash	*Fraxinus pennsylvanica 'Marshall's Seedless'*
Swamp White Oak	*Quercus bicolor*
Kentucky Coffeetree	*Gymnocladus dioica*

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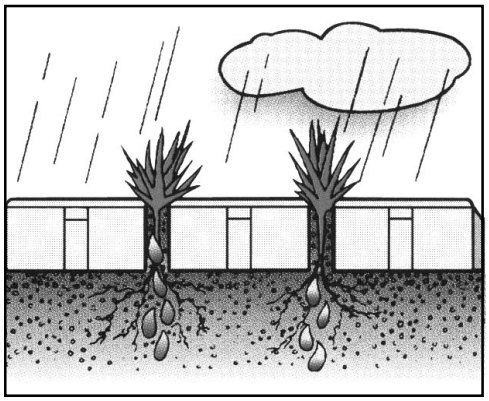
1. Center for Watershed Protection. 2000. "An Introduction to Better Site Design" in *Watershed Protection Techniques.* Vol. 3, No. 2. Ellicott City, MD.
2. Center for Watershed Protection. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Ellicott City, MD.
3. Schueler, Tom. 1995. *Site Planning for Urban Stream Protection.* Center for Watershed Protection, Silver Spring, MD.
4. Valley Branch Watershed District. 2000. *Alternative Stormwater Best Management Practices Guidebook.* Lake Elmo, MN.
5. Wells, Cedar. 1994. "Skinny Streets and One-Sided Sidewalks: A Strategy for Not Paving Paradise" in *Watershed Protection Techniques,* Vol 1. No 3. Center for Watershed Protection. Ellicott City, MD.

Turf Pavers


Source: SF Concrete Tech.

Description

Turf paving includes several techniques that reduce impervious surfaces, thus increasing infiltration and reducing runoff. The options include modular paving blocks or grids, cast-in-place concrete grids and soil enhancement technologies. All of these methods increase a site's load-bearing capacity, allowing for foot and vehicle traffic along with healthy grass growth. But they are not always appropriate for year-round use or in heavily trafficked areas.

Common applications include roadside right-of-ways, emergency access lanes, delivery access routes and overflow parking areas.

Traffic volume, typical vehicle loads and need for snow plowing can limit application. For these reasons, turf pavers for parking are recommended only for summer overflow areas. In residential areas, alternative surfaces can be used for driveways and walkways, but, due to their texture, are not ideal for areas that require accessibility for handicapped people.

(Porous asphalt or concrete are not included in this discussion, due to their limitations in cold climates.)

Modular Paving Blocks and Grids

Modular paving blocks or grass pavers consist of concrete or plastic interlocking units that provide structural stability while a series of gaps planted with turf grass allow for infiltration. Some blocks may also be filled with gravel and left unplanted. (See Fig. 1) Depending on the use and soil type, a sand setting bed and gravel subbase is often added underneath to help further infiltration and prevent settling.

Products include rigid rectangular modules that are installed like paving stones and flexible rolled material that is cut to size and snapped together.

Purpose

Water Quantity

Flow attenuation ◧

Runoff volume reduction ■

Water Quality

Pollution prevention

Soil erosion □

Sediment control ◧

Nutrient loading ◧

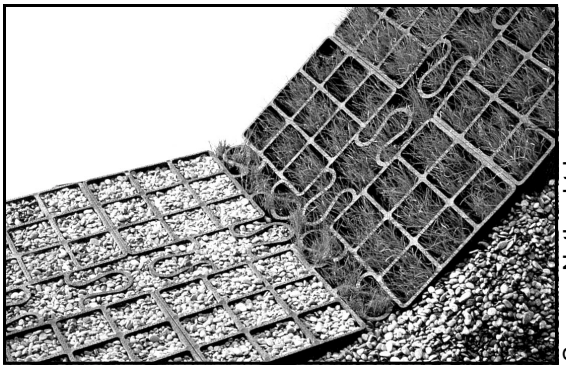
■ Primary design benefit

◧ Secondary design benefit

□ Little or no design benefit

Turf Pavers

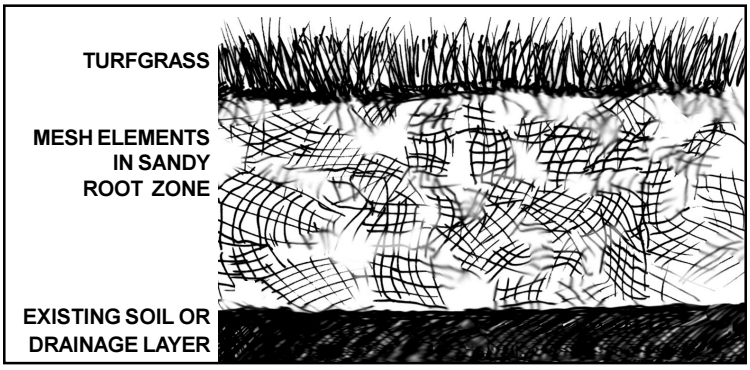
Figure 1



Source: Netlon Ltd.

A modular polyethylene paving system, Netlon SG2000, shown with both gravel and turfgrass.*

Figure 2



Soil amendment technology: Synthetic mesh elements add load-bearing capacity to turf-covered areas.

Cast-in-Place Concrete Systems

Cast-in-place, monolithic concrete pavement incorporates gaps that are filled with topsoil and grass for a free-draining "pavement" with the structural capacity to handle most heavy vehicle loads. The surface is similar to that of modular concrete paving blocks.

Soil Enhancements

The soil-amendment technology discussed here employs synthetic mesh elements blended with a sandy growing medium, resulting in a natural turf surface and an engineered load-bearing root zone. This proprietary technology is appropriate for summer overflow parking, golf courses, recreational fields and areas where the aesthetic appeal of uninterrupted grass is important. See Fig. 2.

Benefits

- Turf pavers reduce or eliminate other stormwater management techniques by reducing runoff.
- Applied in combination with other BMPs, pollutant removal and stormwater management can be further improved.
- Construction costs for turf pavers may be lower or higher than conventional pavements; there may be cost savings due to reduced curb-and-gutter requirements.
- Turf pavers are appropriate for driveways, walkways and overflow parking areas where handicapped access is not required or provided elsewhere.
- Turf helps soften the look of an area and make it more pleasant for pedestrians.
- Soil-enhanced turf systems are advantageous for sports and recreation fields as they resist compaction, thus increasing infiltration, and provide a soft playing surface.
- The mesh elements in engineered soil reportedly stabilize soil without reducing its permeability. The elements are thought to combat compaction, as they flex under pressure and “cultivate” the surrounding soil.

** This mention does not constitute an endorsement of product.*

Turf Pavers

- Snow may melt faster on a porous surface because of rapid drainage below the snow surface.
- Porous pavement can help to reduce the increased runoff temperature commonly associated with impervious cover.

Source: Interlock Paving Systems 2001

Figure 3: Modular Concrete Turfstone™ Pavers*

Limitations

- For reasons of durability and maintenance, turf pavers are not recommended for high-traffic areas.
- Turf paving systems limit wheelchair access.
- Snow removal can be difficult, as plow blades can remove vegetation and catch the edge of the blocks, damaging the surface (see Maintenance).
- Salt and sand in runoff from adjacent impervious pavement can damage turf and clog gaps in the blocks.
- Construction costs for turf paving may be higher or lower than conventional pavements. Maintenance costs are generally higher.
- Clay soils will limit infiltration.
- Since turf paving encourages infiltration, it should not be applied on stormwater hotspots—places where land use or activities generate highly contaminated runoff—due to the potential for groundwater contamination.

Requirements

Design

Modular and Cast-in-Place Concrete Systems

- Soil type will affect infiltration rates and must be considered when designing a turf paver area.
- Subbase depth depends on application and existing soils; 3 to 4 inches of compacted aggregate/gravel may suffice for a light-load/high use road; 8 to 10 inches for a heavy vehicle, fire-access road. Some systems recommend a 1-1/2-inch sand setting bed. Depending on soils, residential applications may not require any added subbase.
- Fill voids with sand or sandy loam planting base (adhere to manufacturer's recommendations).
- Plant with "park grade" turf grasses which are more drought tolerant than "elite grade" grasses.

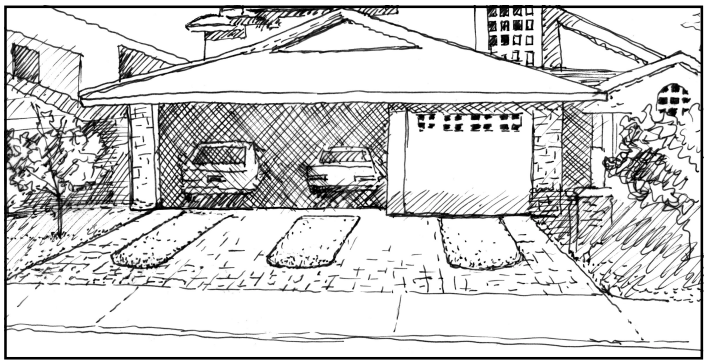
** This mention does not constitute an endorsement of product.*

Turf Pavers

Design Requirements (continued)

- To avoid salt damage and sediment-clogged cells, avoid routing large runoff volume directly from adjacent impervious areas to turf pavers.
- Turf pavers can be attractively combined with dry-set pavers or any number of other pavement types. (See Fig. 4)
- Follow manufacturers' recommendations for each system.

Figure 4



Source: Adapted from NDS

Conventional pavers combined with turf paver "islands" to increase infiltration.

Soil Enhancements

- Depending on site needs and budget, engineered growing medium may be mixed with mesh elements on site or obtained as solid slabs of mature turf with mesh elements already in the growing medium.
- When existing subsoil drainage is poor, slit drains may be necessary. They will consist of perforated or porous pipes in gravel-filled trenches leading to outfall. Spacing of drains, typically 3 to 5 feet, will depend on location and intended use. (See Fig. 5)
- Root zone medium will be 6 to 8 inches deep.
- Aggregate base depth depends on vehicle loading and subgrade strength. Range of aggregate is from approximately 4 to 20 inches (the latter for weak subgrade and use by heavy trucks).

Construction

Modular and Cast-in-Place Concrete Systems

- Cells may be planted in one of three ways:

  1. Fill with a porous backfill mix (some products require sharp sand), scrape or backrake the entire surface to expose pattern. Broadcast seed or stolons or hydroseed and then top dress and fertilize as required.

  2. Fill and scrape or backrake as above, then lay 5/8-inch sod on the assembled pavers. Water the sod, then use a hand water roller or power-driven roller to compress the sod and root system completely into the cells.

  3. Do *not* fill the cells with any type of soil mixture. Lay 1-inch sod on the assembled pavers. Water the sod and compress as above.

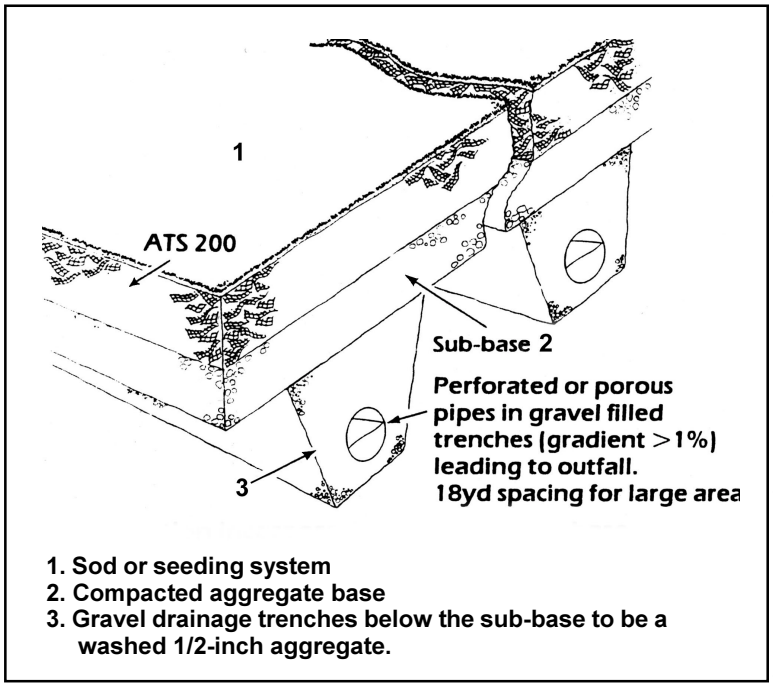
- Some manufacturers may supply or recommend a polymer growing medium to be used with their paving product.

Soil Enhancements

- Sand or a proprietary growing medium is blended with a specific proportion of mesh elements using a mechanical shovel. A 20 kg. sample of mixed material will contain 54.4-66.7 g. of mesh elements (or approximately 44 lb. mesh for 5 cubic yards of sand mix). Manufacturer will supply precise proportions.

Turf Pavers

Figure 5



Source: Adapted from Netlon Advanced Turf Systems

*Example of slit drains with engineered soil, for overflow parking and fire access roads. ATS 200 is a proprietary polypropylene mesh in a sandy growing medium by Netlon Ltd.**

- For some proprietary systems, materials are sourced locally and the patent-holder acts as project manager for the installation, using specially designed machines.
- Grass cover is established using pre-germinated seed, washed turf or conventional seed.
- Nonessential traffic should be kept off the area until grass is well-established.

Maintenance

- Generally, turf pavers and soil-amended turf can be mowed, irrigated and fertilized like any other turf area. Do not aerate.
- High-frequency traffic (a vehicle traveling over the same area three times or more daily) tends to establish a wear pattern. When allowed a "rest," however, the turf will quickly grow back to it's kept height.
- Some products will tolerate plowing providing skids are installed on the corner of the plow blades to raise the blade and keep it from coming into contact with the grass and potentially tearing the product out of the ground. Plow outfitted with a flexible plastic/rubber piece on the bottom of the blade may also be used.

** This mention does not constitute an endorsement of product.*

Turf Pavers

Sources

1. Center for Watershed Protection. 2001. "Alternative Pavers" and "Porous Pavement" fact sheets in *Stormwater Manager's Resource Center.* www.stormwatercenter.net. Ellicott City, MD.
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Green Rooftops

Description

Green rooftops are veneers of living vegetation installed atop buildings, from small garages to large industrial structures. Green rooftops (sometimes called eco-roofs) help manage stormwater by mimicking a variety of hydrologic processes normally associated with open space. Plants capture rainwater on their foliage and absorb it in their root zone, encouraging evapotranspiration and preventing much stormwater from ever entering the runoff stream. What water does leave the roof is slowed and kept cooler, a benefit for downstream water bodies. Green roofs are especially effective in controlling intense, short-duration storms and have been shown to reduce cumulative annual runoff by 50 percent in temperate climates.

Key considerations for implementing green roofs include structural and load-bearing capacity, plant selection, waterproofing and drainage or water storage systems.

All green rooftops include the following basic component layers, listed from the bottom up:

- Waterproofing and root barrier
- Insulation (optional)
- Drainage and filter layer
- Soil and plants

Green rooftops can be built in a variety of ways, but the simplest involves a relatively light system of drainage and filtering components and a thin layer of soil mix (2 to 4 inches), which is installed and planted with drought-tolerant herbaceous vegetation. Roofs built this way are called *extensive* systems.

More complex green rooftops, or *intensive* systems, employ deeper soils to accommodate tree and shrub root systems and structures to support human use. They require higher structural load capacity as

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	■

Water Quality

Pollution prevention

Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Green Rooftops

Source: Velazquez, 1999

well. For the purposes of this document, the information presented hereafter will be limited to the simpler *extensive* roof systems designed for lightweight overburden construction on flat and sloped roofs not meant for human use.

Despite centuries of use in Iceland and recent initiatives to encourage their use in Canada, Germany, France, Austria and Switzerland, green rooftops are relatively rare in this country and the market remains immature. However, several new and planned projects—including last year's retrofit of the Chicago City Hall and a 450,000-square-foot vegetated roof planned for a new Ford assembly plant in Dearborn, Michigan—are raising visibility and encouraging the nascent U.S. market for green roof technology. The Green Institute in Minneapolis is installing a vegetated roof; see Appendix B.

Advantages

- Green rooftops reduce and delay stormwater runoff.
- Help improve air quality by reducing CO^2 levels.
- Insulate buildings, reducing cost of both heating and cooling.
- Sound-absorbing and insulating properties can help make buildings and their surroundings quieter.
- Increase life expectancy of rooftop waterproofing due to protection from ultraviolet rays and mechanical impact.
- Reduce the urban heat island effect by cooling and humidifying surrounding air. They also help filter and bind airborne dust and other particles.
- Increase habitat for birds and butterflies, partially compensating for landscape lost to building development.
- Provide attractive views from other buildings.

Limitations

- Since water is being encouraged to remain on the roof, any damage to waterproofing materials may have serious consequences for a building. (At least one North American company offers an electronic leak detention system. See "Waterproofing," below, for other ways to reduce risk.)
- Can be expensive to design and construct, especially when retrofitting an existing building.
- Planting atop a sloped roof necessitates special erosion control structures.
- Maintenance for a green roof is likely to be higher than for a conventional roof.

Green Rooftops

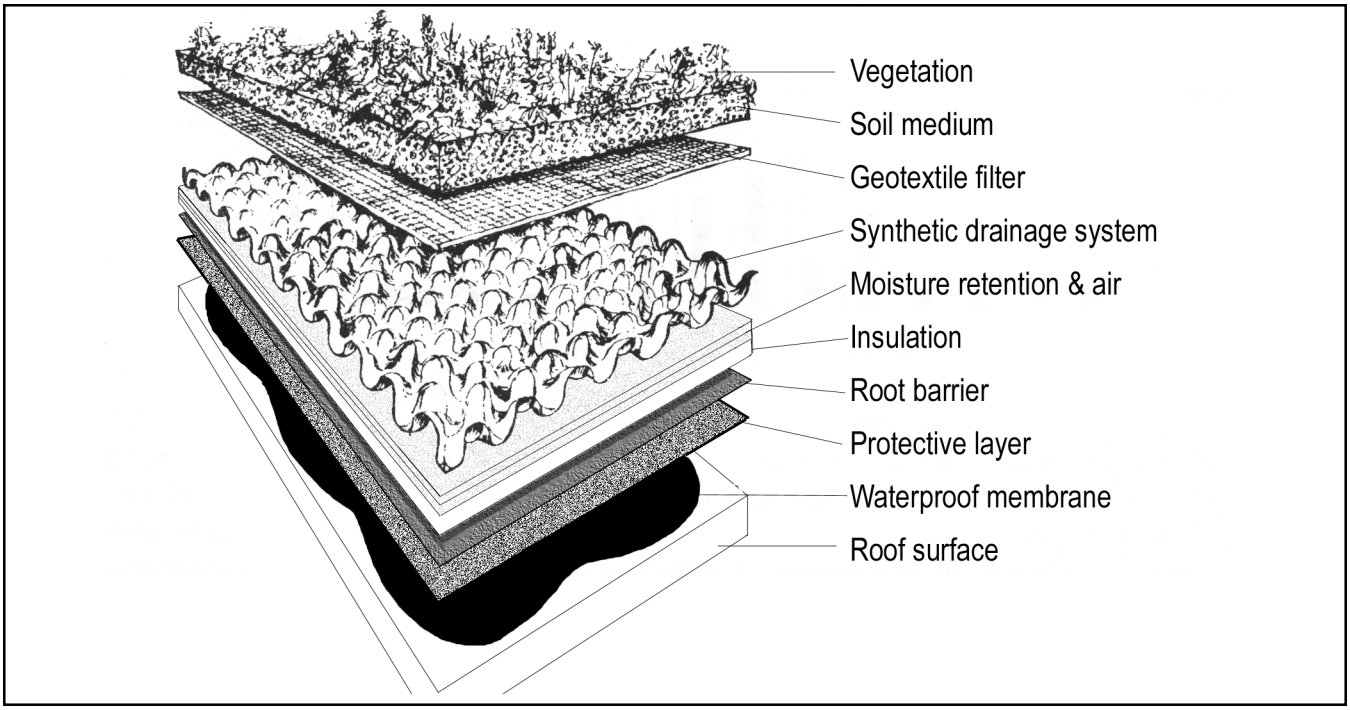

Figure 2: Monolithic Membrane Green Roof
Source: Adapted from Miller 1998 and American Hydrotech*

- Extreme sun and wind conditions present a challenge for plant survival.
- Weight of snow may limit applications to roofs with high-load-bearing capacity or where retrofit budgets are generous.

Requirements

Design

Roof Structure and Location Considerations

The load-bearing capacity of the underlying roof deck is a critical consideration in designing a vegetated rooftop. This means considering both dead load—the total weight of roof materials (including soil and plants) along with snow—and live load. For an extensive green roof, the live load includes people who will be atop the roof during maintenance procedures. Generally, green roofs weighing more than 17 pounds per square foot saturated require consultation with a structural engineer. Design of green roofs can circumvent some structural limitations by placing soil and plants over load bearing members. In retrofit applications, load capacities of existing roofs may be increased, but this is typically difficult and costly.

Flat roofs (or those with a pitch of up to 1.5 percent) are easiest to install and least complex. Those with steeper slopes usually require the addition of cross-battens to hold the drainage layers in place as well as more soil erosion control. With all rooftops, consider sun and shade conditions and

* *This mention does not constitute an endorsement of product.*

Green Rooftops

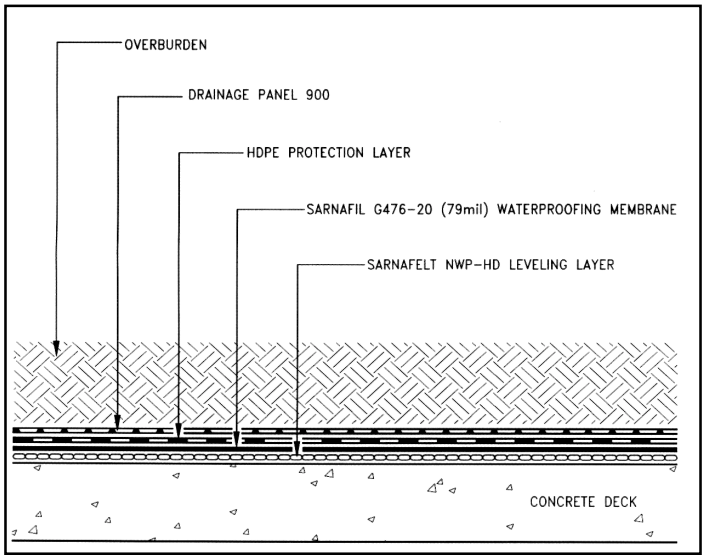

Figure 3: Sheet Membrane Green Roof
Source: Sarnafil*

Design (continued)

plan plantings accordingly; deeply shaded areas may not be suitable for extensive-roof plant species. The maximum slope for a green roof is about 25 percent.

Follow state and/or local standards with respect to wind resistance of rooftop elements. Since uplift pressures tend to be higher at roof corners and perimeters, these areas may be designed as "vegetation-free zones." Substrate soil can be protected from wind via erosion control mats anchored on or near the soil surface.

Fire resistance can be attained by installing soil as specified and, on larger structures, creating firebreaks/barriers a minimum of 130 feet apart. Non-vegetative materials, such as stone or pavers must be installed around all rooftop openings and at the base of all walls that contain openings.

Waterproofing

Monolithic membrane, a rubberized asphalt product applied as a hot liquid, is generally thought to provide superior waterproofing and easier maintenance. Since it is installed directly on the roofing deck, existing roofing must be completely removed.

Thermoplastic sheet membranes are typically installed over a vapor barrier and insulating layer. With certain limitations, sheet membranes may be installed over existing roofing, although manufacturers prefer that existing roofing be removed.

Protective layers are placed atop both types of waterproofing: a modified bituminous protective sheet for the monolithic membranes and high density polyethylene (HDPE) over sheet membranes.

To discourage roots from interrupting the waterproofing, a physical or chemical root barrier is installed over the protective layer. For extensive systems, with their relatively shallow-rooted plants, a thin physical layer is usually sufficient.

On monolithic membranes, a Styrofoam insulation layer may be installed above the root barrier.

Moisture Retention and Drainage

The drainage system, often consisting of recycled-polyethylene elements resembling egg crates, creates a series of small depressions that retain rainwater for plant uptake during dry periods and allow drainage of surplus water. Depth of the drainage layer varies, depending on level of runoff management desired and roof-deck load-bearing capacity.

** This mention does not constitute an endorsement of product.*

Green Rooftops

Source: Velazquez, 1999

Above the drainage system and below the soil, a geosynthetic filter mat prevents fine particles from being washed out of the overlying soil and compromising the drainage layer.

Soil

Soils for green roofs are lighter weight than typical soil mixes; they generally consist of 75 percent mineral and 25 percent organic material. They must be carefully formulated to meet oxygen, nutrient and moisture needs of plants as well as offer the appropriate pH level.

Plants

The range of plants suitable for use in rooftop landscapes is limited by the extremes of the rooftop microclimate, including high wind, drought and low winter temperature due to lack of ambient heat (normally retained in the ground). As a result, alpine or subalpine species are best suited to rooftop applications. These include a variety of sedums, wildflowers and grasses, some of which are listed below. All have shallow root systems, grow no higher and a foot tall and tolerate shallow soils.

3 Inches Soil Minimum	2 Inches Soil Minimum
Dianthus carthusianorum	Sedum album
Dianthus deltoides	Sedum floriferum
Dianthus plumarius	Sedum hybridum
Hieracium pilosella	Sedum reflexum
Koeleria glauca	Sedum sexangulare
Petrorhagia saxifrage	Sedum spurium
Sempervivum hybriden	
Thymus serpyllum	

In more elaborate schemes, infrastructure such as irrigation, increased insulation and venting from interior heat sources can be employed to overcome microclimate stressors.

Construction

- Correct and meticulous application of the waterproof membrane is essential to the viability of the rooftop. Special care must be taken to waterproof areas around flashings, walls and roof perimeter.
- It is essential to mark the position of the roof outlets before installing the protection layer, so that they can be located easily and the root barrier and protection mat cut out accordingly.
- A test for watertightness is usually conducted after membrane and before protective layer is installed.
- Temporary ballasting of individual components and erosion control may be necessary to avoid wind uplift during installation.

Green Rooftops

Requirements

Maintenance

- Weed at least twice annually. This will usually mean pulling any plants taller than a foot—typically tree seedlings.
- Some companies will conduct annual surveys of green roofs to verify that the waterproofing system remains watertight below the vegetated cover.

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Pavement Management

Source: Tennant Co.

Description

Streets and parking lots make up a significant portion of the total impervious area within a developed watershed, and most, if not all of these areas are directly connected to the storm drain system. Pollutants accumulate on these surfaces and are washed off during storm events, particularly during spring snowmelt. A 1993 study in Wisconsin indicated that streets and parking lots were responsible for 54 percent of total runoff volume in residential areas and 80 percent in commercial areas. The same study found that streets and parking lots were significant sources of runoff pollutants, including suspended solids, phosphorus, copper, zinc and fecal coliform.

This document focuses on applications appropriate for sites of five acres or less. For more in-depth discussion of municipal-level street sweeping, see *Best Practices for Street Sweeping* (Metropolitan Council, 1994).

Three main pavement-related maintenance strategies can help prevent these problems:

- *Sweeping.* When properly designed and implemented, sweeping programs can significantly reduce street and parking lot contributions to pollutant loads.
- *Alternative Products and Application Rates.* Minimizing sand and salt application rates and/or using alternative deicing products can help protect waterways and potentially reduce costs.

Purpose

Water Quantity	
Flow attenuation	**N/A**
Runoff volume reduction	**N/A**
Water Quality	
Pollution prevention	
Soil erosion	**N/A**
Sediment control	* ■
Nutrient loading	* ■
Pollutant removal	
Total suspended sediment (TSS)	* ■
Total phosphorus (P)	* ■
Nitrogen (N)	* ◧
Heavy metals	* ■
Floatables	* ■
Oil and grease	* ■
Other	
Fecal coliform	* ■
Biochemical oxygen demand (BOD)	* ■

* *Depends on timing and frequency of sweeping, and extent to which other measures are employed*

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Pavement Management

- *Other Prevention Measures.* A variety of measures will prevent accumulation of sediments, salts and other pollutants on pavement and stop them from washing off into storm drains and water bodies. These measures include prompt pavement repair, spill cleanup and appropriate snow management.

Sweeping

Sweeping is a common maintenance activity, often done primarily for aesthetic reasons. Sweeping has important water quality ramifications, however, and should be done in ways that increase its effectiveness for preventing sediment loading of runoff and, whenever possible, decreasing costs. Sweeping is most effective for removing coarse particles, leaves and trash.

Timing

- At minimum, pavement should be swept twice yearly: in early spring, to collect sand, salt and winter debris, and in fall, to capture leaves and other debris.
- Sweep as early in spring as possible (after snow has melted from an area) in order to capture sediment before it is washed away by spring rains.
- An additional sweeping in June, after trees drop seeds and flowers, will prevent a fair amount of phosphorus-laden runoff.
- Sweep after activities or in locations that generate debris, such as at construction entry points.
- When loading or unloading salt, sand, gravel or other granular materials, sweep the loading/unloading areas at the end of each day, as well as along the paths that the trucks use.

Source: Barr Engineering Co.

Excessive winter sanding can mean high sediment loading to runoff.

Figure 1

Equipment

- Broom sweepers are effective at picking up large particulate matter and cleaning wet street surfaces. They also cost less to operate than vacuum sweepers. Broom sweepers generally create airborne dust during their operation, which increases atmospheric loading.
- Vacuum sweepers are more effective for removing fine particles, which is important because many pollutants are adsorbed to them. However, vacuum sweepers have the disadvantage of being ineffective at cleaning wet street surfaces. For heavy loads, use a mechanical sweeper for large particles followed by regenerative-air cleaner.
- Consider equipment that can be converted to other uses, such as sanding and plowing in winter.

Pavement Management

- Install an automatic greasing system on sweepers to decrease maintenance time and reduce wear on critical parts, which can cause unscheduled maintenance and missed sweeping opportunities.

Source: American Sweeper Online

Techniques

- Sweep in a pattern that keeps spilled material from being pushed toward catch basin inlets
- Locate storage and disposal sites for the material collected during sweeping so it will not get back to the storm sewer systems.
- Before sweeping, manually rake sand from any adjacent turf areas onto the surface to be swept.
- Use a small pool of highly trained operators.

Residual Material

- Street sweepings may be reused by cleaning out leaves and other debris then mixing the sweepings with new salt/sand mixture for winter application to roads, parking lots or sidewalks. When screening sweepings for reuse in this way, use a small mesh for the final screening to ensure that all of the larger debris has been removed. (A 3/4-inch mesh will screen out much of the debris.)
- Recycle fall leaf sweepings by finding a composting or agricultural facility that will use them.
- Street sweepings may also be reused as daily cover material on sanitary or demolition landfills, but only those that have ground water monitoring systems. While sweeping residuals are not considered hazardous waste, a wide array of inorganic and organic pollutants are contained, so use caution in disposal.

Alternative Products and Application Rates

The sand and salt compounds applied to icy roads are easily carried into storm drain systems and receiving streams, especially during snowmelt. High salt concentrations are harmful to streams. Furthermore, road salt contains cyanide as an anti-caking agent; cyanide may cause acute or chronic toxicity to aquatic organisms. Since salts are soluble and mobile, they may run off before sweeping can begin. So in areas where salts pose a problem, alternative deicing products may help. However, these alternative products are usually more expensive than salt, and may have other environmental impacts, which need to be carefully weighed.

- Consider alternative deicers, such as calcium magnesium acetate (CMA), which, when used instead of road salt, has been shown to decrease sodium levels in groundwater. Be sure to consider their expense and potential environmental impacts prior to purchase.
- Use a deicer additive or replacement in order to reduce rate of application. A liquid organic product called Ice Ban,* derived from fermenting and distillation industries, has been shown to be cost-effective used as an additive (it can also be used alone). However, it has raised some concerns about BOD loading. If used alone, it must be applied prior to snowfall.

** This mention does not constitute an endorsement of product.*

- Apply deicers at the appropriate time to reduce rate of application. Applying before snow falls, based on forecasts, means less material is needed to melt snow. The drawback: if the forecast is inaccurate, the deicer will have been applied needlessly.
- Store salt and deicers on an impervious surface and protected from rainfall to eliminate contamination of runoff.
- Use clean sand, that is, sand free of fines, which are difficult to collect via sweeping and are more troublesome when they reach water bodies.
- Train operators to apply the minimum amount of sand necessary

Other Prevention Measures

Commercial and retail operators can help reduce and prevent accumulation of pollutants by:

- limiting exposure of materials and equipment to rain and snowfall by storing indoors or covering
- promptly cleaning up spills using dry instead of wet cleanup techniques.
- promptly repairing potholes and other pavement damage to help prevent erosion of subbase material.
- training workers about these principles

Snow Storage

Snow piles containing sand and salt that build up over the winter months, generate concentrated releases of sand and salt during spring snow melt conditions. Also, trash and debris usually accumulate in snow piles during snow plowing operations. Therefore, five months of potential pollution accumulation may occur over the winter months for rapid release in the spring.

- Plowed snow should not be directly discharged to lakes, streams or wetlands. Storage locations should be flat and well-drained in order to avoid direct drainage into surface waters.
- Pay attention to the location of snow piles, avoiding nearby surface runoff discharge points and impervious surfaces.
- Install berms, skimmers and detention ponds to settle sediment and trap debris.
- Place snow piles so as to avoid or divert surface water run-on from areas outside the snow piles.
- During spring melt conditions, visually observe the snow piles for runoff/run-on conditions and debris contained in the snow that may be subject to blowing.
- Do not pile snow into wooded areas, around trees or into vegetative buffers. The equipment operators usually try to get the snow as far into the area as possible and wind up striking the tree trunks. These injuries eventually lead to rotting of the trunks and premature tree death.

Pavement Management

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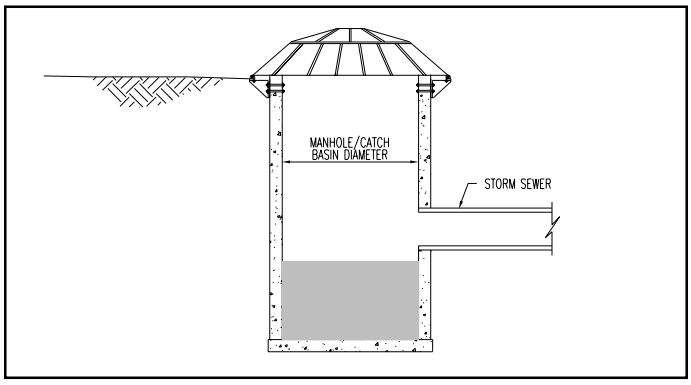
BMP Maintenance



Description

All BMPs require periodic maintenance to maintain and enhance their performance. This section summarizes some of the general maintenance of BMPs in this publication (see individual BMPs for details) as well as routine maintenance that should be applied to existing devices such as catch basins and ditches.

Maintenance schedules vary greatly depending on BMP location, surrounding land use and soil stability in the watershed. Some BMPs require sediment removal every two or three years, while others may not need attention for decades.

Sediment removal applies to pond and wetland systems as well as filtration systems such as grit chambers and surface sand filters. If not removed, sediment reduces storage capacity, short-circuiting removal function and resuspending previously settled particles.

Removing floatables helps prevent outlet structures from becoming blocked and changing hydraulics. It is also valuable from an aesthetic standpoint.

Vegetative maintenance applies to constructed wetlands, filter strips, wet and dry swales and bioretention facilities. Practices (which will differ depending on BMP and condition) include mowing, reseeding, resodding and removing dead plant material.

See Table 1a and 1b for a summary of maintenance on some of the most common BMPs.

Catch Basins

Catch basins, which function as “entrance chambers” to a storm sewer, often have a low area called a sump, which is intended to retain sediment. By trapping coarse sediment, the catch basin prevents solids from clogging the storm sewer or being washed into receiving waters.

Purpose

Water Quantity	
Flow attenuation	* ◧
Runoff volume reduction	* ◧
Water Quality	
Pollution prevention	
Soil erosion	* ◧
Sediment control	* ◧
Nutrient loading	* ◧
Pollutant removal	
Total suspended sediment (TSS)	* ■
Total phosphorus (P)	* ◧
Nitrogen (N)	* □
Heavy metals	* ◧
Floatables	* ◧
Oil and grease	* ◧
Other	
Fecal coliform	* □
Biochemical oxygen demand (BOD)	* □

* *Depends on timing and frequency of maintenance practices.*

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

However, these low areas must be cleaned out periodically to maintain their sediment-trapping ability. In addition to reducing coarse sediment loads, catch basin cleaning also reduces the load of oxygen-demanding substances (such as leaf debris) that reaches surface water.

It has been reported that once a sump is 40 to 60 percent full, any inflow could have a flushing effect and actually generate sediment loading in water passing through the catch basin (Pitt, 1985). The first flush of stagnant water and debris in the sewer system by the stormwater runoff may contain a high concentration of pollutants, such as metals and hydrocarbons. The sediment and debris flushed out may clog downstream stormwater conveyance systems.

The rate at which catch basins fill and the total amount of material collected during different cleaning frequencies is highly variable. In general, if the contributing watershed has active construction or other land uses that create high sediment loads, the catch basin should be cleaned more often than in stabilized areas.

Over a year's time, monthly cleaning removes about six times more sediment than cleaning annually. This can be accomplished either manually or with a vacuum truck.

Of course, there is additional cost associated with more frequent cleanouts. Preventive measures, such as street sweeping and reducing winter road sanding, may reduce deposition significantly, making annual cleanouts adequate. (See Pavement Management.)

Ditches

Roadside ditches can contribute significant sediment to runoff, both from channelization and erosion within the ditch and accumulated sediment and other fine debris from the road surface (especially if pavement is in poor repair). Timely maintenance of deteriorating roads and cleaning and stabilization of ditches can help to reduce pollutant loadings.

Ditches should be inspected at least annually. Periodic repairs may include reseeding or replanting and removing sediment. If problems recur, the ditches may need to be altered. Solutions may include reducing the length and slope of ditch runs and reducing the velocity of runoff by using check dams. (See Check Dams and Dry Swales.)

Sediment Disposal

Stormwater sediments removed from publicly owned systems generally do not meet the criteria of "hazardous waste." However, these sediments are contaminated with a wide array of organic and inorganic pollutants well beyond the levels of these pollutants in the raw storm water itself. Regardless of the source of these residual wastes from stormwater treatment, handling and disposal must be done with care.

- Sediments from constructed wetlands or ponds must be carefully removed to minimize turbidity, further sedimentation, or other adverse water-quality impacts.
- Sediments should be transported by motor vehicle only after they are dewatered.
- Hydraulically transported sediments should go only to a secure disposal facility designed to hold the entire volume of sediment and the transport water.
- Should a spill occur during transportation, prompt and thorough cleanup is important.

BMP Maintenance

BMP	Activity	Schedule
Retention Pond / Wetland[1]	• Cleaning and removal of debris after major storm events • Harvest excess vegetation • Repair of embankment and side slopes • Repair of control structure	Annual or as needed
	• Removal of accumulated sediment from forebays or sediment storage areas	5-year cycle, or as needed
	• Removal of accumulated sediment from main cells of pond once the original volume has been significantly reduced	5- to 10-year cycle
Detention Basin	• Removal of accumulated sediment • Repair of control structure • Repair of embankment and side slopes	Annual or as needed
Infiltration Trench[1]	• Cleaning and removal of debris after major storm events • Mowing[4] and maintenance of upland vegetated areas • Maintenance of inlets and outlets	Annual or as needed
Infiltration Basin[2]	• Cleaning and removal of debris after major storm events • Mowing[4] and maintenance of upland vegetated areas	Annual or as needed
	• Removal of accumulated sediment from forebays or sediment storage areas	3- to 5-year cycle
Sand Filters[3]	• Removal of trash and debris from control openings • Repair of leaks from the sedimentation chamber or deterioration of structural components • Removal of the top few inches of sand and cultivation of the surface when filter bed is clogged (only works for a few cycles) • Clean-out of accumulated sediment from filter bed chamber • Clean out of accumulated sediment from sedimentation chamber	Annual or as needed

-table continued on next page-

1. Modified from Livingston et al (1997)
2. Modified from Livingston et al (1997), based on infiltration trench requirements
3. Modified from Claytor and Schueler (1996)
4. Mowing may be required several times a year, depending on local conditions

Figure 1a: Recommended BMP Maintenance Schedules
Source: U.S. EPA, 1999

BMP Maintenance

BMP	Activity	Schedule
Bioretention[1]	• Repair of eroded areas • Mulching of void areas • Removal and replacement of all dead and diseased vegetation • Watering of plant material	Bi-Annual or as needed
	• Removal of mulch and application of a new layer	Annual
Grass Swale[2]	• Mowing[4] and litter and debris removal • Stabilization of eroded side slopes and bottom • Nutrient and pesticide use management • De-thatching swale bottom and removal of thatching • Disking or aeration of swale bottom	Annual or as needed
	• Scraping swale bottom, and removal of sediment to restore original cross section and infiltration rate • Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle
Filter Strip[3]	• Mowing[4] and litter and debris removal • Nutrient and pesticide use management • Aeration of soil in the filter strip • Repair of eroded or sparse grass areas	Annual or as needed

1. Modified from Prince George's County (1993)
2. Modified from Livingston et al (1997)
3. Modified from Livingston et al (1997), based on grass swale recommendations
4. Mowing may be required several times a year, depending on local conditions

Figure 1b: Recommended BMP Maintenance Schedules
Source: U.S. EPA, 1999

BMP Maintenance

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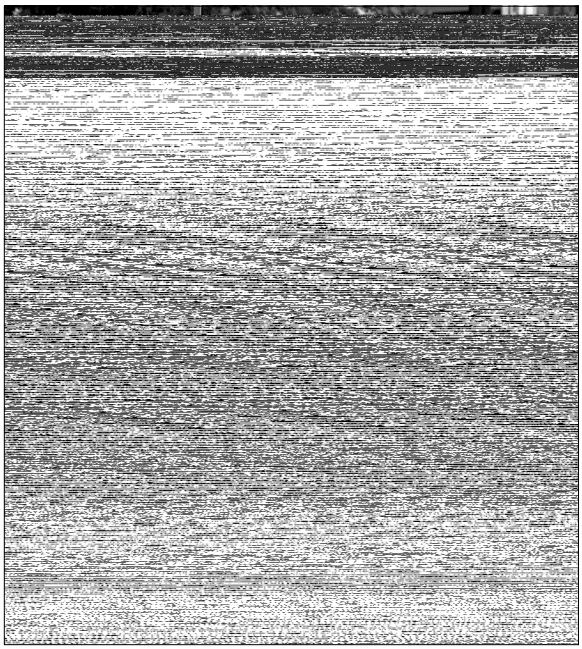
Landscape Design & Maintenance



Fred Rozumalski

Description

Numerous landscape design and maintenance practices negatively impact runoff quantity and downstream water body quality. Overapplication and misapplication of lawn fertilizer can result in nitrogen- and phosphorus-laden runoff to end up in the runoff stream and downstream water bodies, where they contribute to excess algae growth. Leaves, grass clippings and other plant debris can be carried away by runoff, finding their way into natural water bodies, where they decompose and release nutrients.

Due to their high aquatic toxicity, pesticides and herbicides can be a significant source of water quality impairment in streams, lakes and wetlands. U.S. pesticide usage was estimated at more than 1.2 billion pounds of active ingredients in 1995. A portion of this finds its way into stormwater runoff and ultimately into receiving water bodies through spray drift, transport with soils, solubilization by runoff and by spillage, dumping and improper disposal of containers and residuals.

A naturally diverse landscape discourages outbreaks of disease or insects, thus reducing or eliminating the need for chemical controls. Using plants that are well-adapted to local soil conditions, especially native plants with deep root systems, can eliminate the need for fertilizer, herbicides and pesticides. These plants also encourage infiltration and help prevent erosion.

Purpose

Water Quantity

- Flow attenuation
- Runoff volume reduction

Water Quality

Pollution prevention

- Soil erosion
- Sediment control
- Nutrient loading

Pollutant removal

- Total suspended sediment (TSS)
- Total phosphorus (P)
- Nitrogen (N)
- Heavy metals
- Floatables
- Oil and grease

Other

- Fecal coliform
- Biochemical oxygen demand (BOD)

- Primary design benefit
- Secondary design benefit
- Little or no design benefit

On-Lot Infiltration

Rainwater Gardens Plant List

Source:Fred Rozumalski

Mesic-Dry Soils (Sunny)

Native		*Non-Native*	
Butterfly Flower	*Asclepias tuberosa*	Yarrow "Coronation Gold"	*Achillea "Coronation Gold"*
Purple Prairie Clover	*Dalea purpureum*	Feather Reed Grass "Karl Foerster"	*Calamogrostis "Karl Foerster"*
Purple Coneflower	*Echinacea purpurea*	Daylily	*Hemerocallis spp.*
Bee balm	*Monarda fistulosa*	Blazingstar "Kobold"	*Liatris "Kobold"*
Little Bluestem	*Schizachyrium scoparium*	Silverfeather Grass	*Miscanthus sinensis*
Spiderwort	*Tradescantia bracteata*	Garden Phlox	*Phlox paniculata*
		Black-Eyed Susan "Goldsturm"	*Rudbeckia fulgida "Goldsturm"*

Mesic-Dry Soils (Shady)

Native		*Non-Native*	
Wild Columbine	*Aquilegia canadensis*	White Comfrey	*Symphytum grandiflorum*
Wild Geranium	*Geranium maculatum*	Tufted Hair Grass	*Deschamsia caespitosa*
Obedient Plant	*Physostegia virginiana*	Bigroot Geranium	*Geranium macrorrhizum*
Jacob's Ladder	*Polemonium reptans*	Daylily	*Hemerocallis spp.*
Solomon's Seal	*Polygonatum biflorum*	Hosta "Royal Standard"	*Hosta "Royal Standard"*
Zigzag Goldenrod	*Solidago flexicaulis*	Tigerlily	*Lilium tigrinum*
Canada Violet	*Viola canadensis*		
Culver's Root	*Veronicastrum virginium*		

Wet Soil (Sunny)

Native		*Non-Native*	
Giant Hyssop	*Agastache foeniculum*	Joe-Pye "Gateway"	*Eupatorium purpurescens "Gateway"*
Canada Anemone	*Anemone canadensis*	Daylily	*Hemerocallis spp.*
Marsh Milkweed	*Asclepias incarnata*	Siberian Iris	*Iris sibirica*
New England Aster	*Aster novae-angliae*	Tigerlily	*Lilium tigrinum*
Turtlehead	*Chelone glabra*	Switchgrass "Heavy Metal"	*Panicum virgatum "Heavy Metal"*
Joe-Pye Weed	*Eupatorium maculatum*		
Obedient Plant	*Physostegia virginianum*		
Boneset	*Eupatorium perfoliatum*		
Queen of the Prairie	*Filpendula rubra*		
Blueflag Iris	*Iris versicolor*		
Great Blue Lobelia	*Lobelia siphilitica*		
Switchgrass	*Panicum virgatum*		
Mountain Mint	*Pycnanthemum virginianum*		
Tall Meadow Rue	*Thalictrum dasycarpum*		
Culvers Root	*Veronicastrum virginicum*		
Golden Alexander	*Zizia aurea*		

On-Lot Infiltration

Wet Soils (Shady)

Native		***Non-Native***	
Cardinal Flower	*Lobelia cardinalis*	Pink Turtlehead	*Chelone layonii*
Ostrich Fern	*Matteuccia struthiopteris*	Daylily	*Hemerocallis spp.*
Virginia Bluebells	*Mertensia virginica*	Obedient Plant	*Physostegia virginiana*
Sensitive Fern	*Onoclea sensibilis*		

Shrubs (Sunny)

Black Chokeberry	*Aronia melanocarpa*
Red-Osier Dogwood	*Cornus serecia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens "Annabelle"*
Pussy Willow	*Salix discolor*
High Bush Cranberry	*Viburnum trilobum*

Shrubs (Shady)

Black Chokeberry	*Aronia melanocarpa "alata"*
Red-Osier Dogwood	*Cornus sericia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens "Annabelle"*

On-Lot Infiltration

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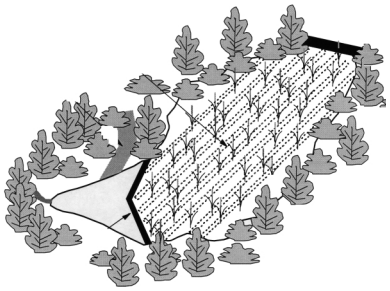
Infiltration Basins



Description

An infiltration basin is stormwater runoff impoundment designed to capture a stormwater runoff volume, hold this volume and infiltrate it into the ground over a period of days. It does not retain a permanent pool of water. Infiltration basins are typically off-line, end-of-pipe BMPs. A flow splitter or weir is usually used to divert runoff from a storm sewer system into the infiltration basin.

Infiltration basins in this BMP Section refer to end-of-pipe infiltration systems that treat stormwater runoff from a few lots or properties as opposed to rainwater gardens which are primarily used for a single lot application (see the On-Lot Infiltration BMP Section for information on this type of BMP).

A key feature of an infiltration basin is its vegetation. It is important to vegetate the bottom of the basin with deep-rooted plants to increase the infiltration capacity of the basin. Roots create small conduits for water to infiltrate. The root penetration and thatch formation of the vegetation maintains and may enhance the original infiltration capacity. Dense vegetation will also impede soil erosion and scouring of the basin floor.

Infiltration basins are not appropriate for areas that contribute high concentrations of sediment, or suspended solids, without adequate pretreatment. Excessive sediment can clog the basin and take up storage volume.

Infiltration basins require pretreatment of stormwater in order to remove as many of the suspended solids from the runoff as possible before the water enters the basin. Pretreatment, such as grit chambers, swales with check dams, filter strips, or a sedimentation basin should be a fundamental component of any BMP system relying on infiltration. Good housekeeping measures should also be investigated (e.g., street sweeping, reduction of sanding or salting practices, etc.). Public education with respect to street and driveway sediments should be provided in areas where an infiltration basin is proposed.

Purpose

Water Quantity	
Flow attenuation	◧
Runoff volume reduction	■
Water Quality	
Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollutant removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	■
Nitrogen (N)	■
Heavy metals	■
Floatables	◧
Oil and grease	◧
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Infiltration Basins

The design storm for an infiltration basin is typically a frequent, small storm such as the 1-year event. This provides treatment for the "first flush" of stormwater runoff. Infiltration basins provide total peak discharge, runoff volume and water quality control for all storm events equal to or less than the design storm. This infiltration reduces the volume of runoff, removes many pollutants and provides stream baseflow and groundwater recharge.

Infiltration basins have limited capabilities for controlling peak discharge for storms greater than the design storm. Because infiltration basins will not significantly affect peak discharges of runoff, they are best used in conjunction with other BMPs; downstream detention is often still needed to meet peak-runoff-rate requirements.

Dissolved pollutants are effectively controlled for storm events less than the design storm, but these substances may not be removed from the runoff water as it infiltrates, and some of them could move to the groundwater. For this reason, the impact of infiltrated runoff on the groundwater should be considered, although in most cases, the magnitude of this impact is unknown. Chloride from road salt is an example of a soluble material that will not be removed during the infiltration process. Currently, there is much disagreement as to whether chlorides do indeed pose a significant threat to groundwater. A general guideline for groundwater protection is to design infiltration basins with the bottom of the basin a minimum of 3 feet above the seasonally high groundwater table. This is consistent with the MPCA's guidelines for septic systems (MPCA, 2000). If the water table is too close to the ground surface, infiltration practices should not be used.

Figure 1 provides a schematic of a typical infiltration basin. Figure 2 shows an infiltration basin with pretreatment in the form of a settling pond.

Advantages

- Reduces the volume of runoff from a drainage area
- Can be very effective for removing fine sediment, trace metals, nutrients, bacteria, and oxygen-demanding substances (organics)
- Reduces downstream flooding and protects streambank integrity
- Reduces the size and cost of downstream stormwater control facilities and/or storm drain systems by infiltrating stormwater in upland areas
- Provides groundwater recharge and baseflow in nearby streams
- Reduces local flooding
- Appropriate for small sites (2 acres or less)

Limitations

- Potentially high failure rates due to improper siting, design and lack of maintenance, especially if pretreatment is not incorporated into the design
- Depending on soil conditions and groundwater depth, a risk of groundwater contamination may exist
- Not appropriate for treating significant loads of sediment and other pollutants due to the potential for clogging

Infiltration Basins

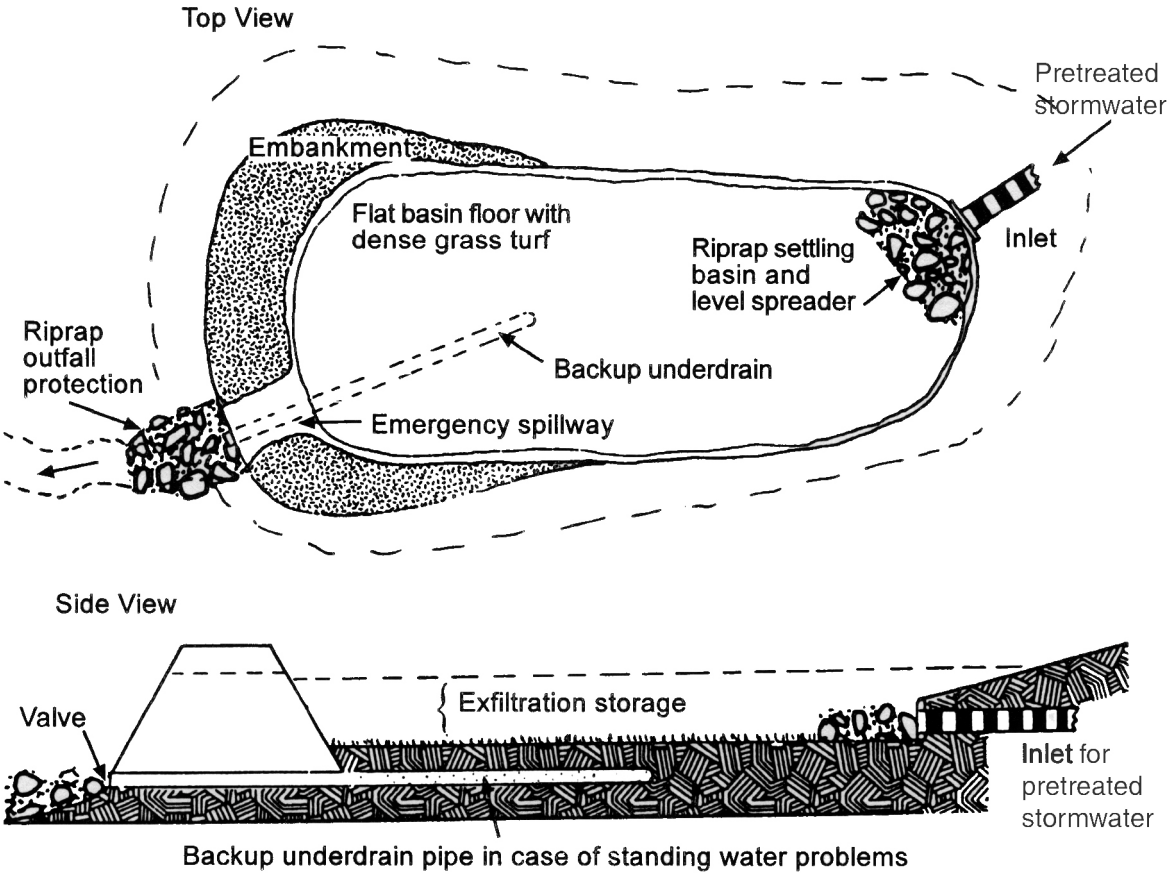


Figure 1: Typical Infiltration Basin

Source: Schueler, 1987

- Not appropriate for industrial or commercial sites where the release of large amounts or high concentrations of pollutants are possible
- Requires a flat, continuous area
- Requires frequent inspection and maintenance

Design

Infiltration basins are generally known to have high failure rates. Such failure rates can be avoided with proper design, taking the following into consideration:

- Careful site selection (discussed later, in the Site Sensitivity Analysis section)
- Incorporation of pretreatment and a bypass for high-flow events

Infiltration Basins

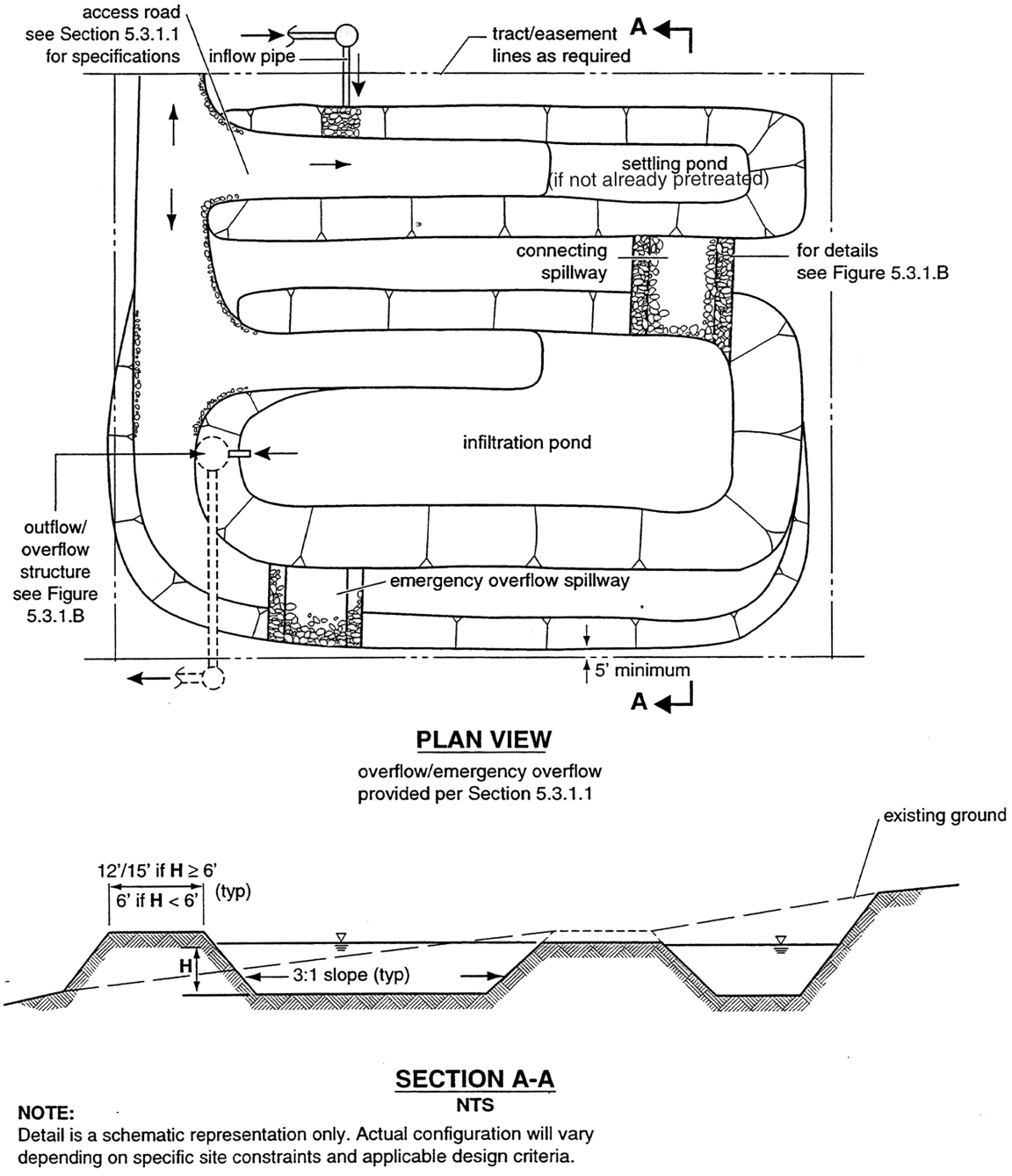


Figure 2: Infiltration Basin with Settling Pond Pretreatment

Source: Schueler, 1987

Infiltration Basins

Design (continued)

- Treatment of a small drainage area (lower sediment loadings)
- Careful consideration of depth of ponding and inundation times that reflect plant tolerances
- Good construction techniques that prevent smearing, over-compaction, and operation of the basin during the construction period
- Performance of regular maintenance

All of these topics are discussed in further detail below.

Site Sensitivity Analysis

Before an infiltration system can be designed, a site sensitivity analysis must be performed. This evaluation may eliminate an infiltration practice from consideration because of soil characteristics or potential effects on groundwater. Because of varying geologic settings, a site evaluation needs to be tailored to the specific site conditions. A team approach to this evaluation is recommended where various disciplines such as engineering, hydrogeology and soil science are represented.

The applicability of infiltration basins on a site depends on numerous site factors, including soils, slope, depth to water table, depth to bedrock or impermeable layer, contributing watershed area, land use, proximity to wells, surface waters, foundations, and others. Generally, infiltration basins are suitable to sites with gentle slopes, permeable soils, relatively deep bedrock and groundwater levels, and a small contributing watershed area (less than 2 acres, ideally).

When performing a site evaluation, the following items should be considered:

- Runoff water quality: If runoff water will contain a significant concentration of soluble pollutants that could contaminate groundwater, an infiltration basin should not be used. Specifically, infiltration basins are not recommended for industrial and commercial land uses since there is a high potential for groundwater contamination from chemical spills and maintenance (salting and sanding) activities. In site-specific cases where infiltration basins are deemed acceptable for these land uses, the design must be located off-line and incorporate some form of upstream treatment (e.g., an upstream oil-grit separator or sand filter).
- Degree of detail: The level of detail required for the study should be considered. For instance, a small structure receiving runoff from a rooftop will not require as much detail as a structure serving a larger area and having a higher potential pollutant load.
- Geologic (groundwater) sensitivity: A site with a highly sensitive geology, such as one with a carbonate or surficial sand aquifer, may eliminate this practice from consideration.
- Depth to water table and bedrock: The seasonally high water table must be far enough below the bottom of the infiltration basin (at least 3 feet) to allow the structure to function hydraulically and to allow trapping and treatment of pollutants by the soil. Similarly, the bottom of the infiltration basin should be at least 3 feet from bedrock, although in the case of fractured bedrock, separations up to 10 feet may be required. This minimum separation distance is required to trap or treat pollutants before they reach the groundwater or bedrock and to maintain vegetation in the basin (MPCA, 2000).

Infiltration Basins

Design (continued)

- Proximity to drinking water wells and building foundations: Basins should be located at least 150 feet away from drinking water wells to limit the possibility of groundwater contamination, and should be situated at least 10 feet downgradient and 100 feet upgradient from building foundations to avoid potential seepage problems.
- Soil infiltration rate: The infiltration rate of the soil must be great enough to drain the structure in a reasonable amount of time, generally 72 hours or less. Sites with clayey soils are not appropriate for infiltration basins. Infiltration rates are discussed in further detail below. If the infiltration rate of the site's soils are not acceptable, the filtration family of BMP systems should be considered.
- Size of the tributary drainage area: Although infiltration basins were originally designed to accommodate larger drainage areas, research which has been undertaken to date indicates that large-scale infiltration is not feasible. One of the main problems with centralized infiltration basins is that water from a large area is expected to infiltrate into a relatively small area. This does not reflect the natural hydrologic cycle and generally leads to problems (groundwater mounding, clogging, compaction). For these reasons, the contributing drainage area to any individual infiltration basin should be restricted to 2 acres or less.

General Design Considerations

Design Volume

Infiltration basin systems infiltrate a portion of the runoff from a rain event (usually the first flush or up to the first inch) while the remaining runoff bypasses the infiltration basin. The design infiltration volume can be calculated in many ways. Ultimately, the magnitude of the design infiltration volume depends on local authorities' practices and requirements.

Off-Line Placement

The purpose of the basin is to temporarily store surface runoff for a specific design frequency storm and allow it to infiltrate through the bottom and sides of the basin. A flow splitter or weir is usually used to divert runoff into an off-line infiltration basin. Infiltration basins provide total peak discharge, runoff volume and water quality control for all storm events equal to or less than the design storm. Storm events greater than the design storm simply continue down the larger conveyance system, bypassing the infiltration basin.

Pretreatment

Infiltration basins are susceptible to high failure rates due to clogging from sediments, and therefore require pretreatment of stormwater in order to remove as much of the suspended solids from the runoff as possible before it enters the basin. Pretreatment, such as grit chambers, swales with check dams, filter strips, or sediment forebays/traps should be a fundamental component of any BMP system relying on infiltration. Even when infiltrating rooftop runoff, it is a practical decision to implement some form of pretreatment to remove sediments, leaf litter, and debris. This pretreatment will help to ensure the proper functioning of the infiltrating facility and allow for longer periods between maintenance. When designed properly, pretreatment devices may remove some 25–30% of sediment loads. Figure 2 shows and infiltration basin with pretreatment in the form of a settling pond.

Infiltration Basins

Infiltration Rate

The soils of a prospective site are an important consideration when determining the suitability for infiltration. County soil surveys are useful for preliminary screening of a site for soil infiltration rate. The Natural Resource Conservation Service (formerly the Soil Conservation Service) Soil Group is found in the National Engineering Handbook. Conservative estimates of infiltration rates for a range of hydrologic soil groups (A through D) have been developed for some Minnesota authorities and are shown below (Riley-Purgatory-Bluff Creek Watershed District, 1999).

Soil Group	Rate (in/hr)	Max. Water Depth (ft)
A	0.38	2
B	0.23	1.4
C	0.1	0.6
D	0.03	0.2

If these estimates are deemed too conservative for the site, a geologic investigation of the specific site should be conducted to verify higher infiltration rates. Infiltration rates should be measured in situ according to the standards presented in:

- *Annual Book of ASTM Standards*, 1997, Section 4, Vol 4.08, Soil and Rock (I): Designation D 3385-94, Standard Test Method for Infiltration Rate of Soils in Field Using a Double-Ring Infiltrometer, pp 331-337.
- *Annual Book of ASTM Standards,* 1998, Section 4, Vol 4.09, Soil and Rock (II): Designation D 5093-90, Standard Test Method for Field Measurement and Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring, pp 87-92.
- Johnson, A.I., 1963, "A field method for measurement of infiltration," United States Geological Survey, Water-Supply Paper, W 1544-F, p. F1-F27.

The depth of water within the infiltrometer should be maintained at the following depths:

Hydrologic Soil Type	Water Depth (Inches)
A	18
B	9
C	4
D	1

Notes on alternative infiltration measurement methods:

- Alternative methods other than reference standards should use a double-ring apparatus and be acceptable to local authorities.

Infiltration Basins

Design (continued)

- Proposed alternative infiltration rates must be representative of vertical water infiltration through the soil surface (values that include lateral flow are not acceptable).
- Values that should not be used as alternative infiltration rates include, but are not limited to, the following: hydraulic conductivity, saturated hydraulic conductivity, transmissivity, permeability and percolation rate.

Designers should use their best judgement to determine if the slowest or average measured infiltration rate in the proposed basin area should be used for the design of the basin.

Where feasible, larger-scale infiltration measurements are encouraged. Procedures such as the Pilot Infiltration Test are described in the State of Washington's Stormwater Management Manual (Washington State Department of Ecology, 1999). This document is currently available on the internet at www.ecy.wa.gov. This type of procedure can minimize some of the error associated with smaller-scale tests and provide an indication of a longer-term infiltration rate that better represents the future conditions of the site.

Duration of Ponding:

The depth of the infiltration basin should be adjusted so that maximum drain time is 72 hours for the total runoff volume. However, certain types of vegetation (turf, for example) will require a shorter ponding duration to survive storm events. The design ponding duration should be determined by plant inundation tolerances.

Average Depth

After the infiltration rate of the soil has been determined, the maximum depth of the infiltration basin can be calculated with the following equation:

$$d_{max} = (f) * (T_p)$$

Where: d_{max} = maximum design depth (inches),

f = soil infiltration rate (in/hr), and

T_p = design ponding time (hours).

The maximum depth and ponding time of the infiltration area should promote the survival of vegetation. The maximum depth should be no greater than 2 feet; the ponding time no greater than 72 hours.

In recent monitoring studies (Galli, 1992) one of the causal factors of failure was noted to be the depth of water retained in the basin. The weight of the water is thought to compact the basin, decreasing its infiltration potential. The depth of storage should be limited to a maximum 2 feet in order to minimize the compaction of the basin.

Basin Slopes:

The bottom of the basin should be graded as flat as possible to provide uniform ponding and infiltration of the runoff across the floor. The side slopes of the basin should be no steeper than 3H:1V (flatter slopes are preferred) to allow for proper vegetative stabilization, easier mowing, easier access, and better public safety. Designs for infiltration basins should emphasize accessibility and ease of maintenance.

Infiltration Basins

Basin Shape

The length and width of the basin will be determined by the characteristics of the site in question (topography, size and shape). A desirable length-to-width ratio for an infiltration basin is 3:1 or greater.

Vegetation

A key feature of an infiltration basin is its vegetation. It is important to vegetate the bottom of the basin with deep-rooted plants to increase the infiltration capacity of the basin. Roots create small conduits for water to infiltrate. The root penetration and thatch formation of the vegetation maintains and may enhance the original infiltration capacity. Soluble nutrients are taken up during plant growth, improving the pollutant-removal capacity of the basin. Dense vegetation will also impede soil erosion and scouring of the basin floor.

Immediately following basin construction, the bottom and side slopes of the basin should be stabilized with a dense stand of water-tolerant grass. Use of low-maintenance, rapidly germinating grasses, such as red top (*Agrostis alba*) can be used. Likewise, vegetative buffers around the perimeter of the basin are recommended for erosion control and additional sediment and nutrient removal. A diversity of plant species should be planted to allow for best survivability. Plants that are tolerant of both wet weather and drought should be used. Plantings in an infiltration basin should be able to withstand periods of ponding and maintain or enhance the pore space in the underlying soils. A list on the last page of this BMP section provides some plant recommendations based on different site conditions (Rozumalski, 2001).

Inflow/Bypass

If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice must be designed as an off-line practice.

To prevent incoming flow velocities from reaching erosive levels, which can scour the basin floor, inlet channels to the basin should be stabilized. Riprap may be used for this purpose. The riprap should be designed to terminate in a broad apron, which spreads the runoff more evenly over the basin surface to promote better infiltration.

A bypass system should be implemented for all infiltration basins. A bypass flow path or pipe should be incorporated in the design of an infiltration basin to convey high flows around the basin. This will necessitate the construction of a flow splitter upstream of the basin. The bypass serves several functions. Specifically, the bypass can be used as the normal outlet during 1) stabilization of the site (while the inlet to the basin is blocked off), 2) basin maintenance and 3) winter conditions.

Overflow

All infiltration basins must have an emergency spillway capable of passing runoff from large storms without damage to the impounding structure. The overland flow path of surface runoff exceeding the capacity of the infiltration system should be evaluated to preclude erosive concentrated flow. If computed flow velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography.

Groundwater Mounding:

Calculations to determine groundwater mounding may be necessary in cases where slope stability is a concern and/or a high water table is encountered. A hydrogeologist should be consulted about the potential for groundwater mounding in these areas. The results from groundwater mounding calculations should be regarded as an indication of the mounding potential rather than as an accurate representation of the actual mounding depth.

Infiltration Basins

Design (continued)

Cold Weather Considerations

Consideration should be given to the operation of infiltration basins during the winter period. Winter sanding of roads can clog an infiltration basin without adequate pretreatment, and winter salting will increase the potential for the chloride contamination of groundwater.

If infiltration practices are used as a stand-alone, all-season water quality treatment facility, then oversizing (to account for reduced infiltration rates) and/or extended pretreatment should be considered. Doubling the storage volume for surface infiltration devices is recommended. Redundant pretreatment (more than one pretreatment device in series) is recommended for all infiltration facilities receiving runoff from roads.

Another option is the use of a seasonally operated facility (Oberts, 1994). A seasonally operated infiltration basin combines several techniques to improve the performance of infiltration practices in cold climates. Two features—an underdrain system and level control valves—are useful in cold climates. In the beginning of the winter season, the level-control valve is opened and the soil is drained. As the snow begins to melt in the spring, the underdrain and the level-control valves are closed. The snowmelt is infiltrated until the capacity of the soil is reached. Then the facility acts as a detention facility, providing storage for particles to settle.

Infiltration Basins Plant List

Source: Fred Rozumalski

Mesic-Dry Soils (Sunny)

Native		***Non-Native***	
Butterfly Flower	*Asclepias tuberosa*	Yarrow "Coronation Gold"	*Achillea "Coronation Gold"*
Purple Prairie Clover	*Dalea purpureum*	Feather Reed Grass "Karl Foerster"	*Calamogrostis "Karl Foerster"*
Purple Coneflower	*Echinacea purpurea*	Daylily	*Hemerocallis spp.*
Bee balm	*Monarda fistulosa*	Blazingstar "Kobold"	*Liatris "Kobold"*
Little Bluestem	*Schizachyrium scoparium*	Silverfeather Grass	*Miscanthus sinensis*
Spiderwort	*Tradescantia bracteata*	Garden Phlox	*Phlox paniculata*
		Black-Eyed Susan "Goldsturm"	*Rudbeckia fulgida "Goldsturm"*

Mesic-Dry Soils (Shady)

Native		***Non-Native***	
Wild Columbine	*Aquilegia canadensis*	White Comfrey	*Symphytum grandiflorum*
Wild Geranium	*Geranium maculatum*	Tufted Hair Grass	*Deschamsia caespitosa*
Obedient Plant	*Physostegia virginiana*	Bigroot Geranium	*Geranium macrorrhizum*
Jacob's Ladder	*Polemonium reptans*	Daylily	*Hemerocallis spp.*
Solomon's Seal	*Polygonatum biflorum*	Hosta "Royal Standard"	*Hosta "Royal Standard"*
Zig Zag Goldenrod	*Solidago flexicaulis*	Tigerlily	*Lilium tigrinum*
Canada Violet	*Viola canadensis*		
Culver's Root	*Veronicastrum virginium*		

Infiltration Basins

Wet Soil (Sunny)

Native		***Non-Native***	
Giant Hyssop	*Agastache foeniculum*	Joe-Pye "Gateway"	*Eupatorium purpuescens "Gateway"*
Canada Anemone	*Anemone canadensis*	Daylily	*Hemerocallis spp.*
Marsh Milkweed	*Asclepias incarnata*	Siberian Iris	*Iris sibirica*
New England Aster	*Aster novae-angliae*	Tigerlily	*Lilium tigrinum*
Turtlehead	*Chelone glabra*	Switchgrass "Heavy Metal"	*Panicum virgatum "Heavy Metal"*
Joe-Pye Weed	*Eupatorium maculatum*		
Obedient Plant	*Physostesia virginianum*		
Boneset	*Eupatorium perfoliatum*		
Queen of the Prairie	*Filpendula rubra*		
Blueflag Iris	*Iris versicolor*		
Great Blue Lobelia	*Lobelia siphilitica*		
Switchgrass	*Panicum virgatum*		
Mountain Mint	*Pycnanthemum virginianum*		
Tall Meadow Rue	*Thalictrum dasycarpum*		
Culvers Root	*Veronicastrum virginicum*		
Golden Alexander	*Zizia aurea*		

Wet Soils (Shady)

Native		***Non-Native***	
Cardinal Flower	*Lobelia cardinalis*	Pink Turtlehead	*Chelone layonii*
Ostrich Fern	*Matteuccia struthiopteris*	Daylily	*Hemerocallis spp.*
Virginia Bluebells	*Mertensia virginica*	Obedient Plant	*Physostegia virginiana*
Sensitive Fern	*Onoclea sensibilis*		

Shrubs (Sunny)

Black Chokeberry	*Aronia melanocarpa*
Red-Osier Dogwood	*Cornus serecia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens "Annabelle"*
Pussy Willow	*Salix discolor*
High Bush Cranberry	*Viburnum trilobum*

Shrubs (Shady)

Black Chokeberry	*Aronia melanocarpa "alata"*
Red-Osier Dogwood	*Cornus serecia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens "Annabelle"*

Infiltration Basins

Requirements

Sequencing

Care should be taken during construction to minimize the risk of premature failure of the infiltration basin. This failure is caused by the deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper sequencing.

- Ideally, construction of the infiltration basin should take place after the site has been stabilized.
- No runoff should enter the infiltration basin prior to completion of construction and the complete stabilization of the tributary areas.
- Diversion berms or silt fence should be placed around the perimeter of the infiltration basin during all phases of construction. Sediment and erosion controls should be used to keep runoff and sediment away from the infiltration basin.
- Initial excavation of the basin should be carried out to within one foot of the final grade of the basin floor. Final excavation of the basin floor should be delayed until all disturbed areas in the drainage area are stabilized. All excavation should be performed by equipment with tracks exerting relatively light pressures. This will prevent compacting of the basin floor, which would reduce the infiltration capacity.
- In order to avoid soil compaction, absolutely no equipment should be driven in the area of the basin before and after its construction.
- After final grading, the basin floor should be tilled to a depth of at least 6 inches to provide a well-aerated, porous surface texture. Six inches of compost should be tilled in at this time if soils are even the slightest bit compacted. This will help to facilitate infiltration and root growth.
- During and after excavation, all excavated materials should be placed downstream, away from the infiltration basin, to prevent redepositing during runoff events.
- Immediately following basin construction, the bottom and side slopes of the basin should be stabilized with a dense stand of appropriate plants.

Construction

Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction. The construction sequence and specifications for each infiltration practice must be precisely followed.

- Infiltration basins should not be used as temporary sediment traps during construction.
- Infiltration basins will operate as designed only if they are constructed properly. There are three main rules that must be followed during the construction of an infiltration basin:
  - Basins should be constructed at the end of development construction
  - Smearing of the soil at the interface with the basin floor must be avoided and/or corrected by raking or rototilling
  - Compaction of the basin during construction must be minimized

Infiltration Basins

- Before the development site is graded, the area of infiltration basin should be roped off to prevent heavy equipment from compacting the underlying soils.
- Light earth-moving equipment should be used to excavate the infiltration basin. Use of heavy equipment causes compaction of the soils beneath the basin floor and side slopes, resulting in reduced infiltration capacity. Since some compaction of soils will occur during construction, the basin floor should be tilled with a rotary tiller to restore infiltration rates after final grading.

Maintenance

Maintenance is required for the proper operation of infiltration basins, as it is with all BMPs. Plans for infiltration basins should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule. The use and regular maintenance of pretreatment BMPs will significantly minimize maintenance requirements for the basin.

- Pretreatment devices associated with basins should be inspected and cleaned at least twice a year, and ideally every other month.
- Once the basin has gone on-line, inspections should occur after every major storm for the first few months to ensure proper stabilization and function. Attention should be paid to how long water remains standing in the basin after a storm; standing water within the basin more than 72 hours after a storm indicates that the infiltration capacity may have been overestimated. Factors responsible for clogging (such as upland sediment erosion and excessive compaction of soils) should be repaired immediately. Also, the newly established vegetation should be inspected several times to determine if any remedial actions (reseeding, irrigation, etc.) are necessary.
- Thereafter, the infiltration basin should be inspected at least twice per year. Important items to check include: differential accumulation of sediment, erosion of the basin floor, condition of riprap and the health of the vegetation. Eroded or barren spots should be replanted immediately after inspection to prevent additional erosion and accumulation of sediment.
- Sediment removal within the basin should be performed when the sediment is dry enough so that it is cracked and readily separates from the basin floor. This also prevents smearing of the basin floor.
- Light equipment, which will not compact the underlying soil, should be used to remove the top layer of sediment. The remaining soil should be tilled and revegetated as soon as possible.
- Vegetation should be maintained to control weed growth and maintain the health of the vegetation in the basin. Weed once monthly during the first two growing seasons. After that, weeding two or three times per growing season may suffice.

Infiltration Basins

Sources

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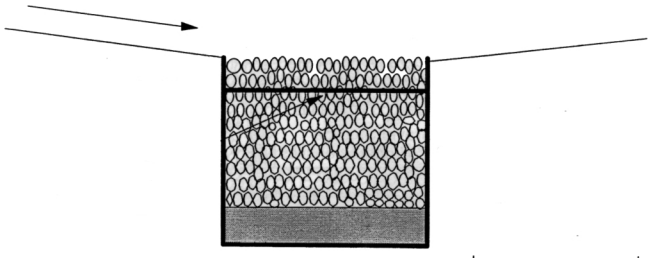
Infiltration Trenches



Description

Infiltration trenches are shallow (3- to 12-foot) excavations that are lined with filter fabric and filled with stone to create underground reservoirs for stormwater runoff from a specific design storm. The runoff gradually percolates through bottom and sides of the trench into the surrounding subsoil over a period of days. Infiltration trenches are typically implemented at the ground surface to intercept overland flows. Runoff can be captured by depressing the trench surface or by placing a berm at the down gradient side of the trench.

Infiltration trenches in this BMP Section refer to surface trenches that collect sheet flow from a few lots or properties as opposed to soakaway pits which are primarily used for a single lot application (see the On-Lot Infiltration BMP Section for information on this type of BMP).

Infiltration trenches require pretreatment of stormwater in order to remove as much of the suspended solids from the runoff as possible before it enters the trench. Pretreatment practices, such as grit chambers, swales with check dams, filter strips, or sediment forebays/traps should be a fundamental component of any BMP system relying on infiltration. Source controls should also be investigated (e.g., eliminate excessive sanding/salting practices). Public education with respect to street/driveway sediments should be provided in areas where an infiltration trench is proposed.

The design storm for an infiltration trench is typically a frequent, small storm such as the 1-year event. This provides treatment for the "first flush" of stormwater runoff. Infiltration trenches provide total peak discharge, runoff volume and water quality control for all storm events equal to or less than the design storm. This infiltration reduces the volume of runoff, removes many pollutants and provides stream baseflow and groundwater recharge.

Infiltration trenches have limited capabilities for controlling peak discharge for storms greater than the design storm. Because infiltra-

Purpose

Water Quantity	
Flow attenuation	◧
Runoff volume reduction	■
Water Quality	
Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollutant removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	■
Nitrogen (N)	■
Heavy metals	■
Floatables	◧
Oil and grease	◧
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Infiltration Trenches

tion trenches will not significantly impact peak discharges of runoff, they are best used in conjunction with other BMPs; downstream detention is often still needed to meet peak runoff rate requirements.

Dissolved pollutants are effectively controlled for storm events less than the design storm, but these substances may not be removed from the runoff water as it infiltrates, and a portion could move to the groundwater. For this reason, the impact of infiltrated runoff on the groundwater should be considered, although in most cases, the magnitude of this impact is unknown. Chloride from road salt is an example of a soluble material that will not be removed during the infiltration process. Currently, there is much disagreement as to whether chlorides do, indeed, pose a significant threat to groundwater. A general guideline for groundwater protection is to design infiltration trenches with the bottom of the trench a minimum of 3 feet above the seasonally high groundwater table. This is consistent with the MPCA's guidelines for septic systems (MPCA, 2000). If the water table is too close to the ground surface, infiltration practices should not be used.

Figure 1 provides a schematic of a typical infiltration trench. Figures 2 and 3 illustrate two different examples of infiltration trench layouts- in a parking lot and in a median strip.

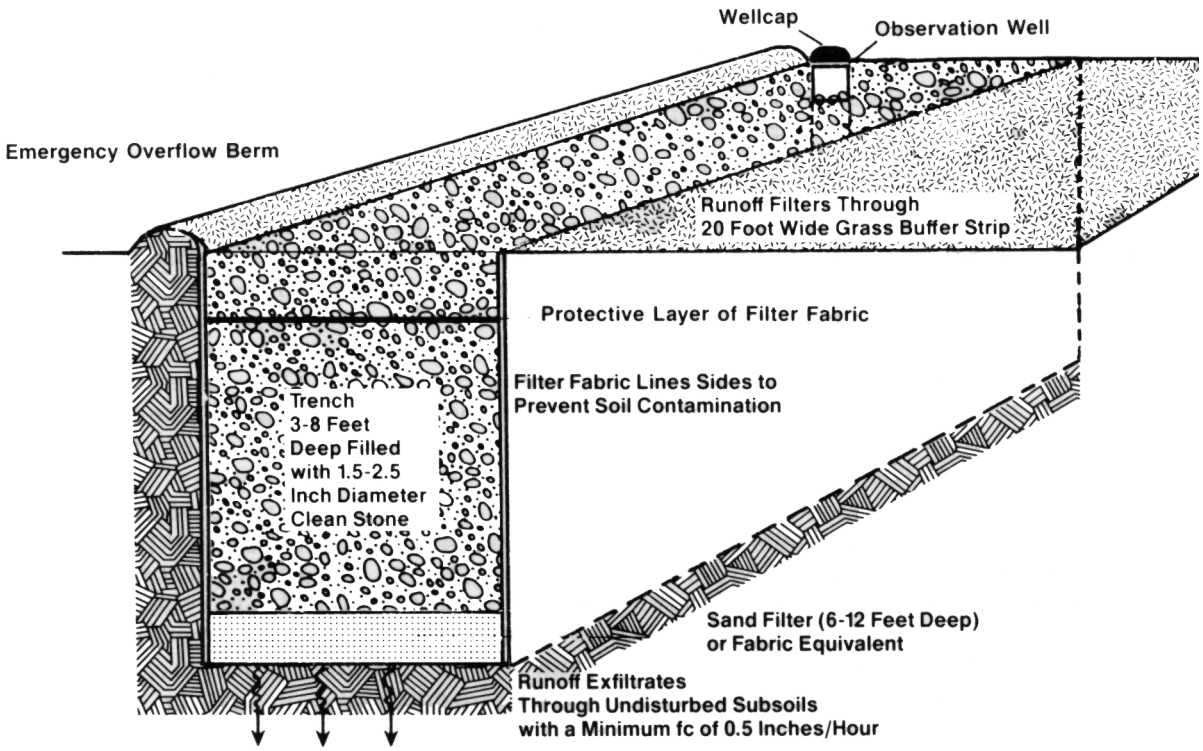


Figure 1: Typical Infiltration Trench Design
Source: Schueler, 1987.

Infiltration Trenches

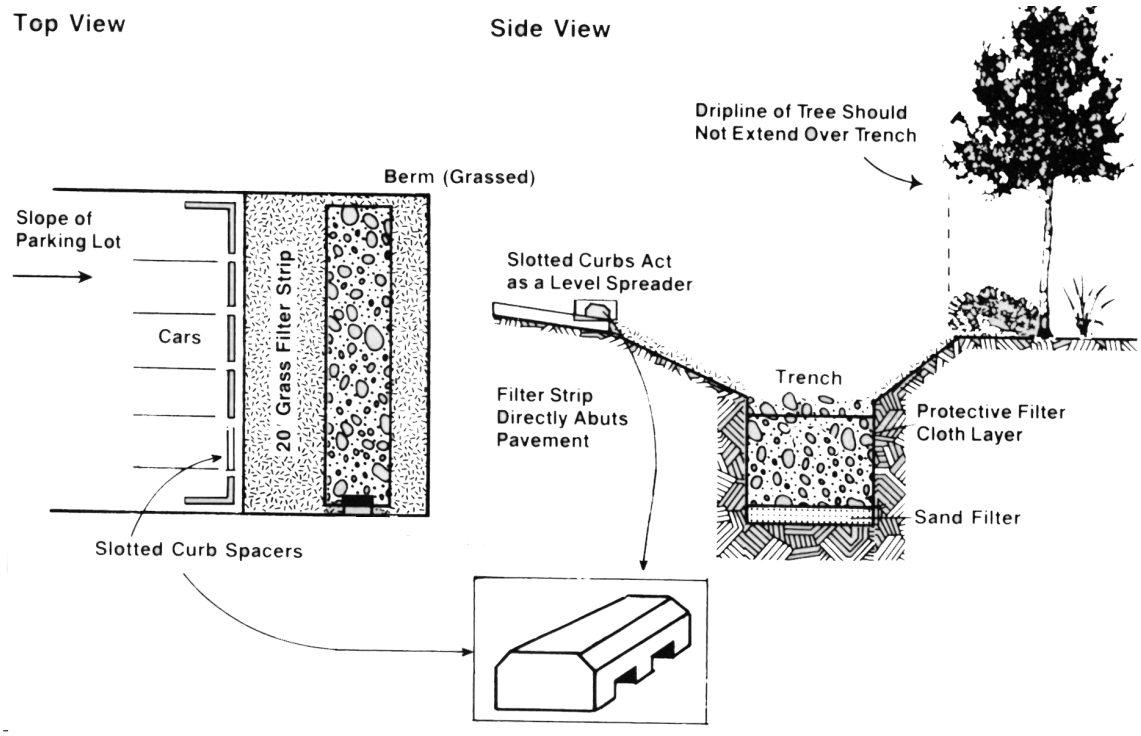


Figure 2: Parking Lot Perimeter Trench Design

Source: Schueler, 1987.

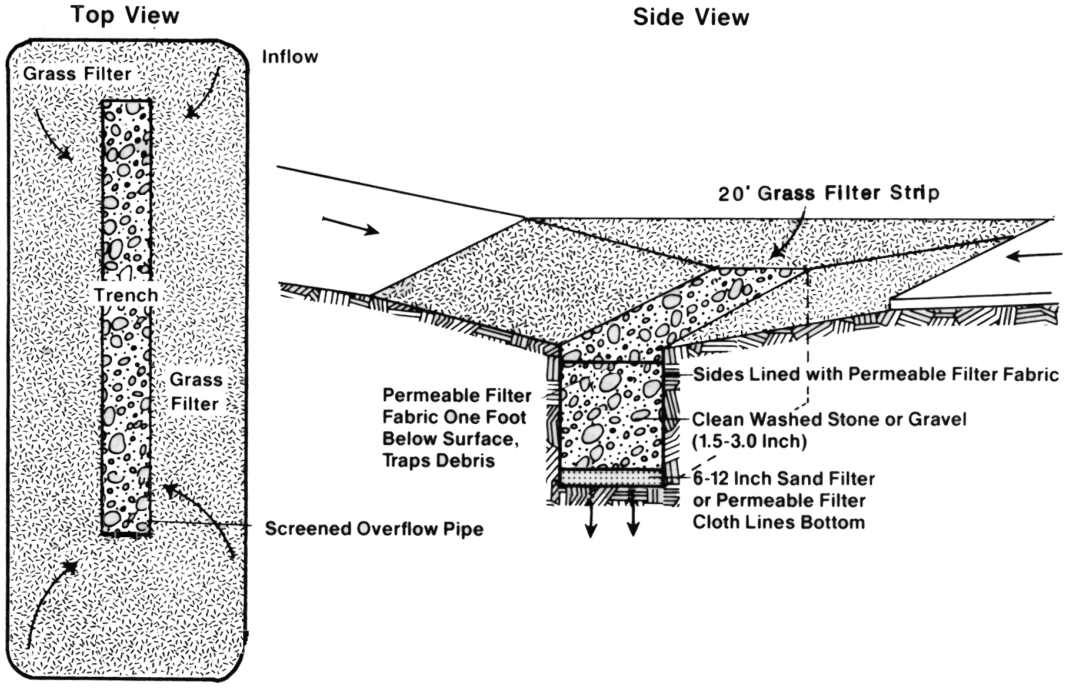


Figure 3: Median Strip Trench Design

Source: Schueler, 1987.

Infiltration Trenches

Advantages

- Reduces the volume of runoff from a drainage area
- Can be very effective for removing fine sediment, trace metals, nutrients, bacteria, and oxygen-demanding substances (organics)
- Reduces downstream flooding and protects streambank integrity
- Reduces the size and cost of downstream stormwater control facilities and/or storm drain systems by infiltrating stormwater in upland areas
- Provides groundwater recharge and baseflow in nearby streams
- Reduces local flooding
- Appropriate for small sites (2 acres or less)
- Can be utilized where space is limited, due to their narrow dimensions

Limitations

- Potential failure due to improper siting, design and lack of maintenance, especially if pretreatment is not incorporated into the design.
- Depending on soil conditions, land use in the watershed and groundwater depth, a risk of groundwater contamination may exist.
- Not appropriate for industrial or commercial sites where the release of large amounts or high concentrations of pollutants is possible.
- Susceptible to clogging by sediment, resulting in frequent maintenance
- Requires frequent inspection and maintenance

Requirements

Design

Infiltration trench failure can be avoided with proper design, taking the following topics into consideration:

- Careful site selection (discussed further in the Site Sensitivity Analysis section)
- Treatment of sheet flow from a small drainage area
- Incorporation of pretreatment and a bypass for high flow events
- Good construction techniques that prevent smearing, over-compaction, and operation of the trench during the construction period.
- Performance of regular maintenance

All of these topics are discussed in further detail below.

Infiltration Trenches

Site Sensitivity Analysis

Before an infiltration system can be designed, a site sensitivity analysis must be performed. This evaluation may eliminate an infiltration practice from consideration because of soil characteristics or potential effects on groundwater. Because of varying geologic settings, a site evaluation needs to be tailored to the specific site conditions. A team approach to this evaluation is recommended where various disciplines such as engineering, hydrogeology and soil science are represented.

The applicability of infiltration trenches on a site depends on numerous site factors including, soils, slope, depth to water table, depth to bedrock or impermeable layer, contributing watershed area, land use, proximity to wells, surface waters, foundations, and others. Generally, infiltration trenches are suitable to sites with gentle slopes, permeable soils, relatively deep bedrock and groundwater levels, and a small contributing watershed area (less than 2 acres, ideally).

When performing a site evaluation, the following items should be considered:

- Runoff water quality: If runoff water will contain a significant concentration of soluble pollutants that could contaminate groundwater, an infiltration trench should not be used. Specifically, infiltration trenches are not recommended for industrial and commercial land uses where there is a high potential for groundwater contamination from chemical spills. In site specific cases where infiltration trenches are deemed acceptable for these land uses, the design must incorporate some form of upstream pretreatment.
- Degree of detail: The level of detail required for the study should be considered. For instance, a small structure receiving runoff from a roof top will not require as much detail as a structure serving a larger area and having a higher potential pollutant load.
- Geologic (groundwater) sensitivity: A site with a highly sensitive geology, such as one with a carbonate or surficial sand aquifer, may eliminate this practice from consideration.
- Depth to water table and bedrock: The seasonally high water table must be far enough below the bottom of the infiltration trench (at least 3 feet) to allow the structure to function hydraulically and to allow trapping and treatment of pollutants by the soil. Similarly, the bottom of the infiltration trench should be at least 3 feet from bedrock, although in the case of fractured bedrock, separations up to 10 feet may be required. This minimum separation distance is required to trap or treat pollutants before they reach the groundwater or bedrock and to maintain vegetation in the trench (MPCA, 2000).
- Frost line of the soil: The maximum effective depth of the trench should be located below the frost line to promote continued percolation of runoff water throughout the winter months. The maximum effective depth is defined as the depth to which the design volume of runoff actually fills the trench; trenches can be constructed to be deeper than they need to be to fit certain site characteristics or shallower if excess space is provided for storage.
- Proximity to drinking water wells and building foundations: Trenches should be located at least 150 feet away from drinking water wells to limit the possibility of groundwater contamination, and should be situated at least 10 feet down-gradient and 100 feet up-gradient from building foundations to avoid potential seepage problems.
- Soil percolation rate: The percolation rate of the soil must be great enough to drain the structure in a reasonable amount of time, generally 72 hours or less. Sites with clayey soils are not appropriate for infiltration trenches. Percolation rates are discussed in further detail below. If the percolation rate of the site's soils are not acceptable, the filtration family of BMP systems should be considered.

Infiltration Trenches

Design (continued)

- Size of the tributary drainage area: Although infiltration trenches were originally designed to accommodate larger drainage areas, the monitoring which has been undertaken to-date indicates that large scale infiltration is not feasible. One of the main problems with centralized infiltration trenches is that water from a large area is expected to infiltrate into a relatively small area. This does not reflect the natural hydrologic cycle and generally leads to problems (groundwater mounding, clogging, compaction). For these reasons, the contributing drainage area to any individual infiltration trench should be restricted to 2 acres or less.

General Design Considerations

Design Volume

Infiltration trench systems infiltrate a portion of the runoff from a rain event (usually the first flush or up to the first inch) while the remaining runoff bypasses the infiltration trench. The design infiltration volume can be calculated in many ways. Ultimately, the magnitude of the design infiltration volume depends on local authorities' practices and requirements.

Duration of Ponding

Trenches should be designed to provide a detention time of 6 to 72 hours. A minimum drainage time of 6 hours should be provided to ensure satisfactory pollutant removal in the infiltration trench (Schueler, 1987; SEWRPC, 1991). Although trenches may be designed to provide temporary storage of stormwater, the trench should drain prior to the next storm event. The drainage time will vary by precipitation zone. In Minnesota, the average time between storm events is estimated to be 72 hours. Therefore, the depth of the infiltration trench should be adjusted so that maximum drain time (based on the soil permeability at the site) is 72 hours for the total design infiltration volume.

Site Soil Permeability

The soils of a prospective site are an important consideration when determining the suitability for an infiltration trench. County soil surveys are useful for preliminary screening of a site for soil infiltration rate. The Natural Resource Conservation Service (formerly the Soil Conservation Service) hydrologic classifications for different soil types can be found in the National Engineering Handbook (NRCS, 1972) or on the NRCS' website at www.wcc.nrcs.usda.gov/water/quality/common/neh630/4content.html.

Permeability, also called "percolation rate" or "hydraulic conductivity", as opposed to infiltration rate, should be used to define the rate at which runoff can seep into the bottom and sides of an infiltration trench. Typically, the permeability of a soil is much higher than infiltration rate, and can be estimated by referencing an NRCS (formerly SCS) Soil Survey Report.

A geologic investigation of the site, however, is always preferable. Several methods of measuring soil permeability have been developed. The most commonly used test is the falling head percolation test. This method is described in detail in:

- Annual Book of ASTM Standards, 1998, Section 4, Vol 4.09, Soil and Rock (II): Designation D 5084-90, Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter, pp 62-69.
- *Onsite wastewater Treatment and Disposal Systems Design Manual.* 1980. EPA, pp 39-49.

Infiltration Trenches

A minimum of two borings should be taken for each infiltration trench. Trenches over 100 feet in length should include at least one additional sample for each 50 foot increment. Borings should be taken at the actual location of the proposed infiltration trench to identify localized soil conditions.

The designer should use their best judgement to determine if the slowest or average measured percolation rate in the proposed trench area should be used for the design of the trench.

Where feasible, larger-scale of measurements of permeability are encouraged, using a procedure such as the Pilot Infiltration Test described in the State of Washington's Stormwater Management Manual (Washington State Department of Ecology, 1999). This document is currently available on the internet at www.ecy.wa.gov. This type of procedure can avoid some of the error associated with smaller-scale tests and can provide an indication of the longer-term infiltration rate that better represents the future conditions of the site.

Trench Volume and Configuration

The volume and surface area of an infiltration trench relate to the design volume of runoff entering the trench from the contributing watershed and the permeability of the soil below the trench. In addition, since the infiltration trench is filled with stone, only the space between the stone (hereafter called the void space in the storage media) is available for runoff storage.

The length and width of the trench will largely be determined by the characteristics of the site in question (topography, size and shape). The dimensions of the trench will also depend on the path of influent water. If stormwater is conveyed to the trench as uniform sheet flow, the length of the trench perpendicular to the flow direction should be maximized. If stormwater is conveyed as channel flow, the length of trench parallel to the direction of flow should be maximized.

The appropriate bottom area of the trench can be calculated using the equation shown below. This equation assumes that all of the infiltration occurs through the bottom of the trench.

$$A = 12V/ (P\ n\ t)$$

where A = bottom area of the trench (ft^2)

V = runoff volume to be infiltrated

P = percolation rate of surrounding native soil (in/h)

n = void space fraction in the storage media (0.4 for clear stone)

t = retention time (maximum of 72 hours)

Trench depths are usually between 3 and 12 feet (SEWRPC, 1991, Harrington, 1989). A site specific, maximum effective trench depth can be calculated based on the soil percolation rate, aggregate void space, and the trench storage time (Harrington, 1989).

$$D=P*t/(n * 12)$$

Where D= depth of the trench, in feet

P = percolation rate of surrounding existing soil (in/hr)

t = retention time (maximum of 72 hours)

n = void space fraction in the storage media (0.4 for clear stone)

Infiltration Trenches

Design (continued)

Infiltration trenches can be constructed to be deeper than they need to be to fit certain site characteristics. The maximum effective depth is defined as the depth to which the design volume of runoff actually fills the trench.

Filter Fabric

The sides and bottom of the infiltration trench should be lined with geotextile fabric (filter fabric). Also, there can be a layer of nonwoven filter fabric 6 to 12 inches below the ground surface to prevent suspended solids from clogging the majority of the storage media. It should be recognized, however, that there may be a need to frequently replace this filter fabric layer depending on the volume of suspended solids transported to the trench.

The filter fabric material must be compatible with the surrounding soil textures and application purposes. The cut width of the filter fabric must have sufficient material for a minimum 12-inch overlap. When overlaps are required between rolls, the upstream roll must lap a minimum of two feet over the downstream roll to provide a shingled effect. The bottom of the infiltration trench can be covered with a six to twelve inch layer of clean sand in place of filter fabric.

Storage Media

The basic infiltration trench design utilizes stone aggregate in the top of the trench to provide storage. The trench should be filled with clean, washed stone with a diameter of 1.5 to 3 inches. This aggregate size provides a void space of 40 percent (SEWRPC, 1991, Harrington, 1989, Schueler, 1987).

This design can be modified by substituting pea gravel for stone aggregate in the top 0.3 meter (1 foot) of the trench. The pea gravel improves sediment filtering and maximizes the pollutant removal in the top of the trench.

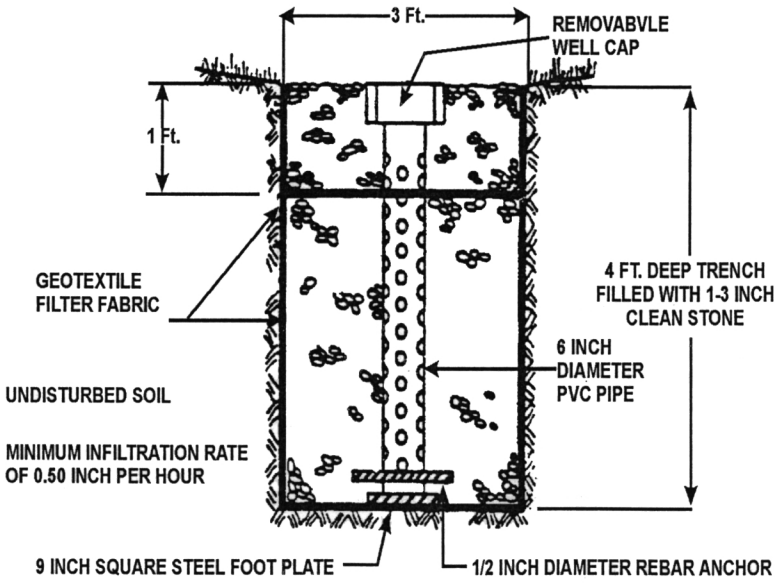


Figure 4: Observation Well Details

Source: SWRPC, 1991.

Infiltration Trenches

When the modified trenches become clogged, they can generally be restored to full performance by removing and replacing only the pea gravel layer, without replacing the lower stone aggregate layers.

It should be noted that while stone is the most common form of storage media in infiltration trenches, there are suppliers that manufacture precast infiltration storage media. These alternative storage media solutions are generally acceptable and should be reviewed and implemented on a case by case basis until there is adequate research/ experience with their performance.

Observation Well:

An observation well located at the center of the trench is recommended to monitor water drainage from the system. The well can be a 4 to 6 inch diameter PVC pipe, which is anchored vertically to a foot plate at the bottom of the trench as shown in Figure 4 . This well should have a lockable above-ground cap.

Pretreatment:

Infiltration trenches are susceptible to high failure rates due to clogging from sediments, and therefore require pretreatment of stormwater in order to remove as much of the suspended solids from the runoff as possible before it enters the trench. Pretreatment, such as grit chambers, swales with check dams, filter strips, or sediment forebays/traps should be a fundamental component of any BMP system relying on infiltration. Even when infiltrating rooftop runoff, it is a practical decision to implement some form of pretreatment to remove sediments, leaf litter, and debris. This pretreatment will help to ensure the proper functioning of the infiltrating facility and allow for longer periods between maintenance. When designed properly, pretreatment devices should remove 25 to 30 percent of sediment loads. Figure 2 and 3 show an infiltration trench with pretreatment in the form of a grass filter strip.

Designs for infiltration trenches should emphasize accessibility and ease of maintenance.

Bypass:

A bypass system should be implemented for all infiltration trenches. A bypass flow path should be incorporated in the design of an infiltration trench to convey high flows around the trench.

The overland flow path of surface runoff exceeding the capacity of the infiltration trench should be evaluated to preclude erosive concentrated flow. If computed flow velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography.

Groundwater Mounding:

Calculations to determine groundwater mounding (local elevation of the water table as a result of infiltrated surface water) may be necessary in cases where slope stability is a concern, and/or a high water table is encountered. A hydrogeologist should be consulted with respect to the potential for groundwater mounding in these areas. The results from groundwater mounding calculations should be regarded as an indication of the mounding potential rather than as an accurate representation of the actual mounding depth.

Infiltration Trenches

Design (continued)

Cold Weather Considerations:

Consideration should be given to the operation of infiltration trenches during the winter period. Winter sanding of roads can clog an infiltration trench without adequate pretreatment, and winter salting will increase the potential for the chloride contamination of groundwater.

In cold climates, the trench surface may freeze, thereby preventing the runoff from entering the trench and allowing the untreated runoff to enter surface water. The surrounding soils may also freeze, reducing the percolation of the water into the soils and groundwater. However, recent studies indicate that if properly designed and maintained, infiltration trenches can operate effectively in colder climates. By keeping the trench surface free of compacted snow and ice, and by ensuring that part of the trench is constructed below the frost line, the performance of the infiltration trench during cold weather will be greatly improved.

If infiltration practices are used as a stand-alone, all-season water quality treatment facility, then oversizing (to account for reduced percolation) and/or extended pretreatment should be considered. Doubling the storage volume for surface infiltration devices is recommended. Redundant pretreatment (more than one pretreatment device in series) is recommended for all infiltration facilities receiving runoff from roads.

Sequencing

Care should be taken during construction to minimize the risk of premature failure of the infiltration trench. This failure is caused by the deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper sequencing.

- Ideally, construction of the infiltration trench should take place after the site has been stabilized.
- Diversion berms or silt fence should be placed around the perimeter of the infiltration trench during all phases of construction. Sediment and erosion controls should be used to keep runoff and sediment away from the infiltration trench.
- Heavy equipment should not operate on the surface location where the infiltration trenches are planned. Soil compaction will adversely effect the performance of the trench, and infiltration trench sites should be roped off and flagged. During excavation and trench construction, only light equipment such as backhoes or wheel and ladder type trenchers should be used to minimize compaction of the surrounding soils.
- During and after excavation, all excavated materials should be placed downstream, away from the infiltration trench, to prevent redepositing during runoff events.

Construction

Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction. The construction sequence and specifications for each infiltration practice must be precisely followed.

- Infiltration trenches should not be used as temporary sediment traps during construction.

Infiltration Trenches

- Infiltration trenches will only operate as designed if they are constructed properly. There are three main rules that must be followed during the construction of an infiltration trench :

  1) Trenches should be constructed at the end of development construction

  2) Smearing of the soil at the interface with the trench bottom and sides must be avoided. Smearing of the trench bottom can be corrected by raking or rototilling.

  3) Compaction of the trench storage media and surrounding soils during construction must be minimized

- Before the development site is graded, the area of infiltration trench should be roped off to prevent heavy equipment from compacting the underlying soils.
- Light earth-moving equipment should be used to excavate the infiltration trench. Use of heavy equipment causes compaction of the soils beneath the trench floor and side slopes, resulting in reduced percolation capacity.

Maintenance

Maintenance is required for the proper operation of infiltration trenches as it is with all BMPs. Plans for infiltration trenches should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule.

- The use of pretreatment BMPs will significantly minimize maintenance requirements of the trench itself. Removing accumulated sediment from a sump pit or a vegetated swale is considerably less difficult and less costly than rehabilitating a trench. Eventually, the infiltration trench should be rehabilitated, but this time span is relative to the effective performance of the trench. With appropriate design and aggressive preventive maintenance, this rehabilitation may not be necessary for a decade or more.
- Once the trench has gone online, inspections should occur after every major storm for the first few months to ensure proper stabilization and function. Water levels in the observation well should be recorded over several days to check trench drainage.
- After the first few months of operation, the infiltration trench should be inspected at least twice per year. Important items to check for include: accumulated sediment, leaves and debris in the pretreatment device, clogging of inlet and outlet pipes and ponded water both inside and on the surface of the infiltration trench.
- When ponding occurs at the surface or in the trench, corrective maintenance is required immediately.
- Clogging in trenches occurs most frequently on the surface. Grass clippings, leaves, and accumulated sediment should be removed routinely from the surface of the trench. If the clogging appears only to be at the surface, it may be necessary to remove and replace the first layer of stone aggregate and the filter fabric.
- Ponded water inside the trench (as visible from the observation well) after 24 hours or several days after a storm event often indicates that the bottom of the trench is clogged, indicating a percolation failure from the bottom. In this case, all of the stone aggregate and filter fabric or media must be removed. Accumulated sediment should be stripped from the trench bottom. At this point the bottom may be scarified or tilled to help induce infiltration. New fabric and clean stone aggregate should be refilled.
- Pretreatment devices associated with trenches should be inspected and cleaned at least twice a year, and ideally every other month.

Infiltration Trenches

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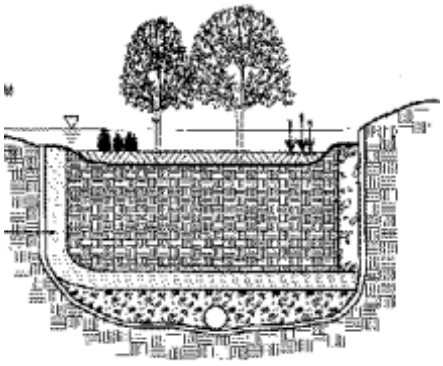
Bioretention Systems



The Bioretention Concept

For the purposes of this manual, Bioretention Systems are presented as a general concept, rather than a specific type of BMP. The Bioretention concept uses biologic activity (plants and microbes) to filter/clean stormwater.

This concept can be incorporated into many different kinds of infiltration or filtration BMP designs, such as:

- Infiltration Basins
- Rainwater Gardens (an On-Lot Infiltration system)
- Surface Sand Filters

In general, Bioretention Systems can be described as shallow, landscaped depressions commonly located in parking lot islands or within small pockets in residential areas that receive stormwater runoff. Stormwater flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition (Prince George's County, MD, 1993). Filtered runoff can either be allowed to infiltrate into the surrounding soil (functioning as an infiltration basin or rainwater garden), or collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters (functioning like a surface sand filter). Runoff from larger storms is generally diverted past the area to the storm drain system.

Some examples of bioretention areas are shown in Figures 1 through 3. In Figure 1, the bioretention system resembles an infiltration basin enhanced with planting soil and sand media. The bioretention system shown in Figure 2 could be considered a rainwater garden in a parking lot. The bioretention example in Figure 3 is essentially a surface sand filter design with planting soil comprising most of the filter's cross section.

Purpose

Water Quantity

Flow attenuation	◧
Runoff volume reduction (for infiltration systems only)	◧

Water Quality

Pollution prevention	
Soil erosion	N/A
Sediment control	N/A
Nutrient loading	N/A
Pollutant removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	■
Nitrogen (N)	■
Heavy metals	■
Floatables	◧
Oil and grease	■
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Bioretention Systems

Advantages

- When properly designed and maintained, more likely to be aesthetically pleasing than other types of filtration or infiltration systems due to incorporation of plants.
- Reduces the volume of runoff from a drainage area.
- Can be very effective for removing fine sediment, trace metals, nutrients, bacteria, and organics (Davis et al. 1998).
- Layout of bioretention facilities can be very flexible, and the selection of plant species can provide for a wide variety of landscape designs.
- Can be applied in many different climates and geologic environments, with some minor design modifications.
- Ideally suited to many highly impervious areas, such as parking lots.
- Reduces the size and cost of downstream stormwater control facilities and/or storm drain systems by infiltrating stormwater in upland areas.
- Reduces downstream flooding and protects streambank integrity.
- Provides groundwater recharge and baseflow in nearby streams.
- Reduces local flooding.
- Can be used as a stormwater retrofit, by modifying existing landscaped areas, or if a parking lot is being resurfaced.

Limitations

- Cannot be used to treat large drainage areas, limiting their usefulness for some sites.
- Susceptible to clogging by sediment, and therefore pretreatment is a necessary part of design.
- Tend to consume space (usually around 5 percent of the area that drains to them).
- Incorporating bioretention into a parking lot design may reduce the number of parking spaces available.
- Construction cost can be relatively high compared with other stormwater treatment practices.

Design

Site Considerations

Before construction, designers must consider the site conditions to ensure that a bioretention system is the appropriate BMP for the site.

- Drainage area: Bioretention areas should usually be used on small sites (i.e., two acres or less). When used to treat larger areas, they tend to clog. In addition, it is difficult to convey flow from a large area to a bioretention area.

Bioretention Systems

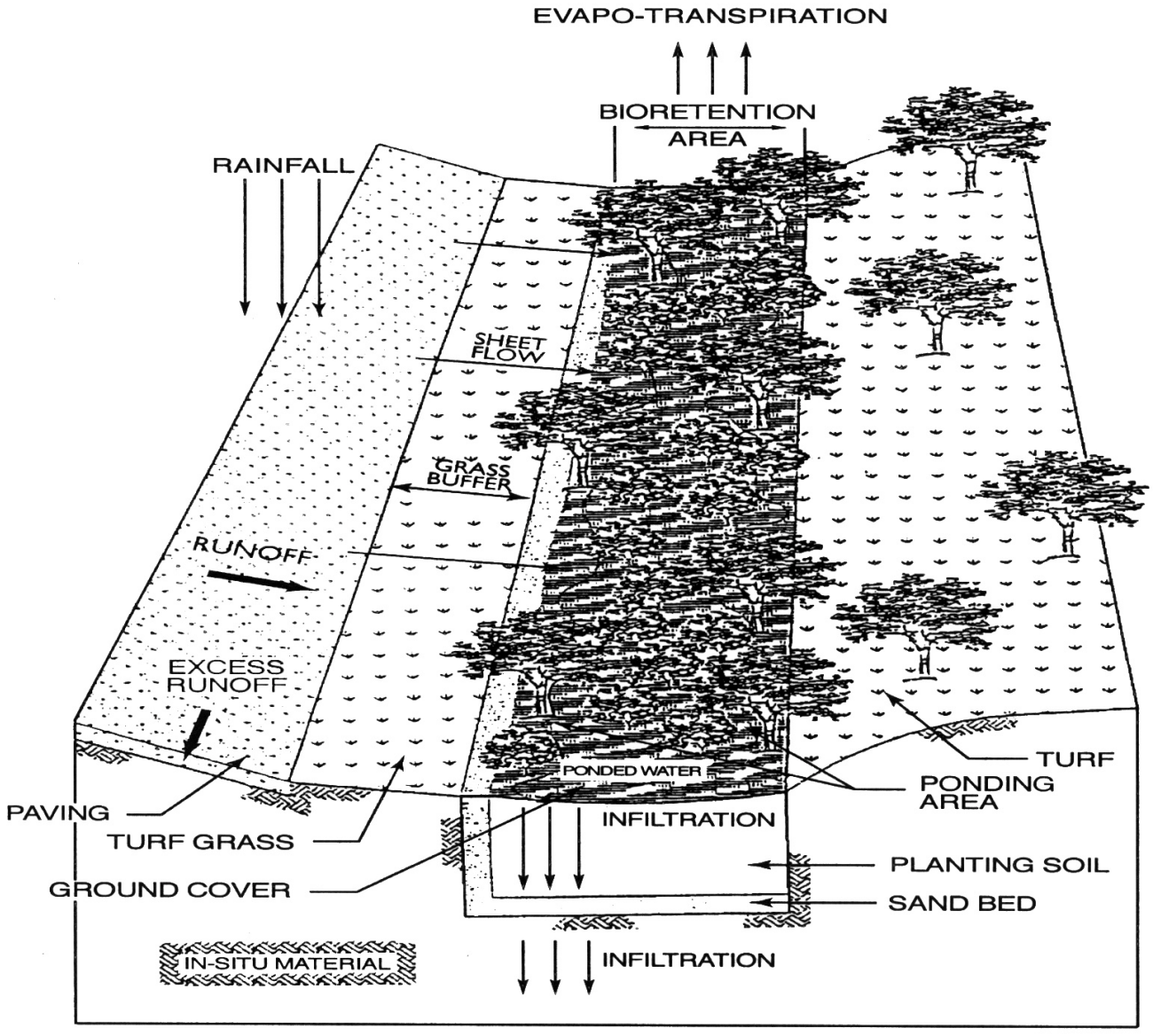


Figure 1: Bioretention Area Conceptual Layout (Functioning like an Infiltration Basin)

Source: Prince George's County Department of Environmental Protection, 1993

Bioretention Systems

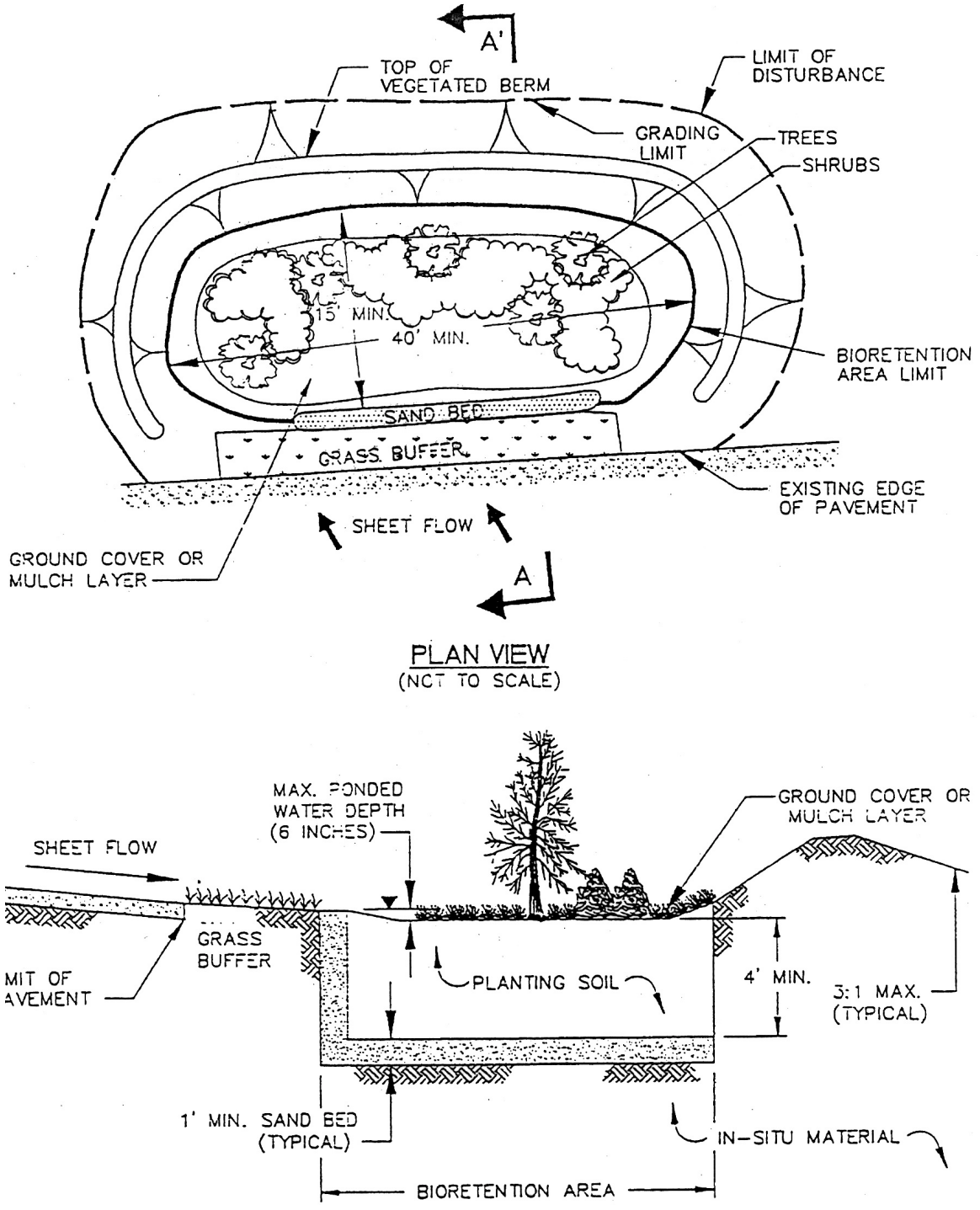


Figure 2: Bioretention Area: Parking Edge and Perimeter Without Curb
(Functioning Like a Rainwater Garden)
Source: Prince George's County Department of Environmental Protection, 1993

Bioretention Systems

Design (continued)

- Available area for the bioretention system: The surface area of the bioretention system should be between 5% and 10% of the impervious area draining to it.
- Slope: Bioretention areas are best applied to areas with relatively shallow slopes (usually about 5%).
- Soils: Bioretention areas can be applied in almost any soils, since in some designs, runoff percolates through a made soil bed, and is returned to the stormwater system. However, it is also possible to design a bioretention system to function like an infiltration system, where runoff percolates through into the native soil below the system. The infiltration option can be applied only when the soils and other site characteristics are appropriate for infiltration (for more information see the Infiltration Trench and Infiltration Basin BMP Sections).

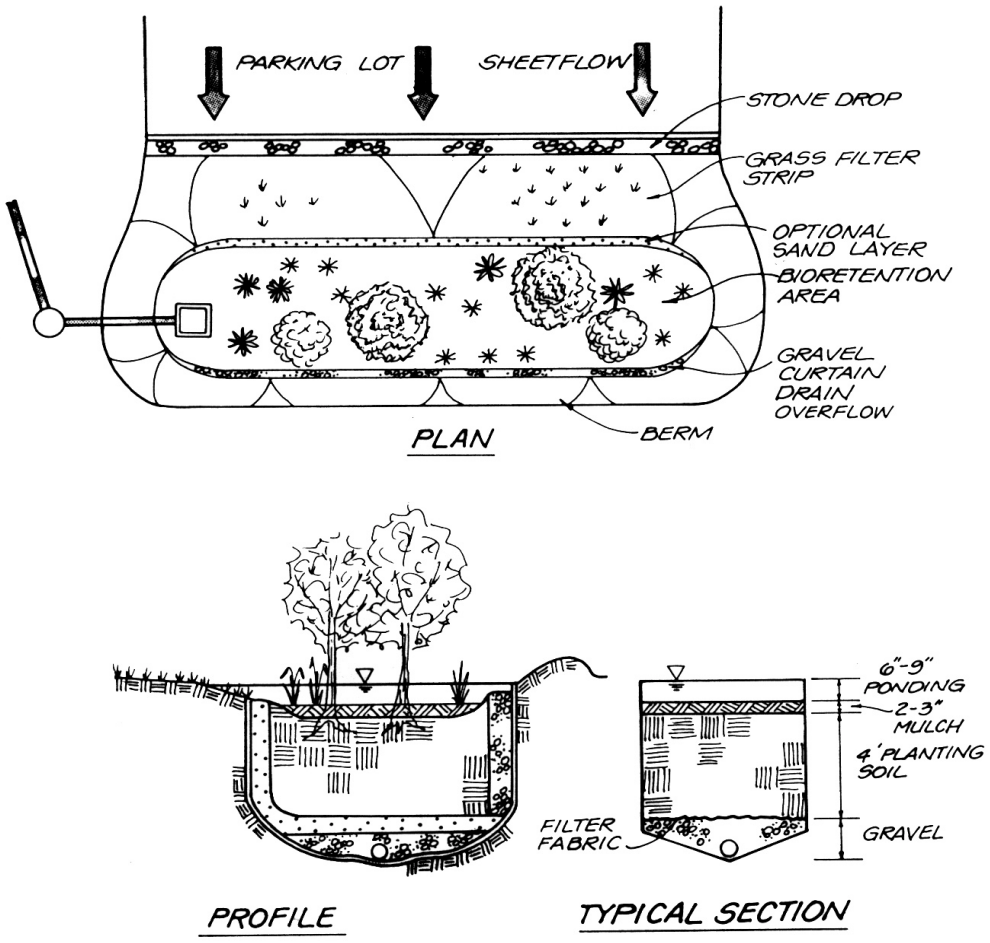


Figure 3: Bioretention Area: Parking Edge and Perimeter Without Curb
(Functioning like a Surface Sand Filter)
Source: Center for Watershed Protection, 1996

Bioretention Systems

- Groundwater: Bioretention should be separated from the water table to ensure that the groundwater does not intersect with the bottom of the bioretention area, in order to prevent possible groundwater contamination and practice failure. Specifically, the seasonally high groundwater table should be at least 3 feet from the bottom of the bioretention area if filtered water is to be infiltrated.
- Cold Climates: In cold climates, bioretention areas can be used as a snow storage area. When used for this purpose, or if used to treat parking lot runoff, the bioretention area should be planted with salt tolerant, and non-woody plant species.

Main Design Components

Design of a bioretention area typically involves the following components:

- Pretreatment: Bioretention systems are susceptible to clogging from sediments. Therefore, pretreatment, such as filter strips, should be a fundamental component of any bioretention system in order to remove as much of the suspended solids from the runoff as possible before it reaches the bioretention system. Pretreatment will help to ensure the proper functioning of the bioretention area and allow for longer periods between maintenance. When designed properly, pretreatment devices should remove 25-30 percent of sediment loads.

  The most efficient way to reduce sediment loadings to a bioretention area in a cost efficient manner is to separate contaminated runoff from uncontaminated runoff. Uncontaminated stormwater runoff may be infiltrated directly, while contaminated runoff (such as from roads, parking areas and driveways) must be collected and treated using an appropriate BMP or BMP combination, and then subsequently routed (after treatment) back into the bioretention area. In this manner, the bioretention area performs double-duty: 1) they filter or infiltrate uncontaminated stormwater during and immediately following the storm event, and 2) they provide filtration or infiltration for pretreated stormwater from polluted areas following an appropriate detention/treatment time for the selected design.
- Ponding area: The ponding area provides for surface storage of storm water runoff before it filters through the soil bed. The ponding area also allows for evaporation of ponded water as well as allows for settling of sediment in the runoff. The bioretention area should be designed to pond 6 to 9 inches above the filter bed.
- Organic Mulch Layer. The organic mulch layer has several functions. It protects the soil bed from erosion, retains moisture in the plant root zone, provides a medium for biological growth and decomposition of organic matter, and provides some filtration of pollutants.
- Planting Soil Bed. The planting soil bed provides water and nutrients to support plant life in the bioretention system. Storm water filters though the planting soil bed where pollutants are removed by the mechanisms of filtration, plant uptake, adsorption and biological degradation. A range of soil types are recommended in the literature, from highly designed potting soil mixes to sandy soil with additional compost to simply maintaining the existing soil at the site. These considerations are discussed further in the Infiltration Basin and Surface Sand Filter BMP Sections.
- Under-drain (If runoff is to be collected rather than infiltrated): An under-drain is a perforated pipe in a gravel bed, installed along the bottom of sand bed that collects and removes filtered runoff, directing it to a storm drain system. Bioretention systems may or may not incorporate an under-drain in their design, depending on treatment goals and site constraints. Potential site constraints that would prohibit infiltrating the filtered water are discussed in further detail in the Infiltration systems family of BMP sections.

Bioretention Systems

- Overflow structure: An overflow structure should be provided to convey flow from large storms (storms that are not treated by the bioretention area) to the storm drain system.
- Plants: Plants are an important component of a bioretention system. Plants remove water though evapotranspiration and remove pollutants and nutrient through uptake. Plant roots enhance the infiltration capacity of the soil, providing conduits for percolation. The plant species selected for a bioretention area should be designed to replicate a forested or grassland ecosystem and to survive stresses such as frequent periods of inundation during runoff events and drying during inter-event periods. The plant list provided below contains some recommended species that can be used in bioretention systems.

Plant List

Source: Fred Rozumalski

Mesic-Dry Soils (Sunny)

Native		***Non-Native***	
Butterfly Flower	*Asclepias tuberosa*	Yarrow 'Coronation Gold'	*Achillea 'Coronation Gold'*
Purple Prairie Clover	*Dalea purpureum*	Feather Reed Grass 'Karl Foerster'	*Calamagrostis 'Karl Foerster'*
Purple Coneflower	*Echinacea purpurea*	Daylily	*Hemerocallis spp.*
Beebalm	*Monarda fistulosa*	Blazingstar 'Kobold'	*Liatris 'Kobold'*
Little Bluestem	*Schizachyrium scoparium*	Silverfeather Grass	*Miscanthus sinensis*
Spiderwort	*Tradescantia bracteata*	Garden Phlox	*Phlox paniculata*
		Black-Eyed Susan 'Goldsturm'	*Rudbeckia fulgida 'Goldsturm'*

Mesic-Dry Soils (Shady)

Native		***Non-Native***	
Wild Columbine	*Aquilegia canadensis*	White Comfrey	*Symphytum grandiflorum*
Wild Geranium	*Geranium maculatum*	Tufted Hair Grass	*Deschamsia caespitosa*
Obedient Plant	*Physostegia virginiana*	Bigroot Geranium	*Geranium macrorrhizum*
Jacob's Ladder	*Polemonium reptans*	Daylily	*Hemerocallis spp.*
Solomon's Seal	*Polygonatum biflorum*	Hosta 'Royal Standard'	*Hosta 'Royal Standard'*
Zig-zag Goldenrod	*Solidago flexicaulis*	Tigerlily	*Lilium tigrinum*
Canada Violet	*Viola canadensis*		
Culver's Root	*Veronicastrum virginium*		

Wet Soil (Sunny)

Native		***Non-Native***	
Giant Hyssop *'Gateway'*	*Agastache foeniculum*	Joe-Pye 'Gateway'	*Eupatorium purpurescens*
Canada Anemone	*Anemone canadensis*	Daylily	*Hemerocallis spp.*
Marsh Milkweed	*Asclepias incarnata*	Siberian Iris	*Iris sibirica*
New England Aster	*Aster novae-angliae*	Tigerlily	*Lilium tigrinum*
Turtlehead	*Chelone glabra*	Switchgrass 'Heavy Metal'	*Panicum virgatum 'Heavy Metal'*
Joe-Pye Weed	*Eupatorium maculatum*		
Obedient Plant	*Physostegia virginianum*		

(plant list continued on next page)

Bioretention Systems

Plant List (continued)

Wet (Sunny) continued

Boneset	*Eupatorium perfoliatum*
Queen of the Prairie	*Filpendula rubra*
Blueflag Iris	*Iris versicolor*
Great Blue Lobelia	*Lobelia siphilitica*
Switchgrass	*Panicum virgatum*
Mountain Mint	*Pycnanthemum virginianum*
Tall Meadow Rue	*Thalictrum dasycarpum*
Culvers Root	*Veronicastrum virginicum*
Golden Alexander	*Zizia aurea*

Wet Soils (Shady)

Native		***Non-Native***	
Cardinal Flower	*Lobelia cardinalis*	Pink Turtlehead	*Chelone layonii*
Ostrich Fern	*Matteuccia struthiopteris*	Daylily	*Hemerocallis spp.*
Virginia Bluebells	*Mertensia virginica*	Obedient Plant	*Physostegia virginiana*
Sensitive Fern	*Onoclea sensibilis*		

Shrubs (Sunny)

Black Chokeberry	*Aronia melanocarpa*
Red-Osier Dogwood	*Cornus sericia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens 'Annabelle'*
Pussy Willow	*Salix discolor*
High Bush Cranberry	*Viburnum trilobum*

Shrubs (Shady)

Black Chokeberry	*Aronia melanocarpa 'alata'*
Red-Osier Dogwood	*Cornus sericia*
Low Bush Honeysuckle	*Diervilla Ionicera*
Annabelle Hydrangea	*Hydrangea arborescens 'Annabelle'*

Bioretention Systems

Maintenance

Bioretention requires seasonal landscaping maintenance. In many cases, bioretention areas require intense maintenance initially until plants are established, but less maintenance in the long term. Designers should ensure that the bioretention area is easily accessible for maintenance. Table 1 lists the typical maintenance activities for bioretention areas (CWP website, 2001).

Table 1. Typical Maintenance Activities for Bioretention Areas

Source: Center for Watershed Protection, 2001

Activity	Frequency
Water plants	As necessary during first growing season
Water as necessary during dry periods	As needed after first growing season
Re-mulch void areas	As needed
Treat diseased trees and shrubs	As needed
Inspect soil and repair eroded areas	Monthly
Remove litter and debris	Monthly
Add additional mulch	Once per year

Bioretention Systems

Sources

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2. Center for Watershed Protection. 1996. *Design of Stormwater Filtering Systems*. Solomons, MD.
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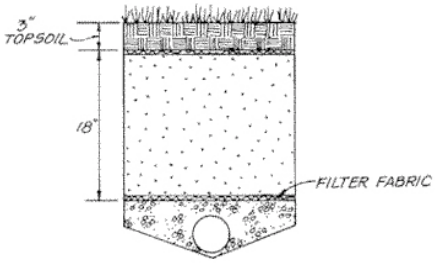
Surface Sand Filters



Description

Also known as filtration basins, filter systems, or media filtration facilities, surface sand filters consist of a pretreatment basin, a water storage reservoir, flow spreader, sand and underdrain piping. A basin liner may also be needed if the treated runoff is not to be allowed to infiltrate into the soil underlying the filtration basin because of groundwater concerns. A related type of filtration system employs organic materials such as peat or compost combined with sand or other materials. The latter types are not discussed in this publication.

Sand filters are intended to address the spatial constraints that can be found in intensely developed urban areas where the drainage areas are highly impervious. They can be used on small urban sites where space is at a premium and where the soils or groundwater concerns would not support an infiltration device.

Sand filters have been demonstrated to be effective in removing many of the common pollutants found in urban stormwater runoff, especially those found in particulate form. They have also been shown to have at least a moderate level of bacterial removal. They have not been effective at removing total dissolved solids and nitrate-nitrogen (subsets of total suspended sediment and nitrogen, respectively).

There are two basic components of a sand filter design: the pretreatment basin and the sand filter. They are both important parts of the design, and neither can be omitted. The pretreatment basin reduces the amount of sediment that reaches the sand filter and helps ensure that stormwater reaches the sand filter as sheet flow. The sand filter traps the finder sediment and sediment-bound pollutants and provides a media for microbial removal of bacteria.

Sand filters work by receiving the first flush of runoff and settling out the heavier sediment in the pretreatment basin. Water flows to and is spread over the sand filter, where pollutants are either trapped or strained out. Sand filters are to be used only for drainage that has been stabilized. Sediment suspended in runoff during construction could quickly clog the sand filter and render it useless.

Purpose

Water Quantity

Flow attenuation	☐
Runoff volume reduction	☐

Water Quality

Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollution removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	■
Floatables	◧
Oil and grease	◧
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
☐ Little or no design benefit

Surface Sand Filters

Drainage areas directed to each sand filter should be less than 5 acres in size. Sand filters are very adaptable, and have few site constraints. They can be applied in areas with thin soils, high evaporation rates, low soil-infiltration rates and limited space.

Sand filters can be used in high-density urban sites with small drainage areas that are completely impervious (such as small parking lots). They can be applicable to many areas that are difficult to retrofit due to space limitations.

Sand filters are most effective when designed as off-line BMPs; they are intended primarily for quality control, not quantity control. A diversion structure, such as a flow splitter or weir, is provided to route the "first flush" of runoff into the sand filter, while the remainder continues on to a stormwater-quantity-control BMP.

Because of the potential for clogging, sand filters should be applied only at sites that have been stabilized and should never be used as sedimentation traps or basins during construction. Any disturbed areas within the sand filter's drainage area should be identified and stabilized to the maximum extent possible.

Advantages

- Applicable in small drainage areas of 1 to 10 acres
- Have few constraints, so can be applied to most development sites
- May require less space than other treatment control BMPs
- Good retrofit capability
- Take up little space and can be used on highly developed and steeply sloped sites
- Provide high removal efficiencies for TSS

Limitations

- Pretreatment required to prevent the filter media from clogging
- Maintenance required every 6 months to 5 years depending on watershed
- Relatively costly to build and install
- An elevation difference of about 4 feet between the inlet and outlet of the filter is usually needed
- Not applicable in areas of high water tables
- Should not be used in areas where heavy sediment loads are expected or in tributary areas that are not fully stabilized
- Generally do not provide quantity control
- Performance reduced if underdrains and filter media freeze

Surface Sand Filters

Requirements Design

General Principles and Sizing

The sand filter design is based on Darcy's law:

$$Q = KiA = VA \text{ (since } V = Ki)$$

where Q = WQ design flow (cfs)

K = hydraulic conductivity (fps)

A = surface area perpendicular to the direction of flow (sf)

i = hydraulic gradient (ft/ft) for a constant head and constant media depth, computed as follows:

$$i = (h + l) / l$$

where h = average depth of water above filter (ft), defined for this design as d/2

d = maximum storage depth above filter (ft)

l = thickness of sand media (typically 1.5 ft)

When water is flowing into the ground, V is commonly called the filtration rate. It is ordinarily measured in a percolation test. The filtration rate V changes with head and media thickness, although the media thickness is constant in the sand filter design. Table 1 shows values of V for different water depths d (remember, d = 2h), assuming a media thickness of 1.5 feet and a hydraulic conductivity of 1 inch per hour.

Unlike the the filtration rate V, the hydraulic conductivity K does not change with head, nor is it dependent on the thickness of the media, only on the characteristics of the media and the fluid. The hydraulic conductivity of 1 inch per hour (2.315×10^{-5} fps) used in this design is based on bench-scale tests of conditioned rather than clean sand. This design hydraulic conductivity represents typical sand-bed condition as silt is captured and held in the filter bed. The designer should determine the correct hydraulic conductivity based on the actual sand used for the filter bed.

For a basic sand filter design, the filter should be sized to completely empty (drawdown time) the design-storm volume in 24 hours or less. Water depth above the filter should be no more than 6 feet. A minimum of one foot of freeboard is recommended when establishing the BMP depth.

Table 1: Sand Filter Design Parameters

	Sand Filter Design Parameters					
Facility ponding depth d (ft)	1	2	3	4	5	6
Filtration rate V (in/hr) *	1.33	1.67	2.00	2.33	2.67	3.0
1/v (min/in)	44	36	30	26	26	20

* *Note:* The filtration rate is not used directly but is provided for information. V equals the hydraulic conductivity K times the hydraulic gradient i. The hydraulic conductivity used is 1 inch/hr. The hydraulic gradient = (h + l) / l, where h = d / 2 and l = the sand depth (1.5 ft).

Source: King County, 1988

Surface Sand Filters

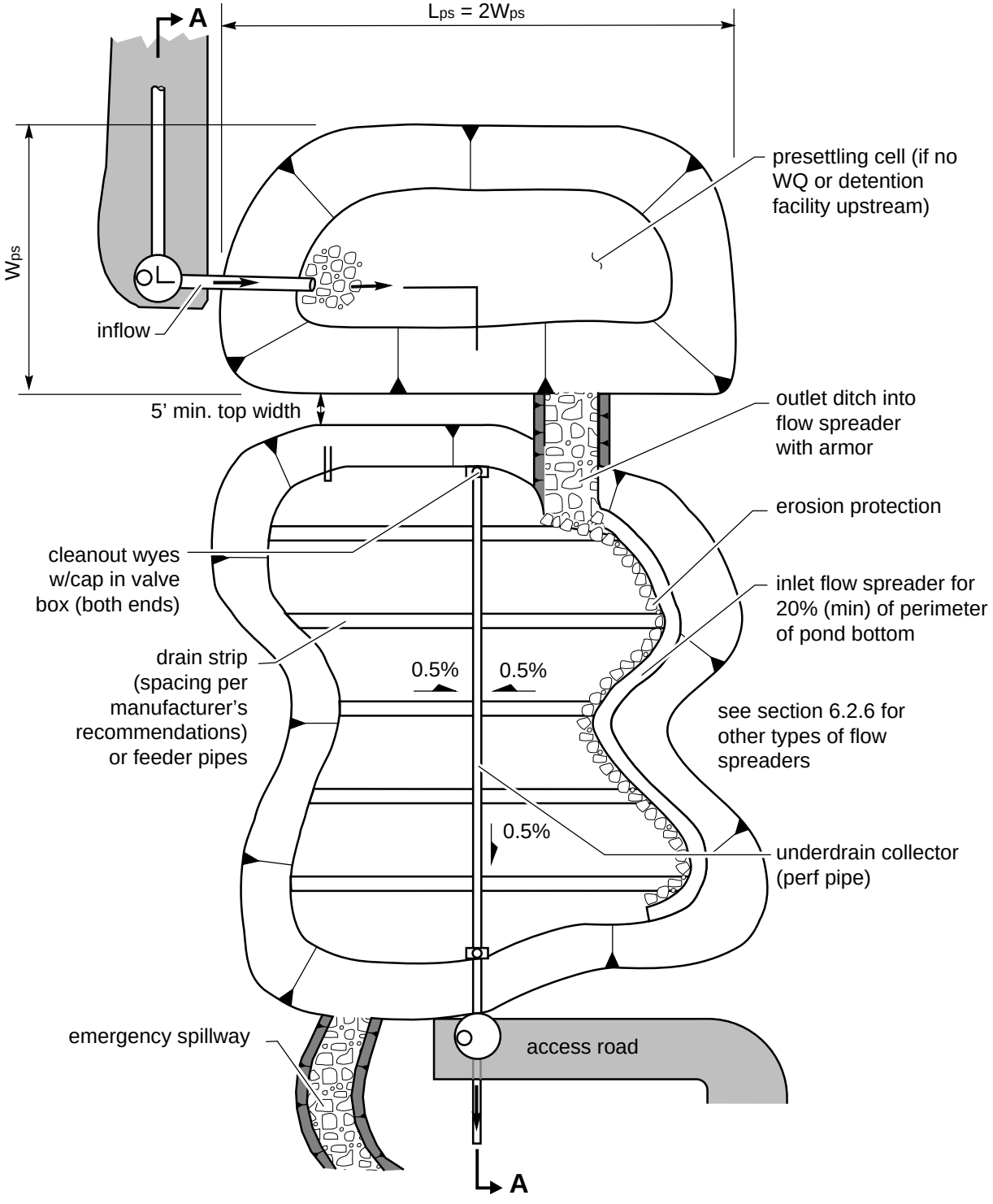


Figure 1: Plan: Surface Sand Filter
Not to Scale
Source: Washington, 2000.

Surface Sand Filters

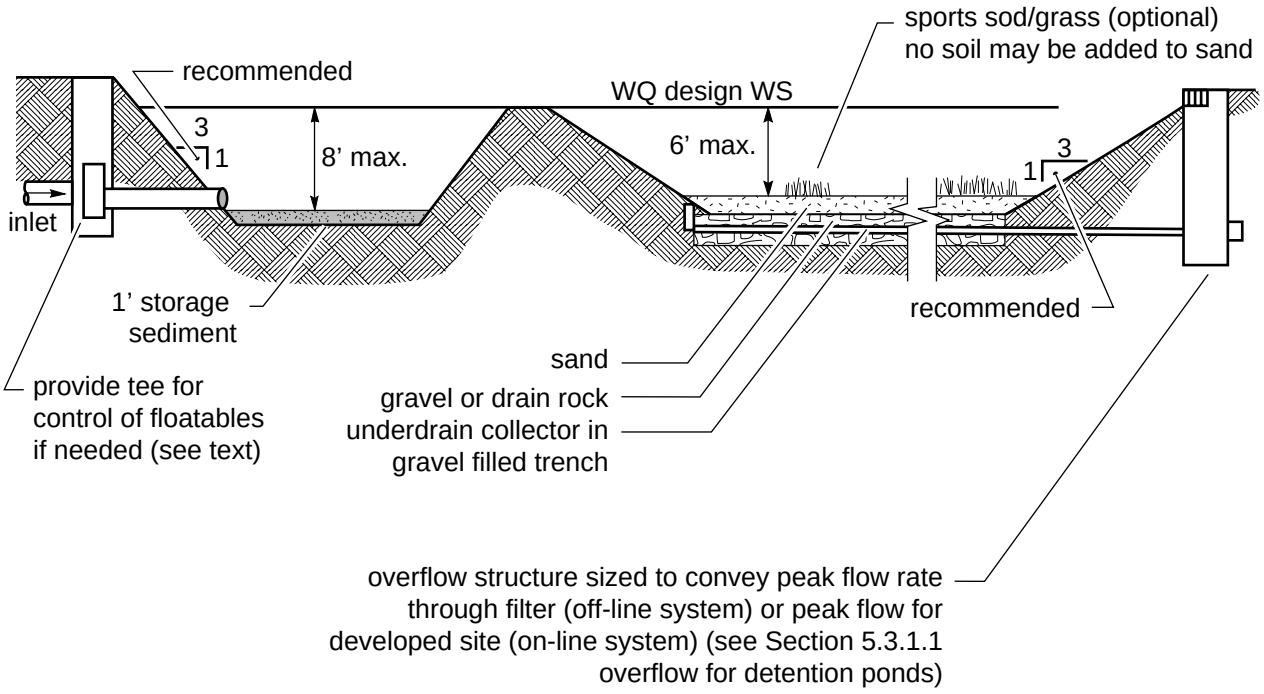


Figure 2: Section A-A: Surface Sand Filter
Not to Scale
Source: Washington, 2000.

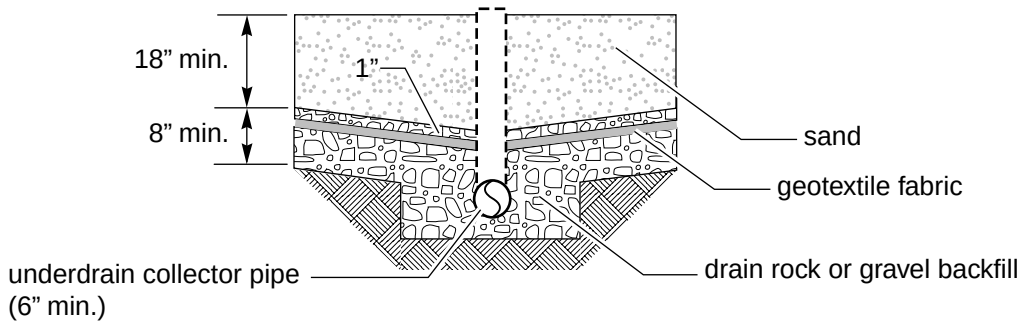


Figure 3: Trench Detail
Not to Scale
Source: Washington, 2000.

Surface Sand Filters

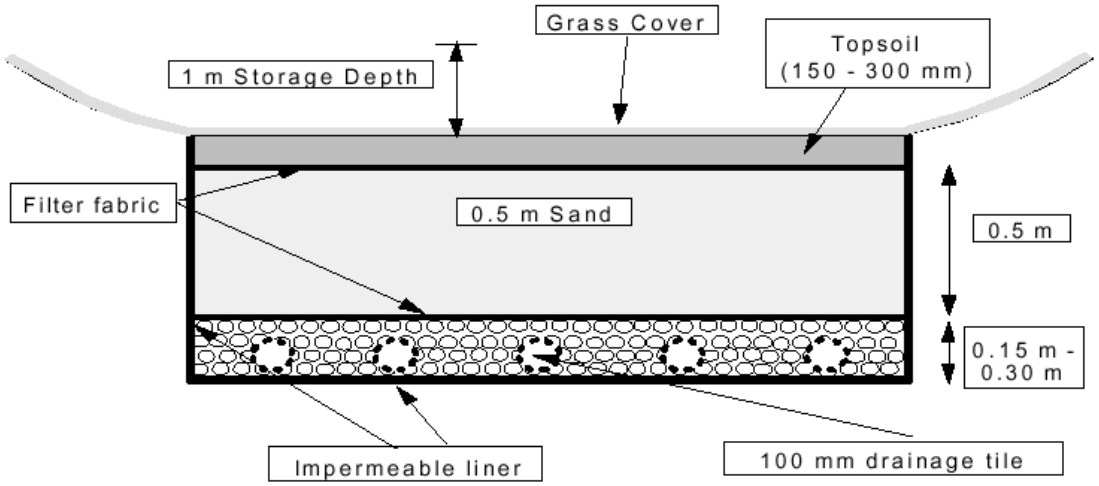


Figure 4: Sand Filter Cross-Section
Not to Scale
Source: Ontario, 1999.

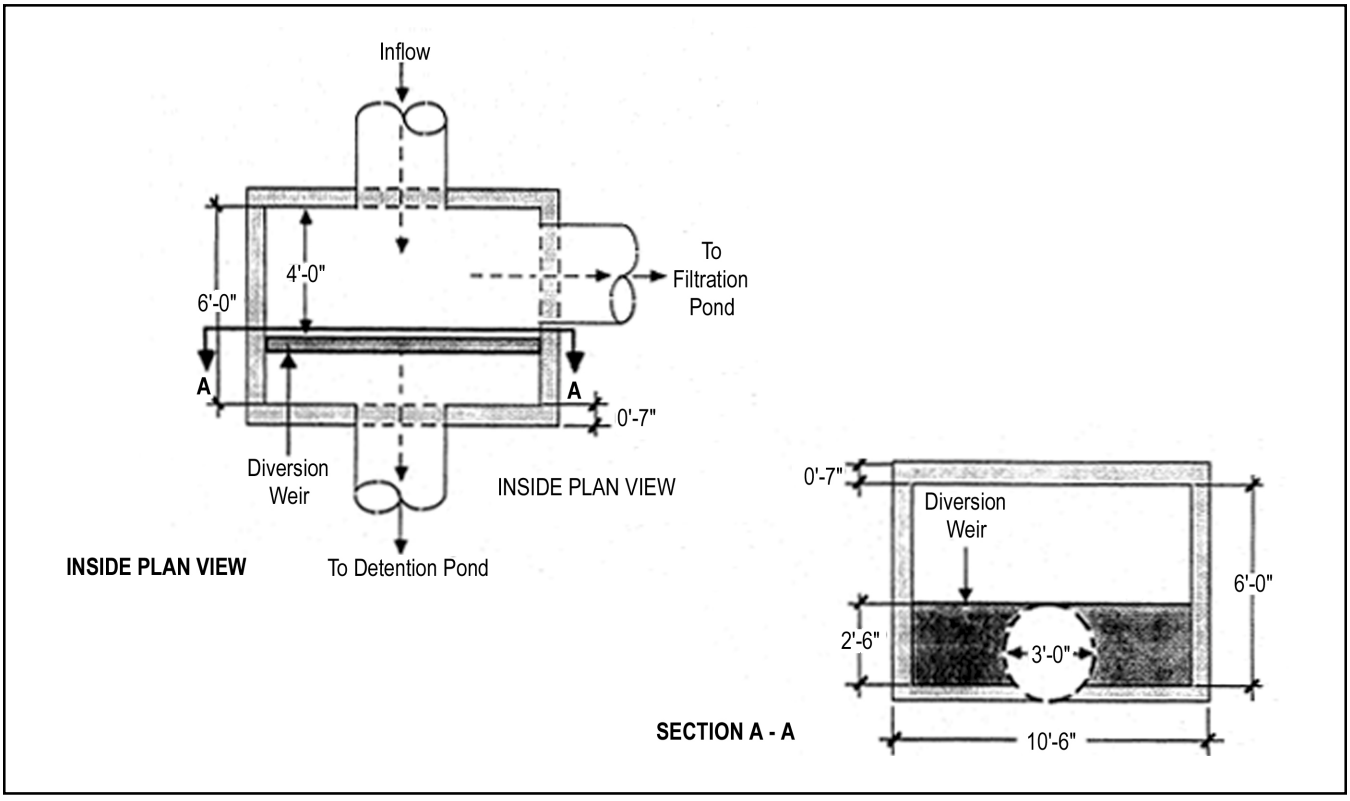


Figure 5: Isolation/Diversion Structure
Not to Scale
Source: Washington, 2000.

Surface Sand Filters

Design (continued)

Basic Components

- Surface sand filters generally employ the following layers, from top to bottom: sand, geotextile and an underdrain system.
- Runoff discharging to the sand filter must be pretreated (via a presettling basin, for example) to remove debris and other gross solids and any oil from high-use sites. (The type of pretreatment device will depend on the type of pollutants present.) The length-to-width ratio of the presettling basin should be 3:1 and the depth at 3 to 6 feet.
- Inlet structures (such as flow spreaders, weirs or multiple orifice openings) should be designed to minimize turbulence and to spread the flow uniformly across the surface of the filter media.
- Stone riprap or other dissipation devices should also be installed to prevent gouging of the sand media and promote uniform flow (see Fig. 1). Off-line outlet structures are typically sized for the 15-minute peak flow of a 2-year, 24-hour storm.
- An impermeable liner (clay, geomembrane or concrete) may be required under the filter to protect groundwater or where underflow could damage structures. If the impermeable liner is not required, a geotextile liner should be installed, unless the bed has been excavated to bedrock.

Sand Specification

The sand in a filter must consist of a medium sand meeting the size gradation (by weight) given in Table 2. The contractor must obtain a grain-size analysis from the supplier to certify that the No. 100 and No. 200 sieve requirements are met. A laboratory analysis to determine the sand's hydraulic conductivity *K* is also highly recommended. The designer should then adjust this number to account for conditioning of the sand during operation.

Underdrain Systems

Several types of underdrains may be used: a central collector pipe (with lateral feeder pipes or a geotextile drain strip in an 8-inch gravel backfill or drain rock bed) or a longitudinal pipe in an 8-inch gravel backfill or drain rock with a collector pipe at the outlet end.

- Hydraulically, the system is typically sized for the 15-minute peak flow from a 2-year, 24-hour storm, with 1 foot of head above the invert of the upstream end of the collector pipe. Local sizing requirements should be used when available.
- Internal diameters of underdrain pipes should be a minimum of 6 inches and 2 rows of half-inch holes spaced 6 inches apart longitudinally (max.), with rows 120 degrees apart (laid with holes downward). Maximum perpendicular distance between two feeder pipes must be 10 feet. All piping is to be schedule 40 PVC or greater wall thickness. Corrugated polyethylene pipe may also be used.

Table 2: Sand Medium Specification

U.S. Sieve Number	Percent Passing
4	95–100
8	70–100
16	40–90
30	25–75
50	2–25
100	<4
200	<2

Source: King County, 1998

- Main collector underdrain pipe should be at a minimum slope of 0.5 percent.

Surface Sand Filters

Table 3: Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	cm/sec	1×10^{-6} max.
Plasticity index of clay	ASTM D-423 & D-424	percent	Not less than 15
Liquid limit of clay	ASTM D-2216	percent	Not less than 30
Clay particles passing	ASTM D-422	percent	Not less than 30
Clay compaction	ASTM D-2216	percent	95% of Standard Proctor Density

Source: City of Austin in Washington State, 2000

Design (continued)

- A geotextile fabric must be used between the sand layer and drain rock or gravel and placed so that one inch of drain rock or gravel is above the fabric. Drain rock should be 1.5- to 0.75-inch rock or gravel backfill, washed free of clay and organic material.
- Cleanout wyes with caps or junction boxes must be provided at both ends of the collector pipes. Cleanouts must extend to the surface of the filter. A valve box must be provided for access to the cleanouts (see Fig. 1).

Impermeable Liners

Impermeable liners should be used when nonconventional soluble pollutants such as metals and organics are present and where the underflow could cause problems with structures or groundwater. Liners may be clay, concrete or geomembrane.

- Clay liners should have a minimum thickness of 12 inches and meet the specifications in Table 3.
- A geomembrane liner should be at least 30 mils thick and ultraviolet resistant. It should be protected from puncture, tearing and abrasion by installing geotextile fabric on the top and bottom of the geomembrane.
- Concrete liners may also be used for basins less than 1,000 square feet in area. Concrete should be 5 inches thick (Class A or better) and reinforced by steel wire mesh. The mesh should be 6 gauge wire or larger and 6- by 6-inch mesh or smaller. An “ordinary surface finish” is required. When the underlying soil is clay or has an unconfined compressive strength of 0.25 ton per square foot or less, the concrete should have a minimum 6-inch compacted aggregate base. This base must consist of either coarse sand and river stone or crushed stone or its equivalent with diameter of 0.75 to 1 inch.
- If an impermeable liner is not provided, an analysis should be made of possible adverse effects of seepage zones on groundwater and near building foundations, basements, roads, parking lots and sloping sites. Sand filters without impermeable liners should not be built on fill sites. They should be located at least 20 feet downslope and 100 feet upslope from building foundations.

Surface Sand Filters

Slopes and Siting

- Include an access ramp with a slope not to exceed 7:1 or equivalent for maintenance purposes at the inlet and the outlet of a surface filter.
- Side slopes for earthen or grass embankments should not exceed 3:1 (horizontal:vertical) to facilitate mowing.
- Some designs may require perimeter fencing to reduce safety hazards.
- High groundwater may damage underground structures or affect the performance of filter underdrain systems. There should be sufficient clearance (at least 2 feet is recommended) between the seasonal high groundwater level (highest level of groundwater observed) and the bottom of the BMP to obtain adequate drainage.
- Maximum longevity of the sand filter may be achievable by limiting its use only to impervious areas.

Sequencing

- Care should be taken during construction to minimize the risk of premature failure of the sand filter. This failure is caused by the deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper sequencing.
- Ideally, construction of the sand filters should take place after the site has been stabilized.
- Diversion berms should be maintained around the perimeter of the sand filters during all phases of construction. Sediment and erosion controls should be used to keep runoff and sediment away from the sand filter. Sand filters should not be used as temporary sediment traps included for construction activities.
- No runoff should enter the sand filter prior to completion of construction and the complete stabilization of the tributary areas.
- During and after excavation, all excavated materials should be placed downstream, away from the sand filters, to prevent redepositing during runoff events.

Construction

- Disturbed areas that are sediment sources in the contributing drainage area should be identified and stabilized to the maximum extent practicable.
- Where possible, excavation should be performed with backhoes rather than loaders. Heavy construction equipment should be avoided in favor of light, wide-tracked or marsh-track equipment. A light, wide-tracked, low-ground-pressure bulldozer (4 psig or less) should be used for grading.
- Overcompaction of the sand filter should be avoided to help ensure adequate filtration capacity.
- The underdrain piping must be reinforced to withstand the weight of the overburden.
- The minimum grade of the piping should be 1/8 inch per foot (approximately 1 percent slope).
- The careful selection of topsoil and sod for natural cover will help reduce the potential for failure. Sod with fine silts and clays will clog the top of the sand filter.

Surface Sand Filters

Requirements

Construction (continued)

- Side slopes of earthen embankments should not exceed 3:1 (horizontal: vertical). Fencing around sand filters may be recommended for some designs to reduce safety hazards.
- Careful level placement of the sand is necessary to avoid formation of voids within the sand that could lead to short-circuiting (particularly around penetrations for underdrain cleanouts) and to prevent damage to the underlying underdrain system. Voids between the trench walls and the geotextile fabric should also be avoided.
- Consolidation of material in the sand filters during construction must be taken into consideration. The depth of the bed can be stabilized by wetting the sand periodically, allowing it to consolidate, and then adding extra sand. This should be repeated until consolidation is complete. Mechanical compaction of the sand should be avoided.
- If sediment does enter the sand bed during construction, the entire sand bed, as well as the underdrain system, must be renewed after the site is stabilized.

Maintenance

- Maintenance is required for the proper operation of sand filters. Plans for sand filters should identify owners, parties responsible for maintenance and an inspection and maintenance schedule.
- All filter system designs must provide adequate access to the filter for inspection and maintenance.
- Most filters will show some decreased effectiveness after a few years, depending mostly on the activities occurring in the drainage area.
- Sand filters should be inspected after every major storm in the first few months after construction to ensure proper function. Thereafter, the sand filter should be inspected at least once every 6 months.
- Maintenance for sand filters consists of removing the first two or three inches of discolored sand and replacing it with new sand. The removed sand should be dewatered if necessary and then landfilled.
- Sediment removal within the basin should be performed when the sediment is dry. This prevents smearing of the basin floor and allows sediment to more readily separate from the basin floor.
- Silt and sediment should be removed from the surface of the filter when an accumulation of 1 inch has occurred or when the drawdown time increases beyond 20 percent of design value.
- Removal of sediment, trash and debris should be performed with rakes if possible. If construction equipment is used, only low-ground-pressure equipment, as specified in the construction requirements section, should be allowed.
- Vegetation should be maintained as needed. Devices with healthy vegetation tend not to clog. The use of flood- and drought-resistant varieties will minimize maintenance needs. Native vegetation may be an important option for some sites. Consider using professionals familiar with plantings used specifically for these design methods.
- Sediments, trash and debris should also be removed from the pretreatment basin on a regular basis to help ensure proper performance.

Surface Sand Filters

Sources

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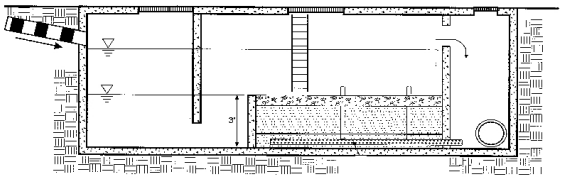
Underground Filters



Description

An underground filter is similar to a surface filter except that the sand (or other media) and underdrains are installed below grade in a vault. Underground filters are intended to address the spatial constraints that can be found in intensely developed urban areas where the drainage areas are highly impervious (such as parking lots). They can be used on small, urban sites where space is at a premium and where the soils or groundwater concerns would not support an infiltration device.

Underground filters are most effective when designed as off-line BMPs; they are intended primarily for quality control not quantity control. A diversion structure, such as a flow splitter or weir, is provided to route the "first flush" of runoff into the underground sand filter, while the remainder continues on to a stormwater quantity control BMP.

Two general types of underground filters are described in this section:

- Underground sand filters
- Proprietary underground filter systems

The underground sand filter is typically a three chamber underground system. The initial chamber takes care of pretreatment, utilizes a wet pool, and temporarily stores runoff. The first chamber is connected to a second sand filter chamber by a submerged wall. Water flows to, and is spread over the sand filter where pollutants are either trapped or strained out. The first two chambers temporarily store water during storms. Perforated drains extend into a third chamber which collects filtered runoff.

Underground sand filters have been demonstrated to be effective in removing many of the common pollutants found in urban stormwater runoff, especially those found in particulate form.

These devices are to be used only for drainage areas that have been stabilized. Sediment suspended in runoff during construction could quickly clog the sand filter and render it useless.

Purpose

Water Quantity

Flow attenuation	☐
Runoff volume reduction	☐

Water Quality

Pollution prevention

Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**

Pollutant removal

Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	■
Floatables	■
Oil and grease	◧

Other

Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
☐ Little or no design benefit

Underground Filters

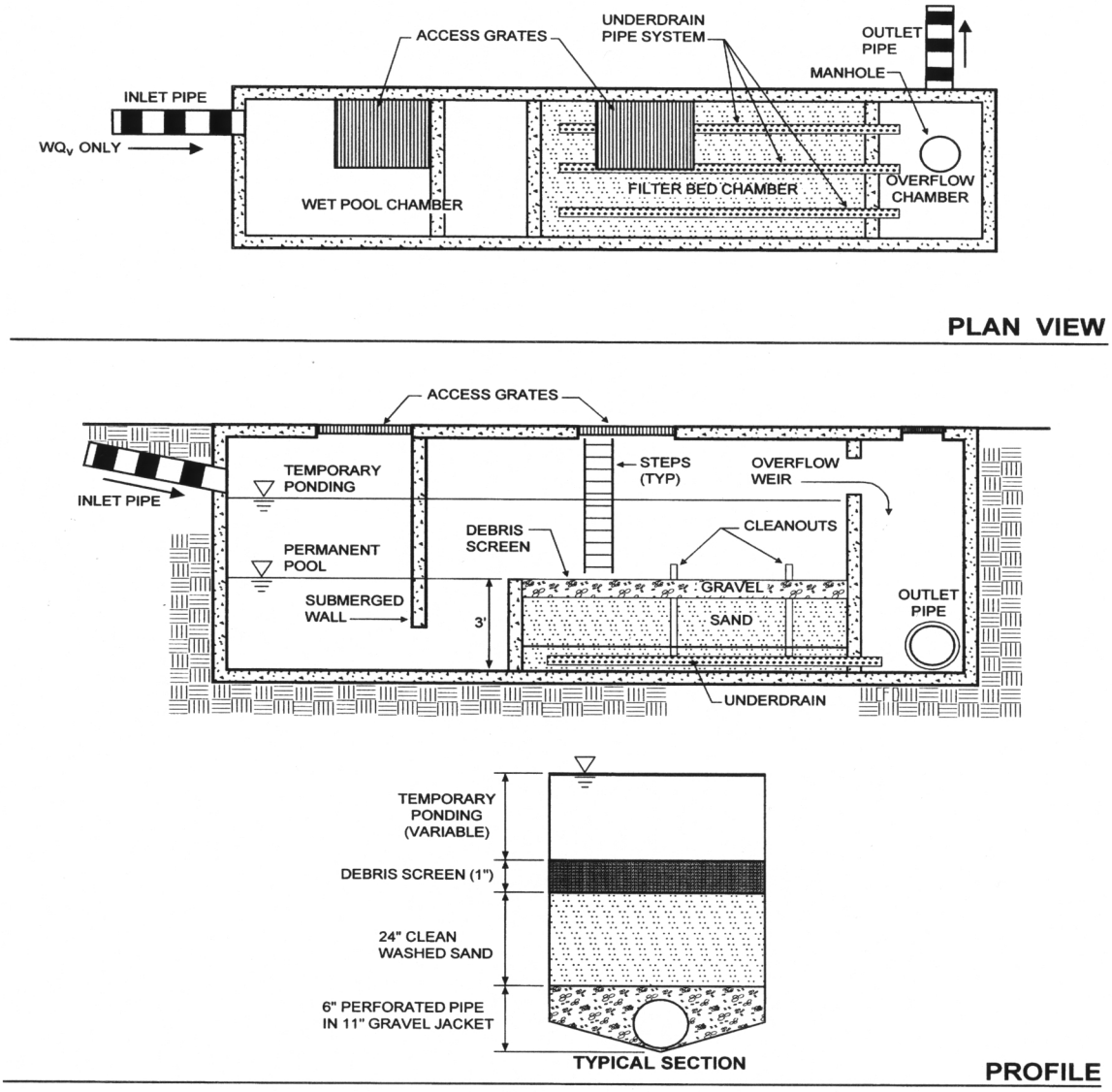


Figure 1: Underground Vault ("D.C.")Sand FIlter

Source: Maryland Department of the Environment, 1998

Underground Filters

A typical underground sand filter is shown in Figure 1. Two types of proprietary underground filters are discussed in further detail in the design section of this document.

Advantages

- Applicable in small drainage areas of 1 to 10 acres.
- Have few constraints; therefore, can be applied to most development sites. Underground filters can be used where space limitations preclude above-ground facilities
- Good retrofit capability.
- May require less space than other treatment control BMPs and can be used on highly developed sites and sites with steep slopes.
- Provides high removal efficiencies for total suspended solids.

Limitations

- May require frequent maintenance, depending on the watershed.
- Relatively costly to build and install.
- A relatively large elevation difference (head) between the inlet and outlet of the filter is usually needed.
- Should not be used in areas where heavy sediment loads are expected. Tributary areas should be fully stabilized.
- Generally do not provide quantity control.
- Performance reduced if underdrains or if filter media freezes.

Design

General Design Considerations for Underground Sand Filters

Sand filter design criteria apply to underground filters as well. In addition, the following specific recommendations apply for underground filters.

- One foot of sediment storage in the presettling cell must be provided.
- If a retaining baffle is necessary for oil/floatables in the presettling cell, must extend at least one foot above to one foot below the design flow water level, and be spaced a minimum of 5 feet horizontally from the inlet. Provision for the passage of flows in the event of plugging must be provided. Access opening and ladder must be provided on both sides of the baffle.
- Optimize inlet flow distribution with minimal sand bed disturbance. A maximum of 8-inch distance between the top of the spreader and the top of the sand bed is suggested. Flows may enter the sand bed by spilling over the top of the wall into a flow spreader pad or alternatively a pipe and manifold system may be used. Any pipe and manifold system must retain the required dead storage volume in the first cell, minimize turbulence, and be readily maintainable.

Underground Filters

Design (continued)

- Erosion protection must be provided along the first foot of the sand bed adjacent to the spreader. Geotextile fabric secured on the surface of the sand bed, or equivalent method, may be used.
- If a pipe and manifold system is used, the minimum pipe size should be 8 inches. Multiple inlets are recommended to minimize turbulence and reduce local flow velocities.
- Provision for access should follow the same general guidelines as access to wet vaults.
- A dewatering gate valve should be constructed just above the sand bed.
- Removable panels must be provided over the entire sand bed. Panels must be at grade, have steel lifting rings, and weigh no more than 5 tons each.
- The filter bed should consist of a sand top layer, a geotextile fabric second layer with an underdrain system
- A geotextile fabric over the entire sand bed that is flexible, highly permeable, three-dimensional matrix, and adequately secured. This is useful in trapping trash and litter. This fabric is to be rolled up, removed, cleaned and reinstalled during maintenance operations.
- To prevent anoxic conditions, a minimum of 24 square feet of ventilation grate must be provided for each 250 square feet of sand bed surface area. For sufficient distribution of air flow across the sand bed, grates may be located in one area if the sand filter is small, but placement at each end is preferred. Small grates may also be dispersed over the entire sand bed area.
- Filter Design: The Surface Sand Filters BMP section provides detailed recommendations for sand filter design. These recommendations are pertinent to underground sand filter design as well.

Cold Weather Considerations

- Subsurface filters, while less susceptible to freezing that surface filters, also suffer in performance because of freezing in underdrain pipes or the filter media. Filters which utilize organic media are particularly prone to freezing because they retain water.
- Filters commonly receive runoff from parking areas and roads which are subject to sanding and salting. As a result, they are particularly susceptible to clogging. Pretreatment is essential to avoid regular problems in this regard.
- Most filter systems can be designed to be operated seasonally using a bypass. Where this is not done, it is recommended that the following measures be implemented in order to improve filter performance during cold weather:

  Flow controls and bypasses should be designed using weirs where possible

  Designs should include an oversized pretreatment chamber (equivalent to 50% of the design treatment volume)

Two specific underground sand filter designs are described below.

Underground Filters

D.C. Sand Filter

The underground vault sand filter was developed by the District of Columbia in the late 1980s. This filter design incorporates three chambers. The first chamber and the throat of the second chamber contain a permanent pool of water and functions as a sedimentation chamber and an oil and grease and floatables trap, as well as provides for temporary runoff storage. A submerged opening or inverted elbow near the bottom of the dividing wall connects the two chambers. This submerged opening provides a water seal that prevents the transfer of oil and floatables to the second chamber which contains the filter bed. During a storm event, water flows through the opening into the second chamber and onto the filter bed. Additional runoff storage volume is provided above the filter bed. Filtered water is collected by a gravel and perforated pipe underdrain system and flows into the third chamber, which contains a clearwell and a connection to the storm drain system. A schematic of the "D.C. Sand Filter" is shown in Figure 1.

Delaware Sand Filter

Another underground vault sand filter, also termed a "perimeter" sand filter because it is particularly suited for use around the perimeter of parking lots, was developed in Delaware by Shaver and Baldwin and is known as the "Delaware Sand Filter." This system contains two chambers and a clearwell. Storm water runoff enters the first chamber, which serves as a sedimentation chamber. Water then flows over a series of weirs and into the second chamber which contains the filter media. Additional storage volume is provided by water temporarily ponding in both chambers. Filtered water is collected by a series of gravel and perforated pipe underdrains, and flows into a clearwell that contains a connection to the storm drain system. A schematic of the Delaware Sand Filter is shown in Figure 2.

Proprietary Designs

There are several different proprietary underground filters as well. These systems consist of the same general configuration, but have special filter media. Two systems presented in this BMP section are StormFilter™ and Hydro-Kleen.™

These systems represent only two of the available proprietary systems on the market; their inclusion in this BMP section are in no way an endorsement. One of the main problems facing the use of proprietary systems is the lack of peer-reviewed performance data for these systems. However, EvTEC (Environmental Technology Evaluation Center) may be including these systems in a series of proprietary BMP evaluations scheduled for 2001. For more information, see EvTEC's website at www.cerf.org/evtec/evals.htm.

StormFilter™

A StormFilter™ system consists of concrete vaults that house siphon-driven cartridges containing alternative filtration media, including fabric inserts, perlite, zeolite, and the patented CSF leaf media. A typical StormFilterTM contains an inlet bay which serves as a grit chamber and provides a flow transition into the cartridge bay. This transition is via a flow spreader that traps floatables, oils, and surface scum prior to their entering the cartridge bay. After the surface scum is separated by the flow spreader, the water passes over an energy dissipater and begins filling the cartridge bay. Once the water in the vault reaches a designed level, the siphon mechanism is triggered which pulls the polluted water through the filtration media where a number of physical and chemical processes remove both high and low concentration pollutants. The treated stormwater passes through a slotted center tube where it is then routed via pipe manifold that is cast into the floor of the concrete vault. After leaving the pipe manifold, the treated water can then be sent directly to a waterway.

Underground Filters

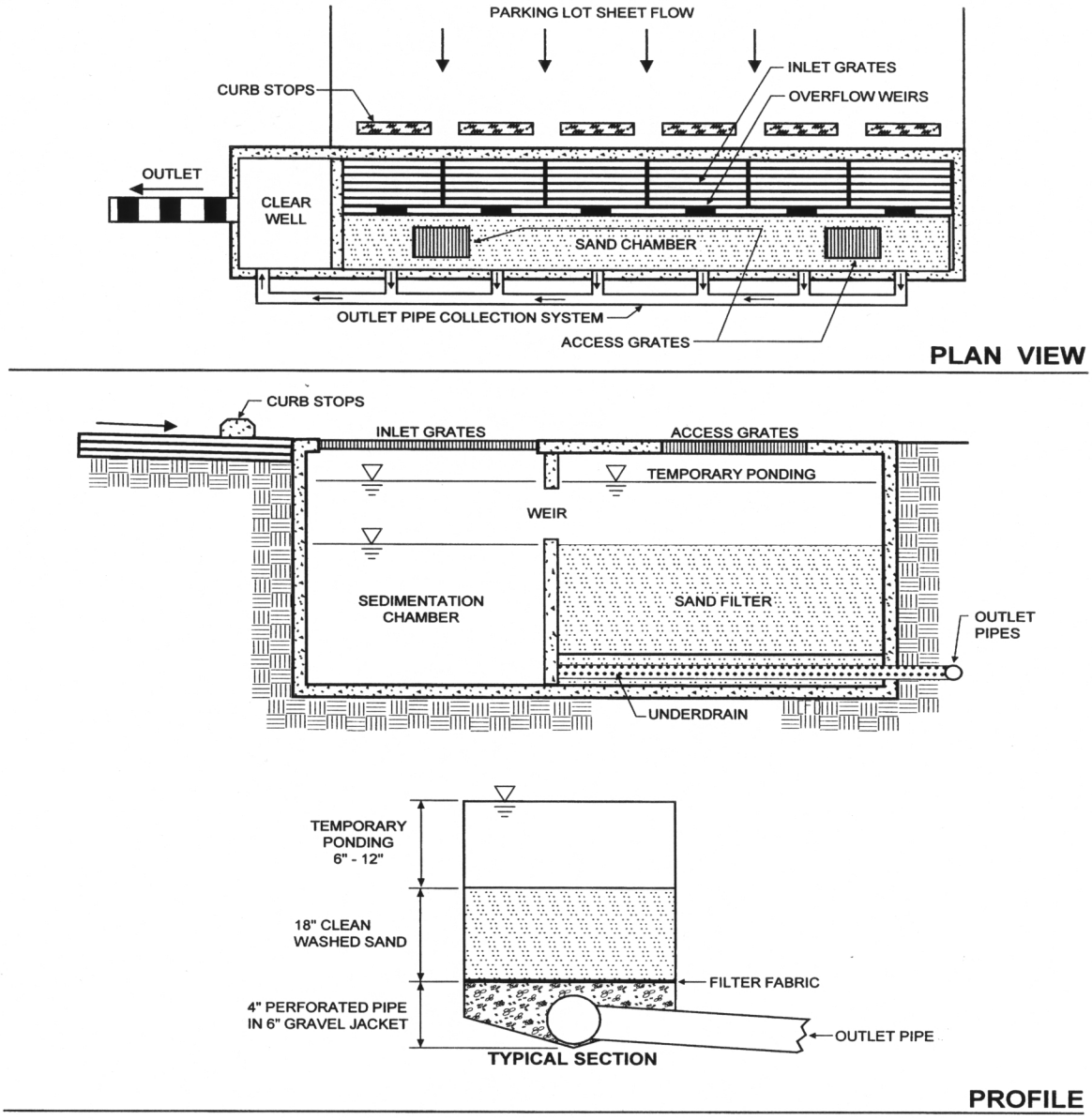


Figure 2: Delaware Sand Filter

Source: Maryland Department of the Environment, 1998

Underground Filters

Design (continued)

The StormFilter™ is offered in four different configurations; cast-in-place, precast, linear and catch basin. Two of these are shown in Figure 3.

Hydro-Kleen™

Hydro-Kleen™ is a system which utilizes a multimedia filtration design combined with sedimentation containment and overflow protection. Each unit is manufactured to fit the catch basin or drain it is inserted into. The units are placed into existing catch basins by removing the cover or grate, inserting the unit into the basin and replacing the cover. Water flow enters the unit and is directed into a sedimentation chamber that collects course sedimentation and debris, which passes through the grate cover. The water then passes from the sedimentation side through a transition inlet at the top of the sedimentation chamber into the filtration side. The first media (Sorb44) catches Hydrocarbon contaminants through absorption to a hydrophobic pulp material. The second media is an activated carbon (AC10), which polishes any remaining Hydrocarbons in the water and removes a variety of organically bound metals and other contaminants that may be in the runoff. The water then passes through the bottom into the catch basin or drainpipes. An illustration of the Hydro-KleenTM system is provided in Figure 4.

Sequencing

- Care should be taken during construction to minimize the risk of premature failure of the sand filter. This failure is caused by the deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper sequencing.
- Ideally, construction of the sand filters should take place after the site has been stabilized.
- No runoff should enter the sand filter prior to completion of construction and the complete stabilization of the tributary areas.
- Sand filters should not be used as temporary sediment traps included for construction activities.
- Maximum longevity of the sand filter may be achievable by limiting its use only to impervious areas.
- Construction runoff may be routed to pretreatment sedimentation BMP's, but discharge from these BMP's should bypass downstream sand filters.

Construction

- Sand filters should not be used as temporary sediment traps during construction.
- Consolidation of material in the sand filters during construction must be taken into consideration. The depth of the bed can be stabilized by wetting the sand periodically, allowing it to consolidate, and then adding extra sand. This should be repeated until consolidation is complete. Mechanical compaction of the sand should be avoided.
- Careful level placement of the sand is necessary to avoid formation of voids within the sand that could lead to short-circuiting, (particularly around penetrations for underdrain cleanouts) and to prevent damage to the underlying underdrain system.

Underground Filters

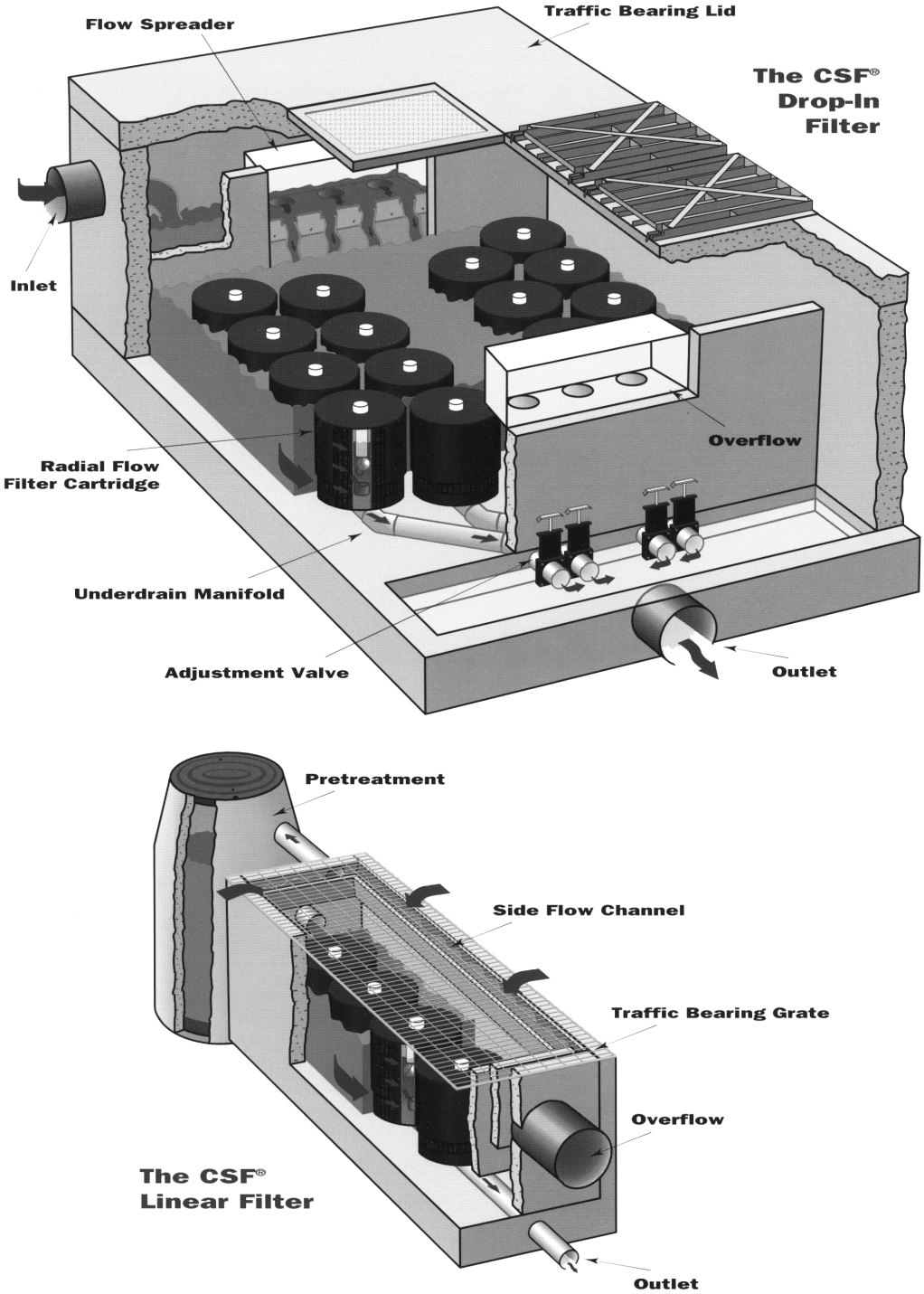


Figure 3: StormFilter™ Systems
Source: Stormwater Management™, Inc.

Underground Filters

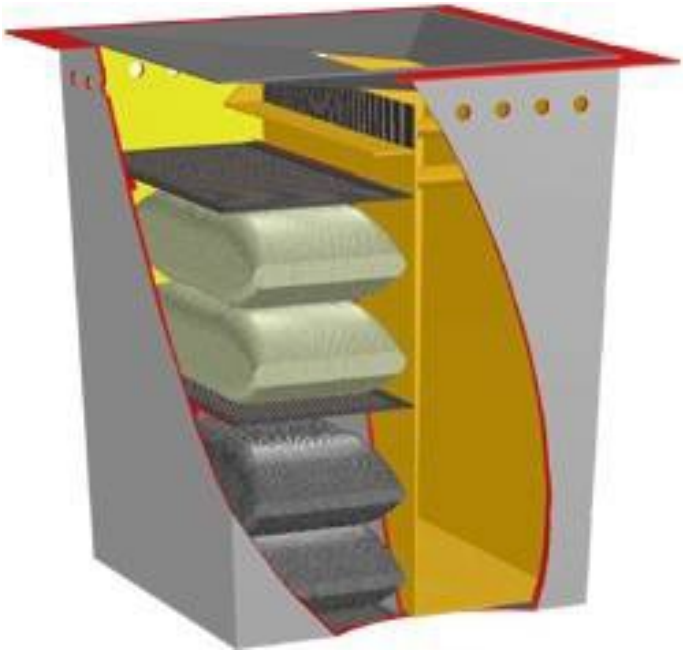


Figure 4: Hydro-Kleen™ System
Source: Hydro Compliance Management™, Inc.

Requirements

Maintenance

- Maintenance is required for the proper operation of sand filters as it is with all BMPs. Plans for sand filters should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule.
- All filter system designs must provide adequate access to the filter for inspection and maintenance.
- Depending mostly on the activities occurring in the drainage area, most filters will show some decreased capacity for filtration after a few years.
- Sand filters should be inspected after every major storm in the first few months after construction to ensure proper function. Thereafter, the sand filter should be inspected at least once every 6 months.
- Maintenance for sand filters consists of removing the first two or three inches of discolored sand, and replacing this with new sand. The sand that has been removed would then be dewatered, if necessary, and then landfilled.
- Silt/sediment should be removed from the surface of the filter when an accumulation of 1 inch has occurred or when the down time increases beyond 20 percent of design value.
- Sediments, trash and debris should also be removed from the pretreatment basin on a regular basis to ensure proper performance.

Underground Filters

Sources

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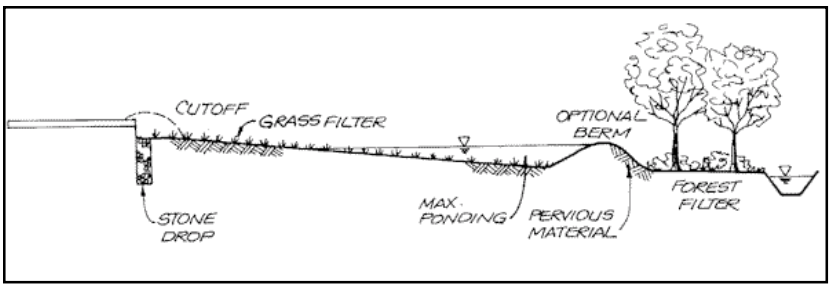
Filter Strips



Description

Filter strips (also known as vegetated filter strips, grass filter strips and grassed filters) are densely vegetated, uniformly graded areas that treat sheet flow from adjacent impervious surfaces. Filter strips function by slowing runoff velocities, trapping sediment and other pollutants and providing some infiltration. While frequently planted with turf grass, filter strips may also employ native vegetation, such as meadow or prairie, which may be more effective in treating nutrients. In addition, trees and shrubs may be incorporated into portions of the strip to create visual screening as well as a physical barrier. (See Figure 1.)

Filter strips are best suited to treating runoff from roads and highways, roof downspouts and small parking lots, and they are ideal components of the "outer zone" of a stream buffer. In addition, filter strips are frequently used as a pretreatment system for stormwater destined for other BMPs such as filters or bioretention systems.

A challenge associated with filter strips is the difficulty of maintaining sheet flow. Urban filter strips are often short-circuited by concentrated flows, which results in little or no treatment of stormwater runoff. To avoid this problem, filter strip design can incorporate a level spreader to distribute concentrated flow along the width of the strip.

Filter strips were originally used as an agricultural treatment practice and have more recently evolved into an urban practice. Studies in agricultural areas indicate that a 15-foot wide grass buffer can achieve a 50 percent removal rate of nitrogen, phosphorus and sediment and that a 100-foot buffer can remove 70 percent of these constituents. Urban runoff studies suggest a minimum removal rate of 35 percent of solids and 40 percent of nutrients. This assumes a filter strip that is properly designed, constructed and maintained.

Purpose

Water Quantity	
Flow attenuation	◧
Runoff volume reduction	◧
Water Quality	
Pollution prevention	
Soil erosion	☐
Sediment control	◧
Nutrient loading	◧
Pollutant removal	
Total suspended sediment (TSS)	◧
Total phosphorus (P)	☐
Nitrogen (N)	☐
Heavy metals	☐
Floatables	◧
Oil and grease	◧
Other	
Fecal coliform	☐
Biochemical oxygen demand (BOD)	☐

■ Primary design benefit
◧ Secondary design benefit
☐ Little or no design benefit

Filter Strips

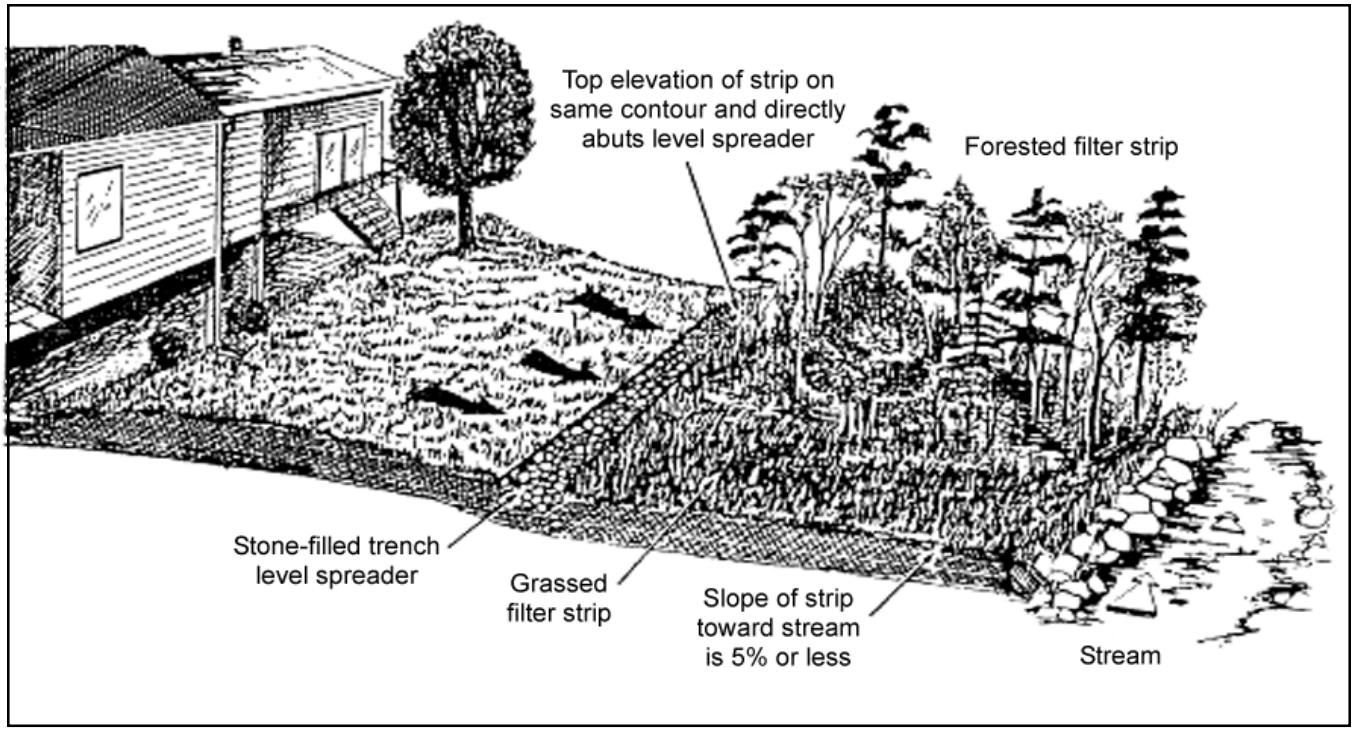


Figure 1: Filter Strip Combining Grassed and Wooded Areas
Source: Claytor, 1996

Advantages

- Filter strips help remove sediment and associated insoluble contaminants from runoff.
- They allow increased infiltration opportunity for soluble nutrients and pesticides to drain into the soil.
- Filter strips work well in residential areas, where they provide open space for recreation activities, help maintain riparian zones along streams, reduce streambank erosion and provide animal habitat. (See Figure 2)
- Since they do not pond water on the surface for long periods, filter strips help maintain temperature norms of the water, thereby protecting or providing habitat for aquatic life.
- Filter strips can be useful as sediment filters during construction. In some settings, this may only require preservation of an appropriately located area of existing vegetation. (See Design section for details.)
- Filter strips with taller, denser vegetation can help provide a visual barrier from such areas as roads, factories or recreation sites.
- Filter strips with dense native vegetation can trap dust blowing off a construction site.
- They are relatively simple and inexpensive to install, employing only planting and perhaps some earthwork.
- Filter strips are relatively low-maintenance practices.

Filter Strips

- They tend to be low-cost as well, since their plantings and maintenance often overlap with what would be done on the site regardless of stormwater management practices.

Limitations

- They are not appropriate for hilly or intensively paved areas due to high-velocity runoff.
- These systems are difficult to monitor, and thus there is less available data on their effectiveness for pollutant removal.
- Use of filter strips tend to be impractical in watersheds where open land is scarce and/or expensive.
- In general, filter strips should not accept highly contaminated "hotspot" runoff, since infiltration could result in groundwater pollution and damage to vegetation..
- Filter strips tend to be poor retrofit options since they consume a relatively large amount of space and cannot treat large drainage areas.
- Improper grading can render the practice ineffective.
- Since filter strips cannot provide enough storage or infiltration to significantly reduce peak discharge or volume of runoff, the practice may be best implemented as one of a series of stormwater BMPs.
- Filter strips are only effective if sheet flow can be maintained through the filter strip.

Requirements

Design

- Ordinarily, forests and other natural areas should not be destroyed to create a filter-strip system. Such areas may already be functional or may only need to be enhanced (with, for example, level spreaders or repair to eroded spots) to function properly as treatment systems.
- The design of filter strips must be specific to the site; widths, for example, vary greatly depending on proximity of streams or lakes.
- Filter strips must be at least 15 feet wide in the direction of flow in order to be effective, however greater widths will enhance treatment. The steeper the slope, the wider the strip should be.
- The Natural Resources Conservation Service (NRCS) recommends a minimum of 150 feet of filtering buffer between a land disturbance activity and a water body. Depending on soil types and slopes, the width may need to be even greater.
- The length of the filter strip should stretch the entire length of the impervious surface from which stormwater originates, and when adjacent to a natural water body, they should stretch the entire length of the property or shoreline.
- If soil and vegetation within designated buffer areas or zones are disturbed as part of the site work, they should be designed to act as filter strips. Disturbance of native vegetation in buffer areas should be avoided whenever possible.

Filter Strips

Design (continued)

- In general, filter strip slopes should be no less than 1 or 2 percent and no greater than 6 percent. Greater slopes will encourage concentrated flow and flatter slopes may result in ponding.
- Top and toe of slope should be as flat as possible to encourage sheet flow and prevent erosion.
- The area immediately upslope from the filter strip may also need to be shaped and graded to ensure sheet flow.
- Concentrated flow should not be discharged into filter strips. If flows are concentrated, a level spreader should be included to spread the flow out over the entire length of the filter strip.

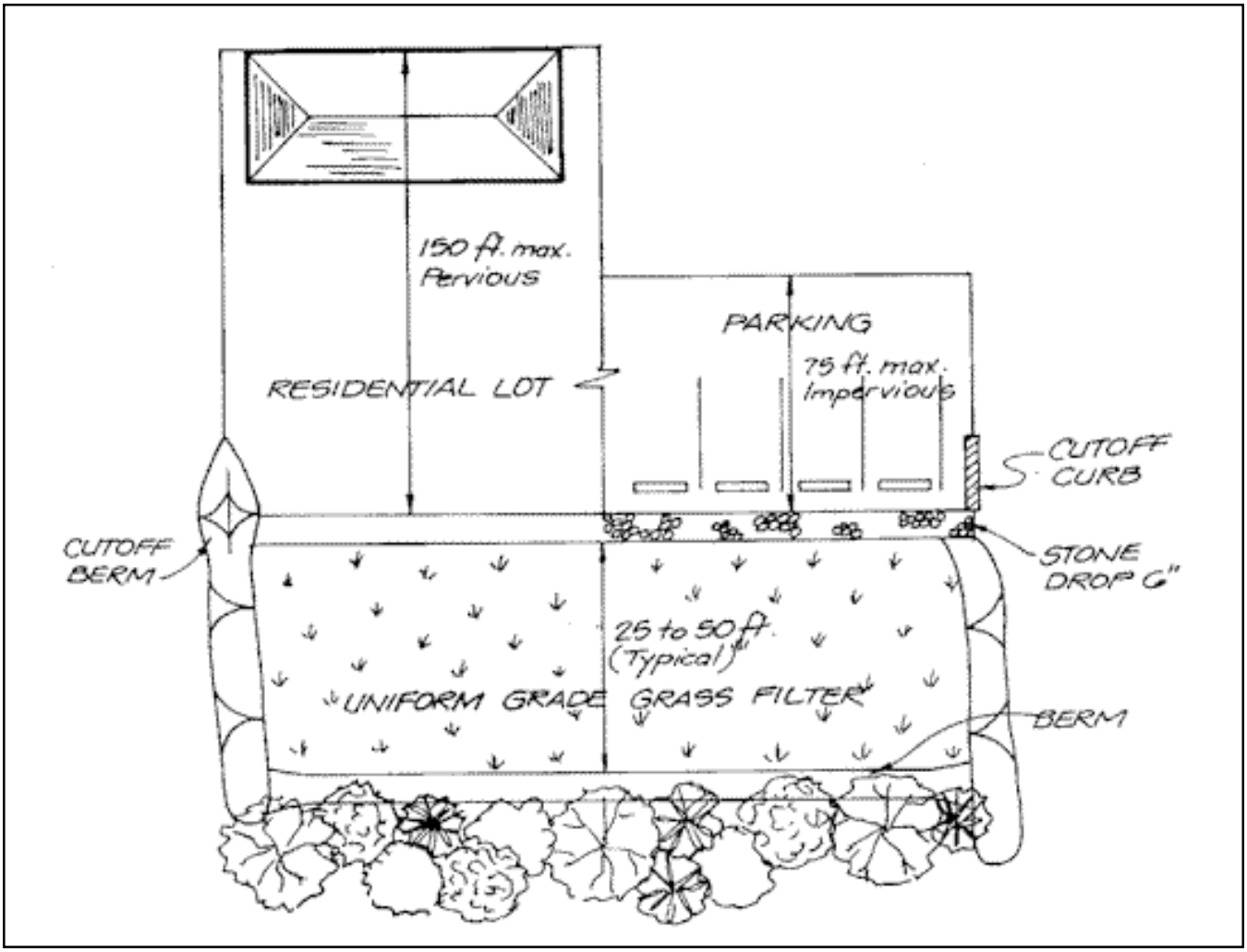


Figure 2: Filter Strip Plan
Source: Center for Watershed Protection, 2000

Filter Strips

- Level spreaders can take on many configurations. Level spreaders must take concentrated flow and spread it out into sheet flow upstream of the filter strip. This can be accomplished in many different ways. The key is that there must be a long, continuous and level overflow elevation. This can be a curb, a concrete weir or a level trench (12 inches wide by 24 inches deep), filled with pea gravel or crushed stone.

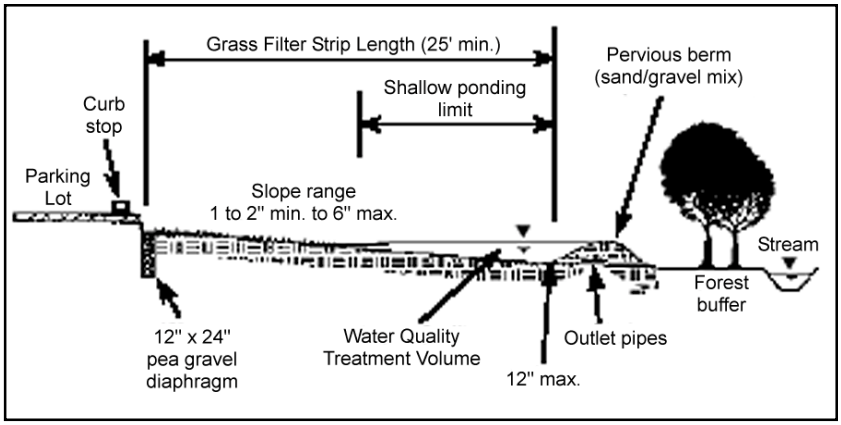


Figure 3: Filter Strip Profile
Source: Claytor & Schueler, 1996.

- To enhance the effectiveness of the filter strip, install a pervious berm of sand and gravel (see Fig. 3) at the toe of the slope. This could also include outlet pipes flowing through it or an overflow weir. This provides an area for temporary shallow ponding to accommodate a portion or all of the water quality volume.
- Select plants that are able to withstand flowing water and both wet and dry periods. See On-Lot Infiltration BMP for plant lists.
- When a filter strip is used during construction, its design should be incorporated into the final post-construction landscape. This may mean selecting vegetation that will reach an appropriate height at maturity and offer an attractive appearance.
- Depending on adjacent land use and traffic, filter strips may require fencing to control destructive access by vehicles, pedestrians and animals.
- Filter strips are typically designed to handle flows from the 1 to 2 year storms and are unable to reduce flow rates of large storm events. Depending on slope and vegetation, the flows from larger storms could damage filter strips. If this is the case, the design should incorporate a bypass system into supplementary BMPs.

Construction

- Accurate grading is essential, since even small departures from design slopes can eliminate sheet flow and decrease effectiveness.
- All filter strips should use appropriate soil-stabilization methods, such as mulch (at a minimum), or preferably mats or erosion control blankets (see other BMP sections).
- If a filter strip must be interrupted by construction entrances, resulting in removal of natural vegetation, artificial buffer techniques must be installed: for example, vehicle tracking pads or silt fences.

With minimal maintenance, filter strips can be effective indefinitely. Those that are not maintained properly may

Filter Strips

Maintenance

quickly become nonfunctional. Maintenance basically involves normal grass or shrub-growing activities such as mowing, trimming, removal of invasive species, and replanting when necessary.

Filter strips require more tending as the volume of sediment increases. Periodically, strips used for sediment removal may require regrading and reseeding of their upslope edge. When used during construction activities, and if a high volume of sediment builds up, the strip may need to be reworked and replanted. The same would be necessary if concentrated flow erodes a channel through the strip.

Annual

(Semiannual in Year 1)

- Inspect pea gravel diaphragm/level spreader for clogging and effectiveness and remove built-up sediment.
- Inspect for rills and gullies. Immediately fill with topsoil, install erosion control blanket and seed or sod.
- Inspect to ensure grass is well established. If not, either prepare soil and reseed or replace with alternative species. Install erosion control blanket.

Regular, Frequent

- Mow turf grass with low ground pressure equipment to a three- or four-inch height. Cut only when soil is dry to prevent tracking damage to vegetation, soil compaction and flow concentrations.

Regular, Infrequent

- Remove sediment and replant in areas of buildup.
- Limit fertilizer applications based on plant vigor and soil test results.

Filter Strips

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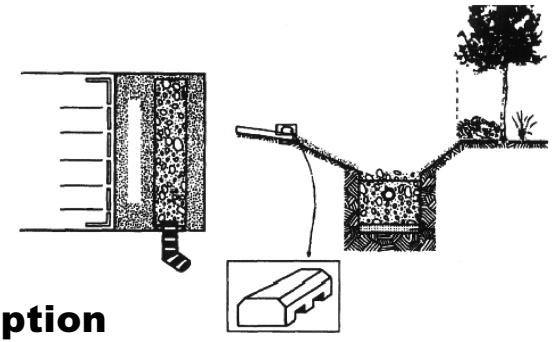
BMPs in Series



Description

BMPs in series incorporate several stormwater treatment mechanisms in a sequence to enhance the treatment of runoff. Also called a "stormwater treatment train," they consist of a series of BMPs and natural features, each designated to treat a different aspect of runoff, maximizing pollutant removal and stormwater infiltration. BMPs in series could, for example, include a combination of vegetated filter strips with grassed swales and infiltration basins, and the use of pond systems. An example of using BMPs in series is shown in Figure 1.

By combining structural and/or non-structural treatment mechanisms in series rather than using a single method of treatment for stormwater runoff, the levels and reliability of pollutant removal can be improved. Employing BMPs in series makes it possible to use a single desired facility that might not provide the necessary level of stormwater treatment because another level of treatment will occur downstream. The effective lifetime of a BMP can be increased by combining it with a pretreatment device, such as a buffer strip and grassed swale, to remove suspended particulates prior to treatment in the downstream unit. Sequencing of BMPs can also reduce the potential for re-suspension of deposited sediments by reducing flow energy levels or by providing longer flow paths for runoff.

Advantages

- Improved water quality and runoff control.
- Creation of wildlife habitat corridors, greenways and open space.
- Community involvement and participation.
- Protection of downstream water bodies.

Limitations

- Requires initial design and layout before construction sequencing can begin.
- Maintenance required on several types of BMPs.
- May require large land area.

Purpose

Water Quantity		
Flow attenuation	*	■
Runoff volume reduction	*	■
Water Quality		
Pollution prevention		
Soil erosion	*	■
Sediment control	*	■
Nutrient loading	*	■
Pollutant removal		
Total suspended sediment (TSS)	*	■
Total phosphorus (P)	*	■
Nitrogen (N)	*	■
Heavy metals	*	■
Floatables	*	■
Oil and grease	*	■
Other		
Fecal coliform	*	■
Biochemical oxygen demand (BOD)	*	■

* *Varies depending upon system design.*

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

BMPs in Series

Requirements

Design

The feasibility of using BMPs in series on a site depends on the characteristics of the individual components in the sequence. Design criteria considerations depend on the requirements of the individual BMPs. The least expensive and most easily maintained component should be placed at the most upstream position in the series.

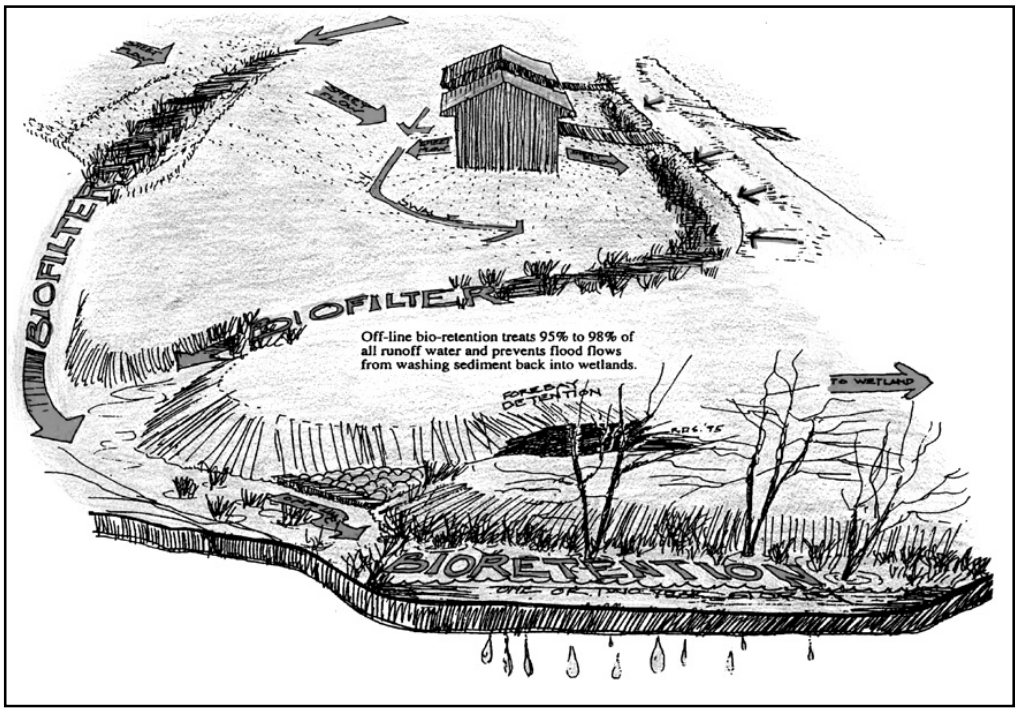


Figure 1. Stormwater Flow
Source: Robert Sykes, Dept. of Landscape Architecture, University of Minnesota

BMPs in Series/ Treatment Train Example: The Ecological Neighborhood

This example is a prototype design of a residential development that uses a treatment train system for stormwater management. It was designed for a site in Marshall, MN where excess runoff throughout the watershed had caused the Redwood River to flood.

The primary goals of stormwater treatment system were:

- To reduce the volume of water draining to the river through infiltration and storage within restored wetlands.
- To extensively clean stormwater before reaching the wetlands restored on site.
- To limit impervious pavement.

The first step in the treatment train process at the Marshall site is the effective management of stormwater on individual home sites. Each lot within the development accommodates stormwater movement in front and back yard grassed swales. Here water is filtered and allowed to infiltrate (See Figure 2). Water then flows from the swales to the end of each block where it enters rainwater gardens (or infiltration basins). Here particulate matter settles and water again has the opportunity to infiltrate. Grass swales and filter strips then connect to restored wetlands and complete the stormwater treatment train.

The system of garden swales and rain water gardens provides the following:

BMPs in Series

- Slows runoff, avoiding sudden extreme changes in wetland water level
- Filters water through vegetation to take up sediment and nutrients.
- Holds water on each block to settle sediment and to store water.
- Garden swales and rain water gardens are the most effective if residents are educated about the wise use of land fertilizers and pesticides.
- Native plants and animals need a diversity of connected wetland types in order to complete their life cycles, and some species at some stages of their lives need to be separated from human disturbance.
- Buffered areas around wetland aid in the protection of wildlife habitat areas.
- Several BMPs such as grassed swales, bioretention, wetlands, and filter strips can be used in series to increase wildlife habitat and increase stormwater storage and pollutant removal capacities (see Figure 4).

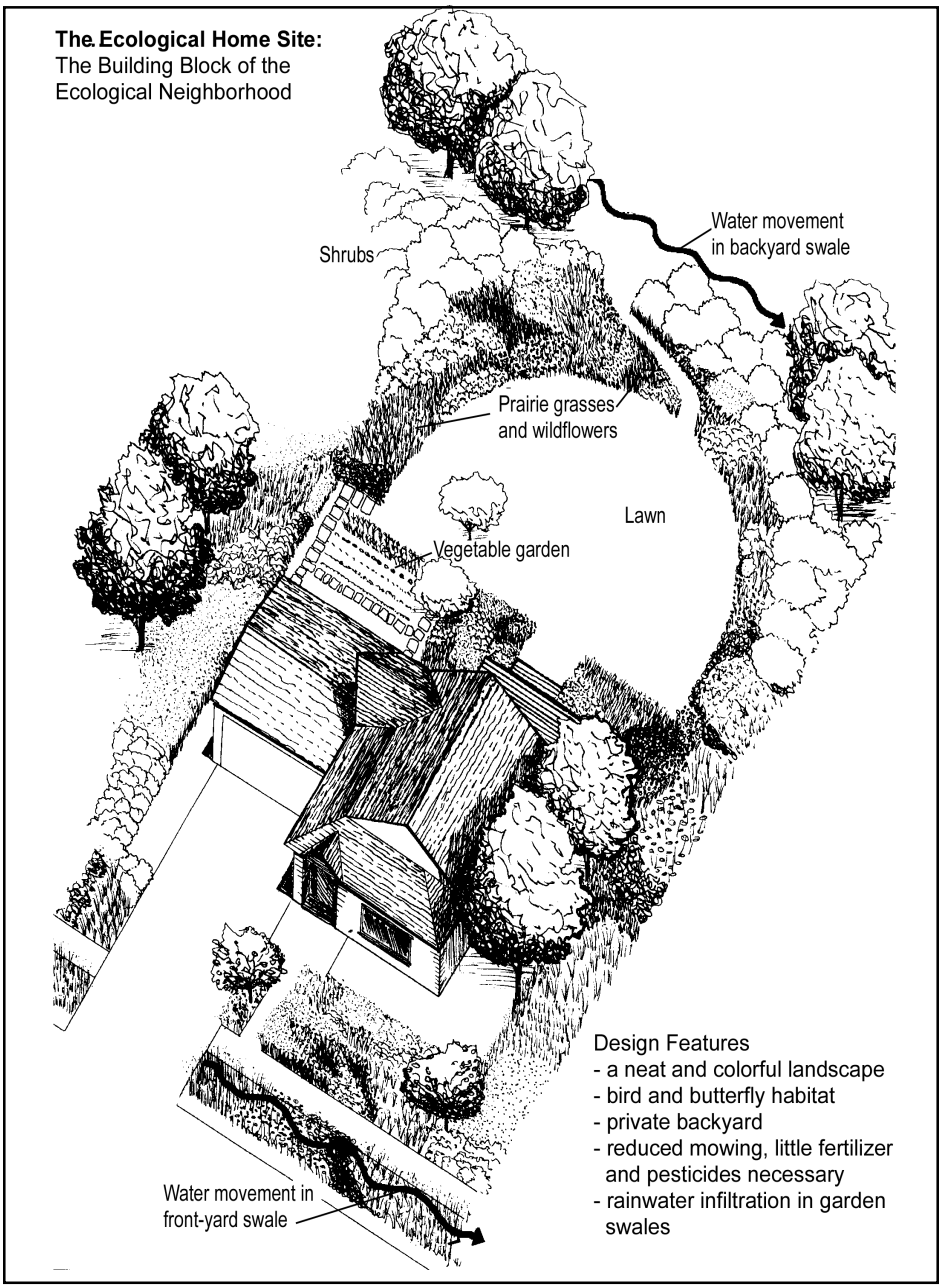


Figure 2. Ecological Neighborhood Home Site
Source: Rozumalski, 1997.

A stormwater treatment train can be designed to serve a multitude of ecological functions, becoming an amenity rater than a necessary utility. Garden swales (see Fig. 3), infiltration basins, and restored wetlands can be ribbons of wildflowers and grasses, and home to wildlife, while they provide stormwater storage.

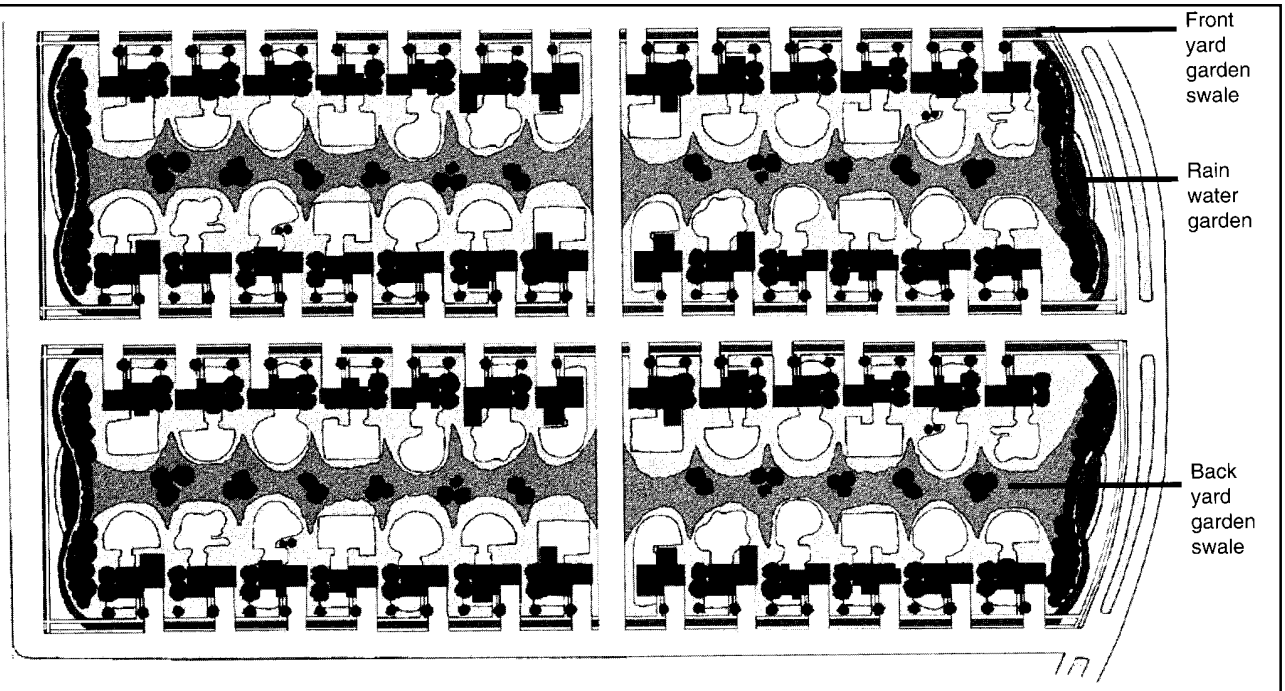


Figure 3. Garden Swales
Source: Rozumalski, 1997.

Design (continued)

Treatment train design should be based on local ecology and local community directives. There are many features that can be incorporated to allow them to be multifunctional.

The following design features can be included:

- Visible overland stormwater drainage with rainwater gardens.
- Rain water infiltration in garden swales.
- Reduced imperviousness surface by narrowing street, reducing front setbacks and building 2 story houses.
- Wildlife habitat.
- Wetlands as amenities and parks.
- Neat and colorful landscape.
- Bird and butterfly habitat.
- Private back yard plantings.
- Reduced mowing, little fertilizer and pesticides necessary.

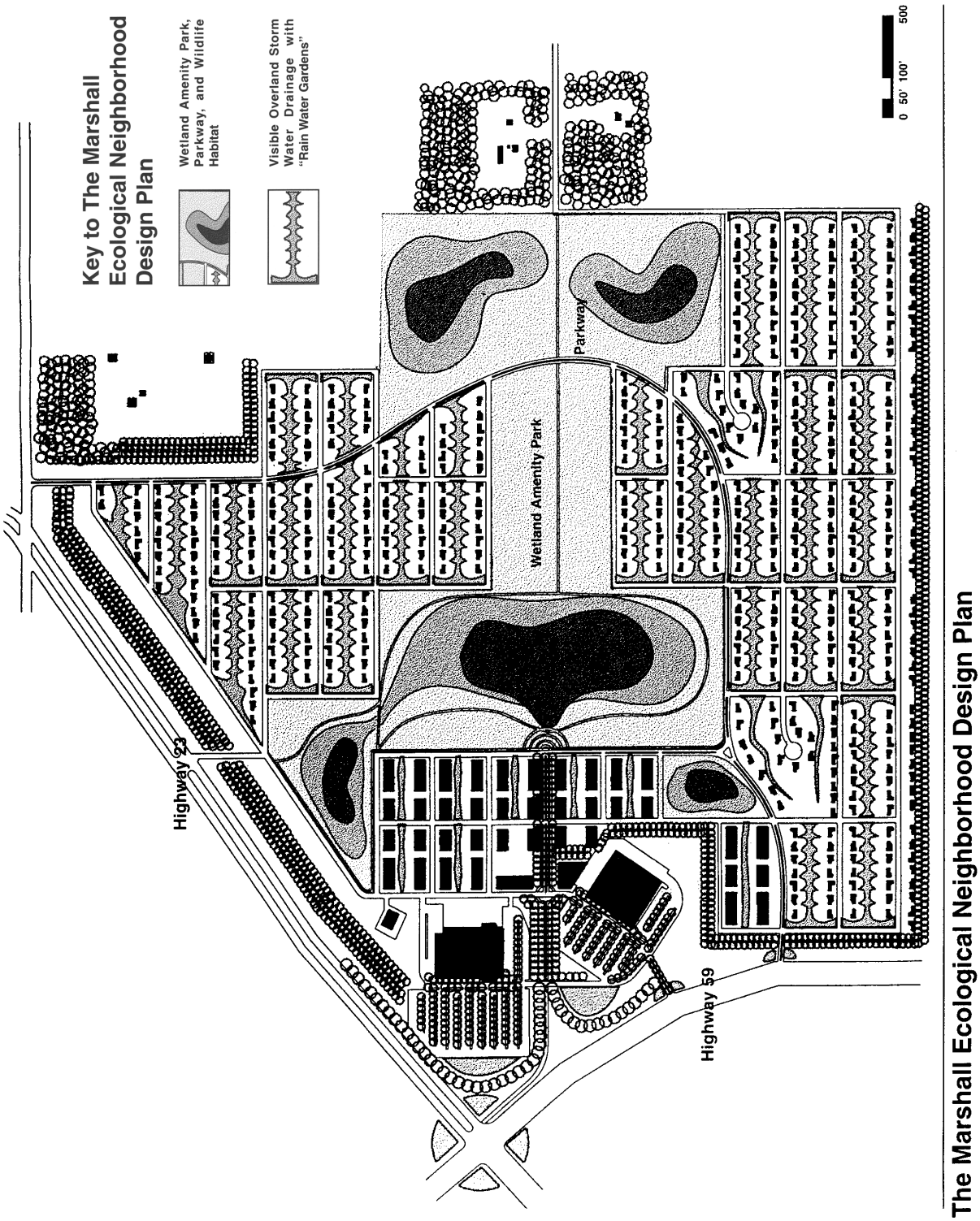


Figure 4. Ecological Design Plan
Source: Rozumalski, 1997.

Requirements

Maintenance

- The maintenance requirements for serial BMPs depend on the requirements of the individual components of the system. (Refer to the individual BMP fact sheets.)
- A firmly established maintenance and inspection program that addresses both routine and non-routine tasks is necessary to ensure that the system functions as designed.
- The placement of the least costly and most easily maintained BMP at the most upstream position in the series can reduce the maintenance requirements for the downstream components in the system.
- If the overall system is designed properly, the cost for maintenance of the individual components of the system can be reduced.

Sources

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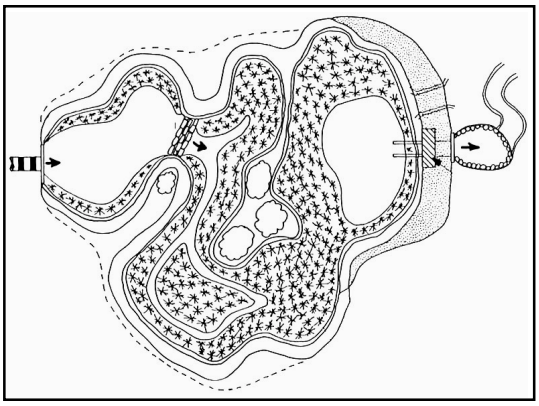
Stormwater Wetlands



Description

Stormwater wetlands are constructed wetland systems designed to maximize the removal of pollutants from stormwater runoff via several mechanisms: microbial breakdown of pollutants, plant uptake, retention, settling and adsorption. Stormwater wetlands temporarily store runoff in shallow pools that support conditions suitable for the growth of wetland plants. Stormwater wetlands also promote the growth of microbial populations which can extract soluble carbon and nutrients and potentially reduce BOD and fecal coliform levels concentrations.

Like detention basins and wet ponds, stormwater wetlands may be used in connection with other BMP components, such as sediment forebays and micropools. These engineered wetlands differ from wetlands constructed for compensatory storage purposes and wetlands created for restoration. Typically, stormwater wetlands will not have the full range of ecological functions of natural wetlands; stormwater wetlands are designed specifically for flood control and water quality purposes. Similar to wet ponds, stormwater wetlands require relatively large contributing drainage areas and/or dry weather base flow. Minimum contributing drainage areas should be at least ten acres, although pocket type wetlands may be appropriate for smaller sites if sufficient ground water flow is available.

The use of stormwater wetlands is limited by a number of site constraints, including soils types, depth to groundwater, contributing drainage area, and available land area. Soils, depth to bedrock, and depth to water table must be investigated before designing and siting stormwater wetlands. Medium-fine texture soils (such as loams and silt loams) are best to establish vegetation, retain surface water, permit groundwater discharge, and capture pollutants. At sites where infiltration is too rapid to sustain permanent soil saturation, an imper-

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	◧

Water Quality

Pollution prevention

Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**

Pollutant removal

Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	◧
Floatables	◧
Oil and grease	■
Other	
Fecal coliform	■
Biochemical oxygen demand (BOD)	■

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

meable liner may be required. Where the potential for groundwater contamination is high, such as runoff from sites with a high potential pollutant load, the use of liners should be required.

Advantages

- Improvements in downstream water quality.
- Settlement of particulate pollutants.
- Reduction of oxygen-demanding substances and bacteria from urban runoff.
- Biological uptake of pollutants by wetland plants.
- Flood attenuation.
- Reduction of peak discharges.
- Enhancement of vegetation diversity and wildlife habitat in urban areas.
- Aesthetic enhancement and valuable addition to community green space.
- Relatively low maintenance costs.

Limitations

- Release of nutrients in the fall.
- May be difficult to maintain vegetation under a variety of flow conditions.
- Geese may become undesirable year-round residents if natural buffers are not included in the wetland design.
- May act as a heat sink, and can discharge warmer water to downstream water bodies.
- Depending upon design, larger land requirements than for other BMPs.
- Until vegetation is well established, pollutant removal efficiencies may be lower than anticipated.
- Relatively high construction costs in comparison to other BMPs.

Requirements

Design

A site appropriate for a stormwater wetland must have adequate water flow and appropriate underlying soils. Baseflow from the drainage area or groundwater must be sufficient to maintain a shallow pool in the wetland and support the vegetation, including species susceptible to damage during dry periods. Underlying soils that are NRCS Types B, C or D will have only small infiltration losses. Sites with type A (sandy) soils have high infiltration rates and may require a geotextile liner or a 15 centimeter (6 inch) layer of clay. After excavation and grading of a basin, at least 10 centimeters (4 inches) of soil should be applied to the site. This material, which may be the previously-excavated soil or other suitable material, is needed to provide a substrate in which vegetation can become established.

Stormwater Wetlands

Wetland Treatment

The design criteria for stormwater wetlands are the same as those for active settling ponds. They can be designed to meet particle size removal efficiencies and treatment volume criteria. However, care must be taken to design the wetland so that the bounce in the pool is compatible with the wetland vegetation. The bounce must be considered in addition to any discharge requirements for particle size, flood control or downstream erosion control settling ponds with special attention to keeping solids from overtaking the vegetation.

Factors which increase the settling rate of suspended solids in stormwater wetlands include:

- Laminar settling in zero-velocity zones created by plant stems
- Anchoring of sediments by root structure, helping to prevent scour in shallow areas
- Increased biological activity removing dissolved nutrients
- Increased biological floc formation.

Basic Stormwater Wetland Design Types

Design criteria and other considerations for the following four wetland types are summarized in Table 2.

Design 1: Shallow Marsh System (Fig. 1)

- Shallow marsh systems are configured with different low marsh and high marsh areas, which are referred to as cells (see Fig. 5). They also include a forebay for coarse particulate settlement before the wetland cell and a micropool at the outlet.
- Shallow marshes are designed with sinuous pathways to increase retention time and contact area.
- Most shallow marsh

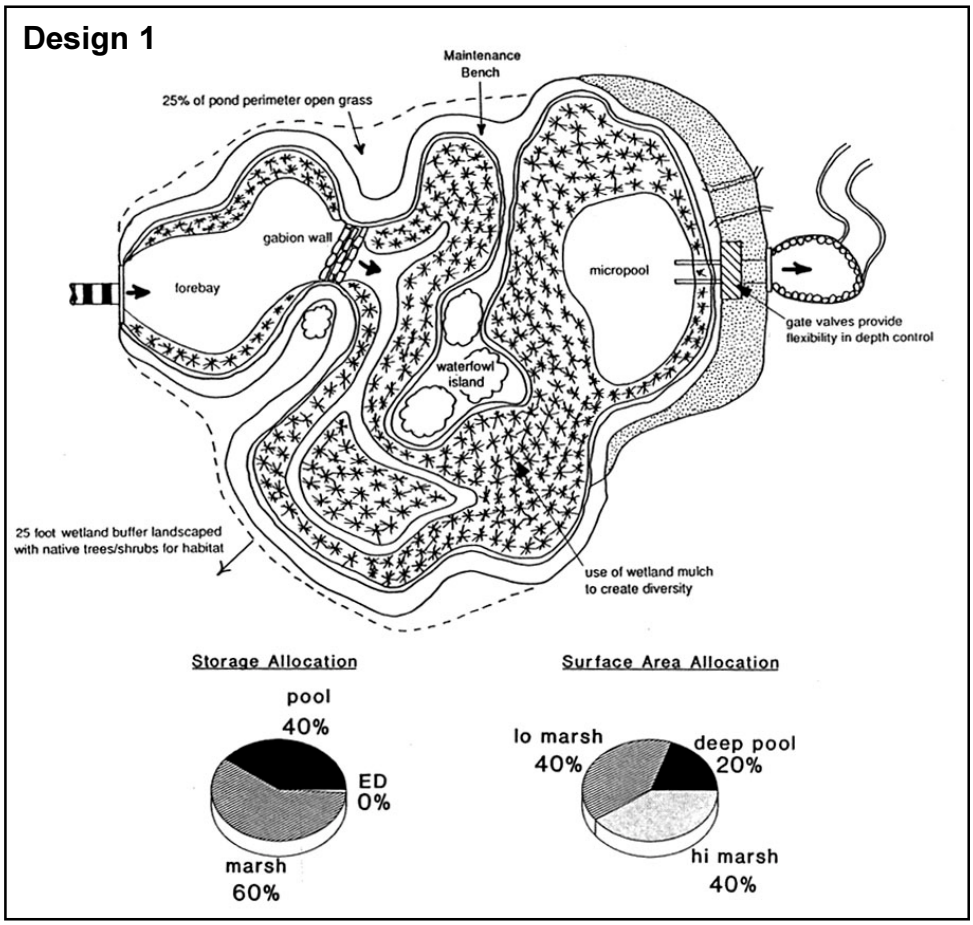


Figure 1. Shallow Marsh System
Source: Schueler, 1992.

Stormwater Wetlands

ATTRIBUTE	DESIGN No. 1 SHALLOW MARSH	DESIGN No. 2 POND/ WETLAND	DESIGN No. 3 ED WETLAND	DESIGN No. 4 POCKET WETLAND
POLLUTANT REMOVAL CAPABILITY	moderate, reliable removal of sediments and nutrients	moderate to high, reliable removal of nutrients and sediment	moderate, less reliable removal of nutrients	moderate, can be subject to resuspension and groundwater displacement
LAND CONSUMPTION	high, shallow marsh storage consumes space	moderate, as vertical pool substitues for marsh storage	moderate, as vertical ED substitutes for marsh storage	moderate, but can be shoehorned in site
WATER BALANCE	dry weather baseflow normally recommended to maintain water elevations. Groundwater not recommended as the primary source of water supply to wetland			water supply provided by execavation to groundwater
WETLAND AREA / WATERSHED AREA	minimum ratio of .02	minimum ratio of .01	minimum ratio of .01	minimum ratio of .01
CONTRIBUTING WATERSHED AREA	DA of 25 acres or greater, with dry weather Q	DA of 25 acres or greater, with dry weather Q	minimum of ten acres required for ED	1 to 10 acres
DEEP WATER CELLS	forebay, channels micropool	pond micropool	forebay micropool	micropool, if possible
OUTLET CONFIGURATION	reversed slope pipe extending from riser, withdrawn approximately one foot below normal pool. Pipe and pond drain equipped with gate valve			broad crested wier with half round trash rack, and pond drain
SEDIMENT CLEANOUT CYCLE (approximate)	cleanout of forebay every 2-5 years	cleanout of pond every ten years	cleanout of forebay every 2 to 5 years.	cleanout of wetland every 5 to 10 years, onsite disposal and stockpile mulch
NATIVE PLANT DIVERSITY	high, if complex microtopography is present	high, with sufficient wetland complexity and area	moderate, fluctuating water levels impose physiological constraints	low to moderate, due to small surface area and poor control of water levels
WILDLIFE HABITAT POTENTIAL	high, with complexity and buffer	high, with buffer, attracts waterfowl	moderate, with buffer	low, due to small area and low diversity

Table 1: Wetland Characteristics
Source: Schueler, 1992.

systems consist of pools ranging from 6 to 18 inches during normal conditions.

- Shallow marshes may require larger contributing drainage areas than other systems, as runoff volumes are stored primarily within the marshes, not in deeper pools where flow may be regulated and controlled over longer periods of time.

Design 2: Pond/Wetland Systems (Fig. 2)

- Multiple cell systems, such as pond/wetland systems, utilize at least one pond component in conjunction with a shallow marsh component.
- The first cell is typically the wet pond which provides for particulate pollutant removal. The wet pond is also used to reduce the velocity of the runoff entering the system.

Design 2

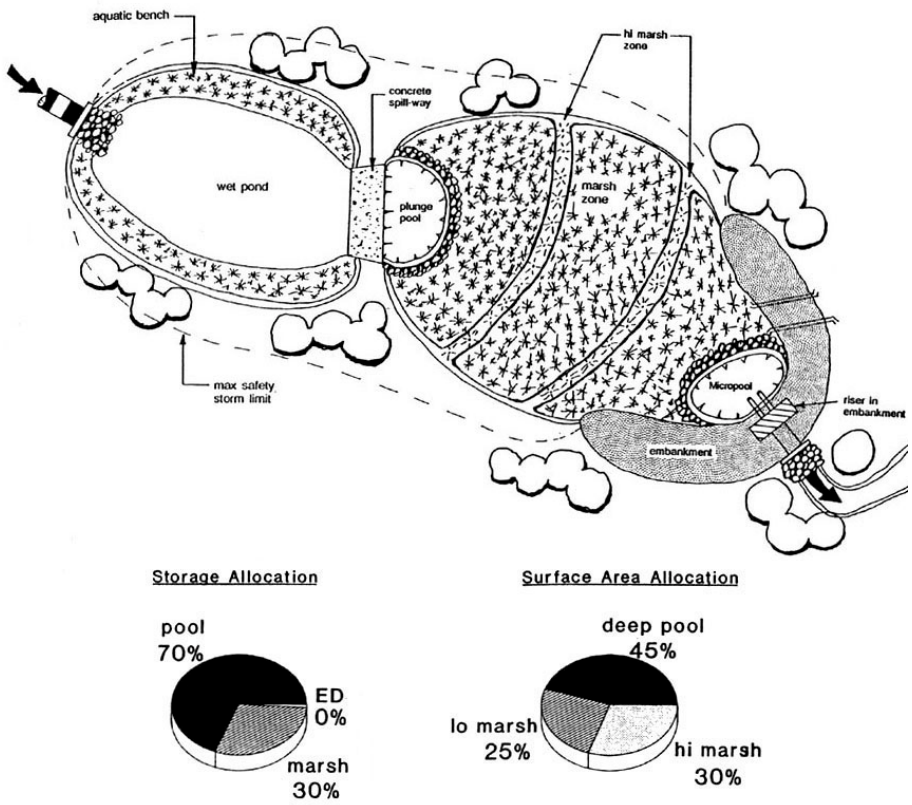


Figure 2. Pond/Wetland System
Source: Schueler, 1992.

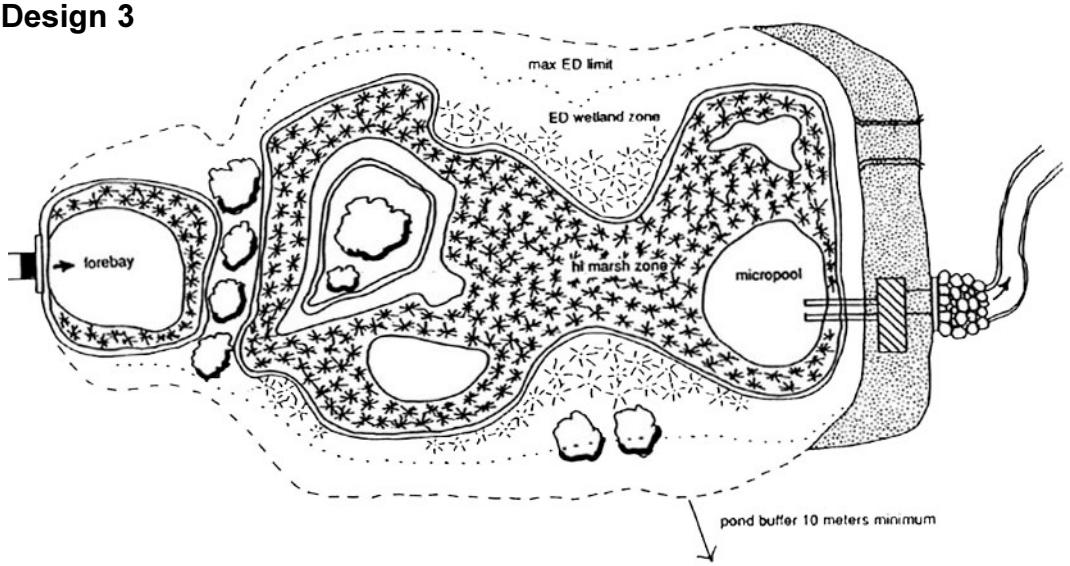
- The shallow marsh provides additional treatment of the runoff, particularly for soluble pollutants. These systems require less space than the shallow marsh systems and generally achieve a higher pollutant removal rate than other stormwater wetland systems.

Design 3: Extended Detention Wetlands (Fig. 3)

- Extended detention wetlands provide a greater degree of downstream channel protection. These systems require less space than the shallow marsh systems, since temporary vertical storage is substituted for shallow marsh storage.
- The additional vertical storage area also provides extra runoff detention above the normal elevations.
- Water levels in the extended detention wetlands may increase by as much as three feet after a storm event and return gradually to normal within 24 hours of the rain event.

Requirements
Design (continued)

Design 3



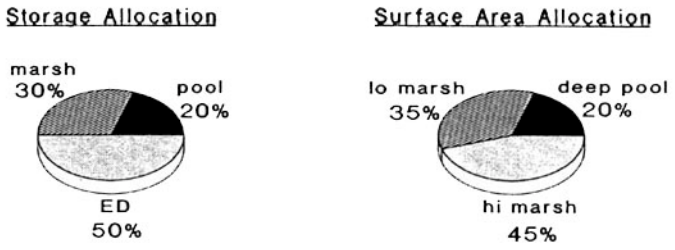


Figure 3. Extended Detention Wetland System
Source: Schueler, 1992.

- The vegetated area in extended detention wetlands expands from the normal pool elevation to the maximum surface water elevation.
- Wetlands plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above the shallow marsh elevations.

Design 4: Pocket wetlands (Fig. 4)

- These systems may be utilized for smaller sites of one to ten acres.
- To maintain adequate water levels, pocket wetlands are generally excavated down to the groundwater table.
- Pocket wetlands which are supported exclusively by stormwater runoff generally will have difficulty maintaining marsh vegetation due to extended periods of drought.

Stormwater Wetlands

General Design Considerations

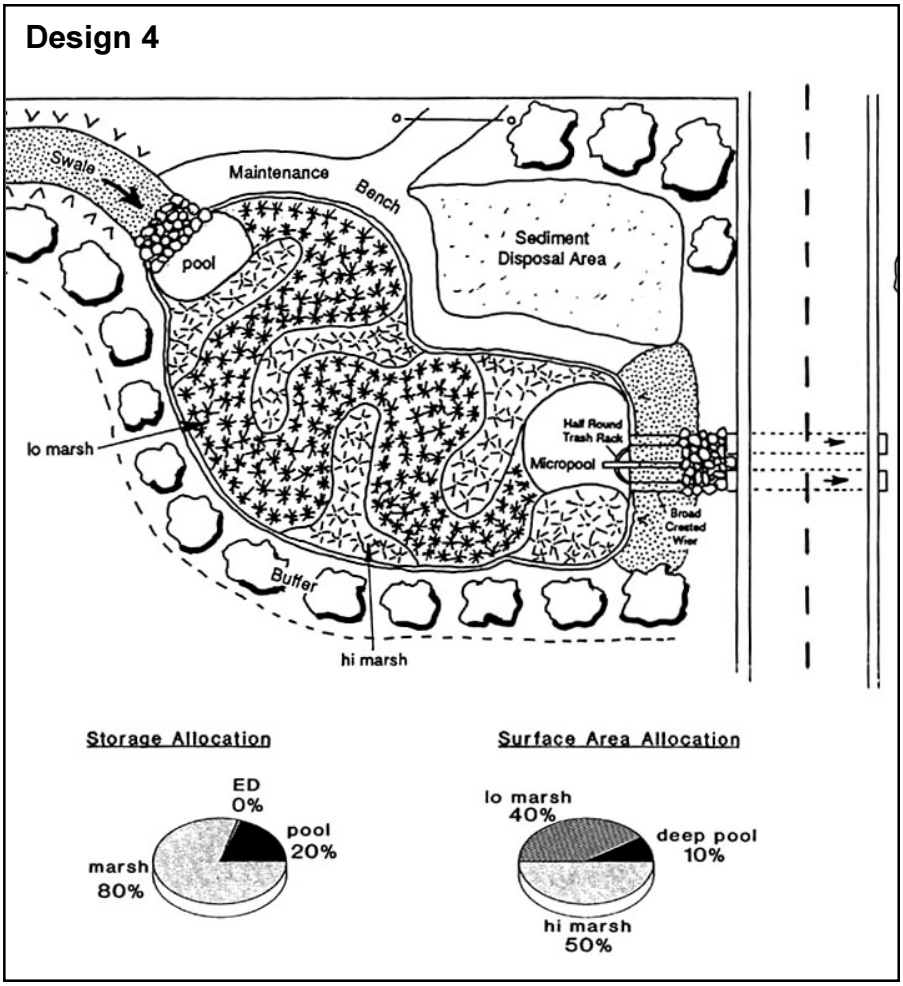


Figure 4. Pocket Wetland System
Source: Schueler, 1992.

- Sediment forebays are recommended to decrease the velocity and sediment loading to the wetland. The forebays provide the additional benefits of creating sheet flow, extending the flow path, and preventing short circuiting. The forebay should contain at least 10 percent of the wetland's treatment volume and should be 4 to 6 feet deep. The forebay is typically separated from the wetland by gabions, gravel/riprap or by an earthen berm.
- The wetland design should include a buffer to separate the wetland from surrounding land. Buffers may alleviate some potential wetland nuisances, such as accumulated floatables, odors and or geese.
- A buffer of 25 feet is recommended, plus an additional 25 feet when wildlife habitat is of concern. Leaving trees undisturbed in the buffer zone will minimize the disruption to wildlife and reduce the chance for invasion of nuisance vegetation such as cattails and primrose willow.
- Above ground berms or high marsh wedges should be placed at approximately 50 foot intervals, at right angles to the direction of the flow to increase the dry weather flow path within the stormwater wetland.
- Before the outlet, a four- to six-foot deep micropool (having a capacity of at least ten percent of the total treatment volume), should be included in the design to prevent the outlet from clogging. A reverse slope pipe or a hooded, broad crested weir is the recommended outlet control (See Figure 3b Wet Ponds BMP).
- The outlet from the micropool should be located at least one foot below the normal pool surface. To prevent clogging, trash racks or hoods should be installed on the riser (See Figure 3b Wet Ponds BMP).
- To facilitate access for maintenance, the riser should be installed within the embankment (See Figure 3b in Wet Ponds BMP).

Design Requirements (continued)

- Install a bottom drain pipe with an inverted elbow to prevent sediment clogging in order to completely drain the stormwater wetland for emergency purposes or routine maintenance (See Figure 3b Wet Ponds BMP).
- Fit both the outlet pipe and the bottom drain pipe with adjustable valves at the outlet ends to regulate flows (See Figure 3b Wet Ponds BMP).
- Surround all deep-water cells with a safety bench having a minimum width of ten feet and a depth of zero to 18 inches below pool's normal water level.
- Remember that wetland treatment systems' effectiveness in removing urban pollutants depends on the system's physical characteristics, such as wetland-size-to-watershed-size ratio, runoff residence time in the wetland and water budget.
- In general, as the wetland-to-watershed area ratio increases, the average runoff residence time increases and the effectiveness of the wetland for pollutant removal also increases.
- Prepare a water budget to demonstrate that the water supply to the stormwater wetland is greater than the expected loss rate.

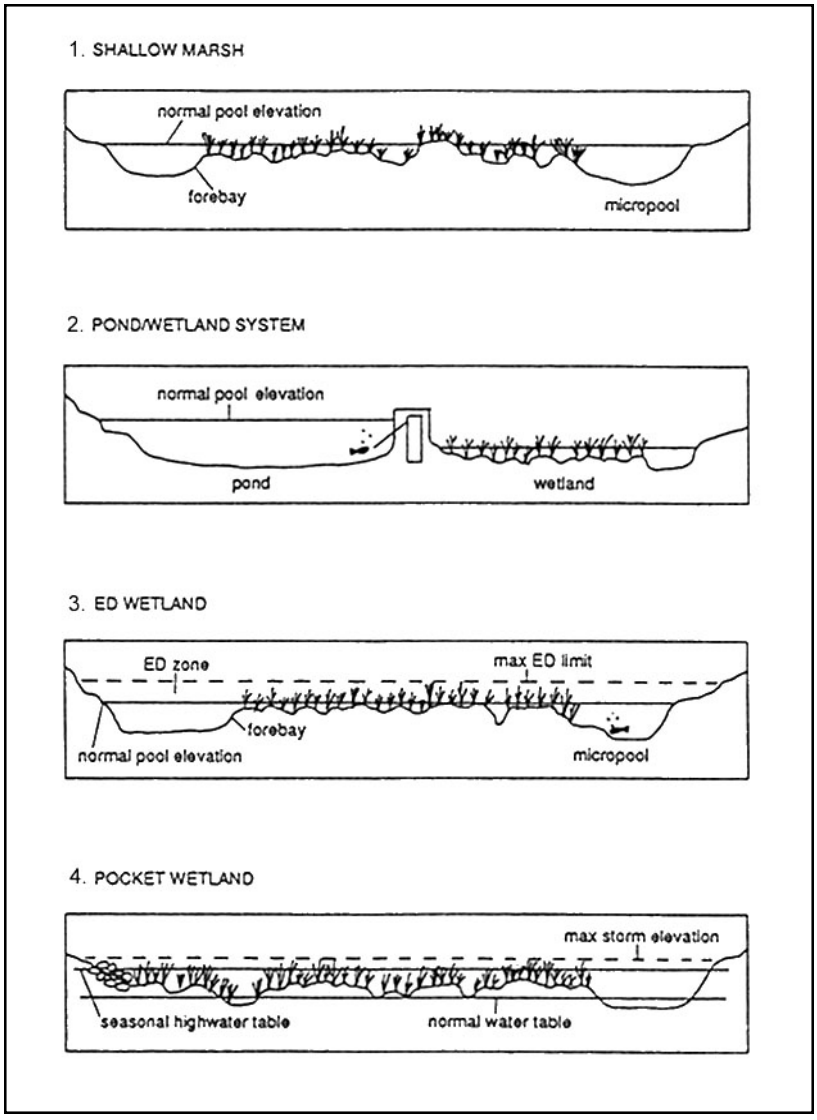


Figure 5: Comparative Profiles of the Four Stormwater Wetland Designs
Source: Schueler, 1992.

Wetland Size

The stormwater wetland should be designed to store the water quality treatment volume as required by the local permitting agency. The Metropolitan Council of Governments (Schueler, 1992) has developed guidelines for constructing wetland stormwater basins (see Table 3). Those guidelines recommend a wetland surface area of 1 to 2 percent of the watershed area, depending on the nature of the watershed and the design of the facility.

Stormwater Wetlands

DESIGN CRITERIA	DESIGN No. 1 SHALLOW MARSH	DESIGN No. 2 POND/ WETLAND	DESIGN No. 3 ED WETLAND	DESIGN No. 4 POCKET WETLAND
Wetland/Watershed Ratio	0.2	.01	.01	.01 (target)
Minimum Drainage Area	25 ac.	25 ac.	10 ac.	1-10 ac.
Length to Width Ratio (minimum)	1:1	1:1	1:1	1:1 (target)
Extended Detention	No	No	Yes	No
Allocation of Treatment Volume (pool, marsh, ED)	40/60/0	70/30/0	20/30/50	20/80/0
Allocation of Surface Area (deep, lo, high)	20/40/40	45/25/30	20/35/45	10/40/50
Cleanout Frequency	2-5 yrs	10 yrs	2-5 yrs	10 yrs
Forebay	Required	No	Required	Optional
Micropool	Required	Required	Required	Optional
Outlet Configuration	reverse-slope pipe or hooded broad crest weir	same	same	hooded broad crested weir
Propogation Technique	Mulch or Transplant	Mulch or Transplant	Mulch or Transplant	Volunteer
Buffer (feet)	25 to 50	25 to 50	25 to 50	0 to 25
Pondscaping Plan Requirements	Emphasize wildlife habitat marsh micro-topography, buffer	Emphasize wildlife habitat and hi marsh wedges	Emphasize stabilization of ED zone, project pondscaping zones	pondscaping plan optional

Table 2: Wetland Design Criteria
Source: Schueler, 1992.

Requirements
Design (continued)

During dry weather, flow must be adequate to provide a baseflow and to maintain the vegetation. The flow path should be maximized to increase the runoff's contact time with plants and sediments.

Outlet Design

- Extended detention design criteria are strongly recommended for the outlet structure design (see Extended Detention).
- An orifice or other outlet structure can be used to restrict the discharge to the required flow. Because of the abundance of vegetation in the wetland, a trash guard should be used to protect the orifice.
- A trash guard large enough so that velocities through it are less than 2 fps will reduce clogging problems.
- Flow from the wetland should be conveyed through an outlet structure that is located within the deeper areas of the wetland. Discharging from the deeper areas using a reverse slope pipe prevents the outlet from becoming clogged. A micropool just prior to the outlet will also prevent outlet clogging.
- The micropool should contain approximately 10 percent of the treatment volume and be 4 to 6 feet deep.
- An adjustable gate-controlled drain capable of dewatering the wetland within 24 hours should be located within the micropool.
- A typical drain may be constructed with an upward-facing inverted elbow. The dewatering feature eases planting and follow-up maintenance.

Wetland Vegetation

(See Figure 6 for techniques to enhance wildlife habitat in stormwater wetlands.)

- Vegetation can be established by three methods: allowing volunteer vegetation to become established (not recommended) planting nursery vegetation and seeding.
- A higher diversity wetland can be established when nursery plants are used. Vegetation from a nursery should be planted during the growing season—not during late summer or fall—to allow vegetation time to store food reserves for their dormant period.
- Select species adaptable to the broadest ranges of depth, frequency and duration of inundation (hydroperiod). Match site conditions to the environmental requirements of plant selections. Take into account hydroperiod and light conditions.
- Give priority to species that have already been used successfully in constructed wetlands and that are commercially available.
- Allowing species transmitted by wind and water fowl to voluntarily become establish in the wetland is unpredictable.
- Wetlands established with volunteers are usually characterized by low plant diversity with monotypic stands of exotic or invasive species.

Stormwater Wetlands

Sizing Criteria	DESIGN No.1 SHALLOW MARSH	DESIGN No.2 POND/ WETLAND	DESIGN No.3 ED WETLAND	DESIGN No.4 POCKET WETLAND
Runoff Treatment Volume (V_t)	Capture 90% of the Annual runoff volume from site Vt = (1.25 inches) (Runoff Coefficient) (Site Area) Minimum Vt of 0.25 watershed-inches			
Wetland to Watershed Area Ratio	.02	.01	.01	.01
Allocation of Surface Area (%)	20 - deep 40 - lo m. 40 - hi m.	45 - deep 25 - lo m. 30 - hi m.	20 - deep 35 - lo m. 45 - hi m.	10 - deep 40 - lo m. 50 - hi m.
Allocation of Treatment Volume (%)	40 - pool 60 - marsh 0 - ED	70 - pool 30 - marsh 0 - ED	20 - pool 30 - marsh 50 - ED	20 - pool 80 - marsh 0 - ED
Flow Path a. length to width ratio b. dry weather path	 1:1 2:1	 1:1 2:1	 1:1 2:1	 NA 2:1
Water Balance	Confirm inflow rate > 0.002 cfs/acre, compute water balance during dry weather			Confirm dry weather water table elevation in field
Extended Detention	Not Employed	Not Employed	EDv = 50% of Vt 12 to 24 hrs ED range ≤3 ft.	Not Employed

Table 3: Wetland Sizing Criteria
Source: Schueler, 1992.

Stormwater Wetlands

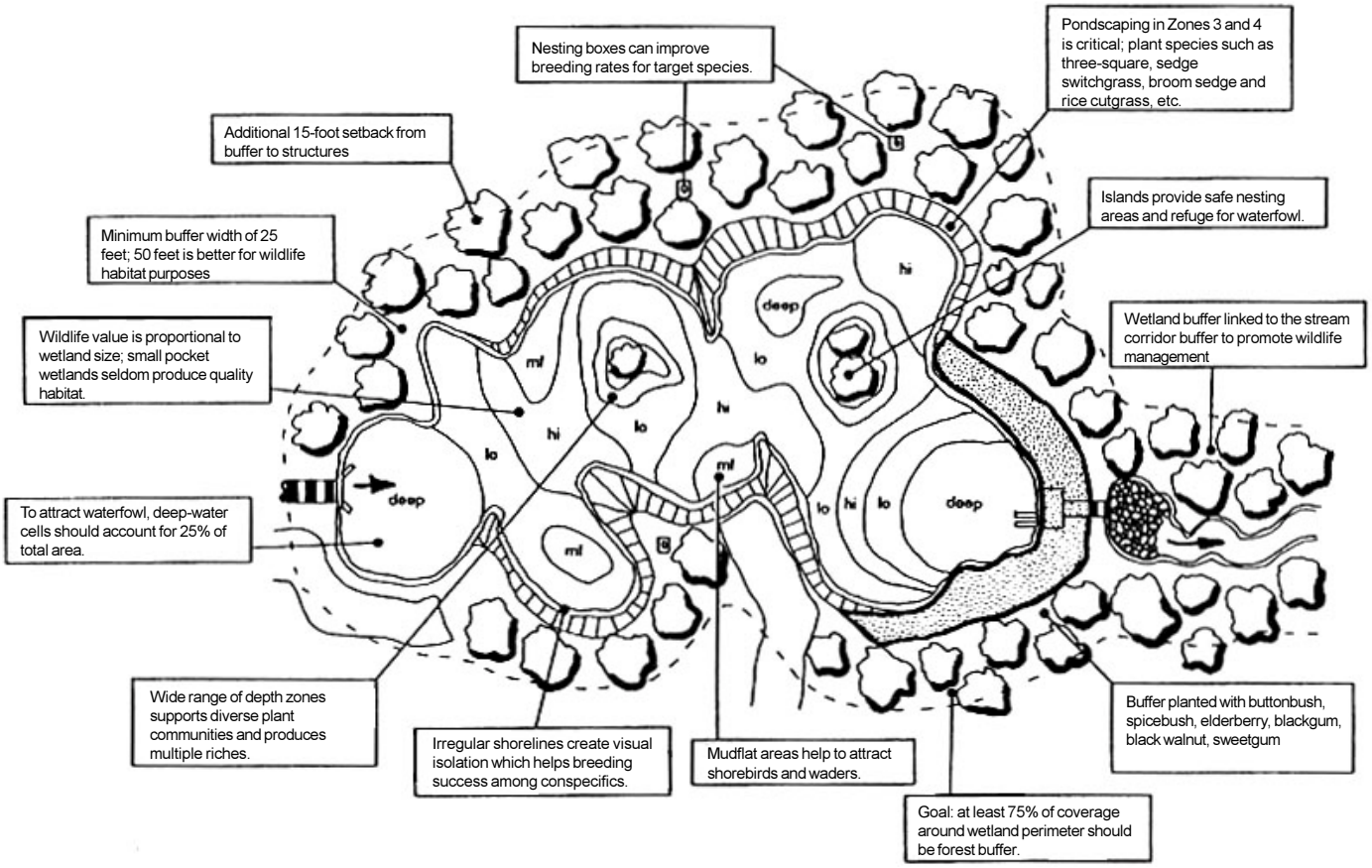


Figure 6. Techniques for Enhancing Wildlife in Stormwater Wetlands.
Source: Schueler, 1992.

Requirements

Sequencing

- Sites must be carefully evaluated when planning stormwater wetlands. Soils, depth to bedrock, and depth to water table must be investigated before designing and siting stormwater wetlands. A "pondscaping plan" should be developed for each stormwater wetland.
- This plan should include hydrological calculations (or water budget), a wetland design and configuration, elevations and grades, a site/soil analysis, and estimated depth zones.
- The plan should also contain the location, quantity, and propagation methods for the stormwater wetland plants. Site preparation requirements, maintenance requirements and a maintenance schedule are also necessary components of the plan.
- The water budget should demonstrate that there will be a continuous supply of water to sustain the stormwater wetland. The water budget should be developed during site selection and checked after preliminary site design.

- Drying periods of longer than two months have been shown to adversely effect plant community richness, so the water balance should confirm that drying will not exceed two months.
- After excavation and grading, the wetland should be kept flooded until planting.
- Six to nine months after being flooded and two weeks before planting, the wetland is typically drained and surveyed to ensure that depth zones are appropriate for plant growth. Revision may be necessary to account for any changes in depth.
- Next, the site is staked to ensure that the planting crew spaces the plants within the correct planting zone.

Maintenance

Stormwater wetlands require routine maintenance. The small forebay should be dredged every other year to protect the wetland from excessive sediment buildup. Careful observation of the system over time is required. In the first three years after construction, twice-yearly inspections are needed during both the growing and non-growing season. Data gathered during these inspections should be recorded, mapped and assessed.

- The following observations should be made during the inspections:
  - Types and distribution of dominant wetland plants in the marsh.
  - The presence and distribution of planted wetland species.
  - The presence and distribution of invasive wetland species.
  - Signs that invasive species are replacing the planted wetland species.
  - Percentage of unvegetated standing water (excluding the deep water cells which are not suitable for emergent plant growth)
  - The maximum elevation and the vegetative condition in this zone, if the design elevation of the normal pool is being maintained for wetlands with extended zones.
  - Stability of the original depth zones and the microtopographic features, accumulation of sediment in the forebay and micropool, and survival rate of plants in the wetland buffer.
- Inspections should be conducted at least twice a year for the first three years and annually thereafter.
- Regulating the sediment input to the wetland is the priority maintenance activity.
- The majority of sediments should be trapped and removed before they reach the wetlands either in the forebay or in a pond component. Gradual sediment accumulation in the wetland results in reduced water depths and changes in the growing conditions for the emergent plants. Furthermore, sediment removal within the wetland can destroy the wetland plant community. Shallow marsh and extended detention wetland designs include forebays to trap sediment before reaching the wetland. These forebays should be cleaned out every other year.
- Pond/wetland system designs do not include forebays as the wet pond itself acts as an oversized forebay. Sediment cleanout of pond/wetland systems is needed every 10 years.

Requirements
Maintenance (continued)

- The key to using the wetland effectively is that the ponds must function so as not to destroy the wetland vegetation. Slight modification of operations and plantings may be necessary as operations proceed.
- Harvesting of wetland vegetation can also be considered to remove nutrients from the wetland system and to minimize nutrient release when vegetation dies in the autumn. This is not generally recommended, but in special cases it will remove the nutrients contained in the vegetation from the system. If vegetation is to be harvested, design features should be included that will allow the wetland to be dewatered (Schueler, October 1992).
- Maintenance requirements for constructed wetlands are particularly high while vegetation is being established (usually the first three years). This is likely to include removal of invasive species and replanting natives.
- Additional routine maintenance tasks, which can be conducted on the same schedule, include removing accumulated trash from trash racks, outlet structures and valves.

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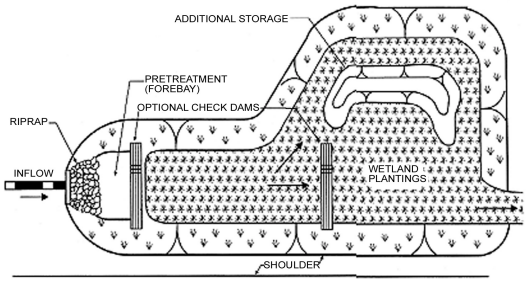
Wet Swales



Description

The wet swale, also called a grassed open channel consists of a broad open channel capable of temporarily storing water. Unlike the dry swale, a wet swale does not have an underlying filtering bed. The wet swale is constructed directly within existing soils and may or may not intersect the water table. Similar to the dry swale, water quality storage should be approximately 24 hours. The wet swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and microbial breakdown of pollutants. Wet swales reduce the flow velocity of storm water runoff and may promote infiltration.

Wet swales are similar to stormwater wetlands in their use of vegetation to treat stormwater runoff. Wet swales can serve as part of a stormwater drainage system and can replace curbs, gutters and storm sewer systems.

The feasibility of installing a wet swale at a particular site depends on the area and slope of the contributing watershed, as well as dimensions of the areas in which the swale system is to be installed. Wetland vegetation can be planted or allowed to naturally colonize these systems. Wet swales are designed to retain the water quality volume for 24 hours. Vegetated swales are easy to design and can be incorporated into a site drainage plan.

A wet swale occurs when the water table is located very close to the surface. As a result, swale soils often become fully saturated, or have standing water all or part of the year after the channel has been excavated. This “wet swale” essentially acts as a very long and linear shallow wetland treatment system. Like the dry swale, the entire water quality treatment volume is stored and retained within a series of cells in the channel, formed by berms or checkdams.

In some cases, the cells may be planted with emergent wetland plant species to improve removal rates. Existing perennial vegetation adjacent

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	■

Water Quality

Pollution prevention

Soil erosion	◧
Sediment control	■
Nutrient loading	◧

Pollutant removal

Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	◧
Floatables	□
Oil and grease	□

Other

Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Wet Swales

to receiving waters of interest may provide wildlife benefits, but not significant pollutant-reduction benefits, depending on ground cover and runoff type. However, wet swale design should consider preserving natural areas.

Wet swales are typically located along property boundaries along a natural grade, although they can be used effectively wherever the site provides adequate space. The water quality volume (WQv) for high density residential, commercial and industrial land uses will most likely be too great to be accommodated with most swale designs. However, swales may be appropriate for pretreatment in association with other practices for these higher density land uses.

The difference between water quality swales and drainage channels is in the design and planned use of the open channel conveyance. Wet swales are designed primarily for the prescribed stormwater water quality volume and have incorporated specific features to enhance their stormwater pollutant removal effectiveness. Pollutant removal rates are significantly higher for wet swales than for drainage channels.

Advantages

- Control peak discharges by reducing runoff velocity and promoting infiltration.
- Provide effective pretreatment for BMPs in series by trapping, filtering and infiltrating pollutants.
- Accent natural landscape.
- Reduce peak flows.
- Increase pollutant removal efficiency.
- Promote runoff infiltration.
- Offer lower capital costs than traditional storm sewer system.
- Convey water in properly protected channels.
- Divert water around potential pollutant sources..
- Provide water quality treatment by sedimentation and biological uptake.
- Enhance biological diversity and create beneficial habitat between upland and surface waters.

Limitations

- Impractical in areas with very flat grades, steep topography, or wet or poorly drained soils.
- May erode when flow volumes and/or velocities are high during storm events.
- Area requirements can be excessive for highly developed sites.
- Roadside swales become less feasible as the number of driveway entrances requiring culverts increases.

Wet Swales

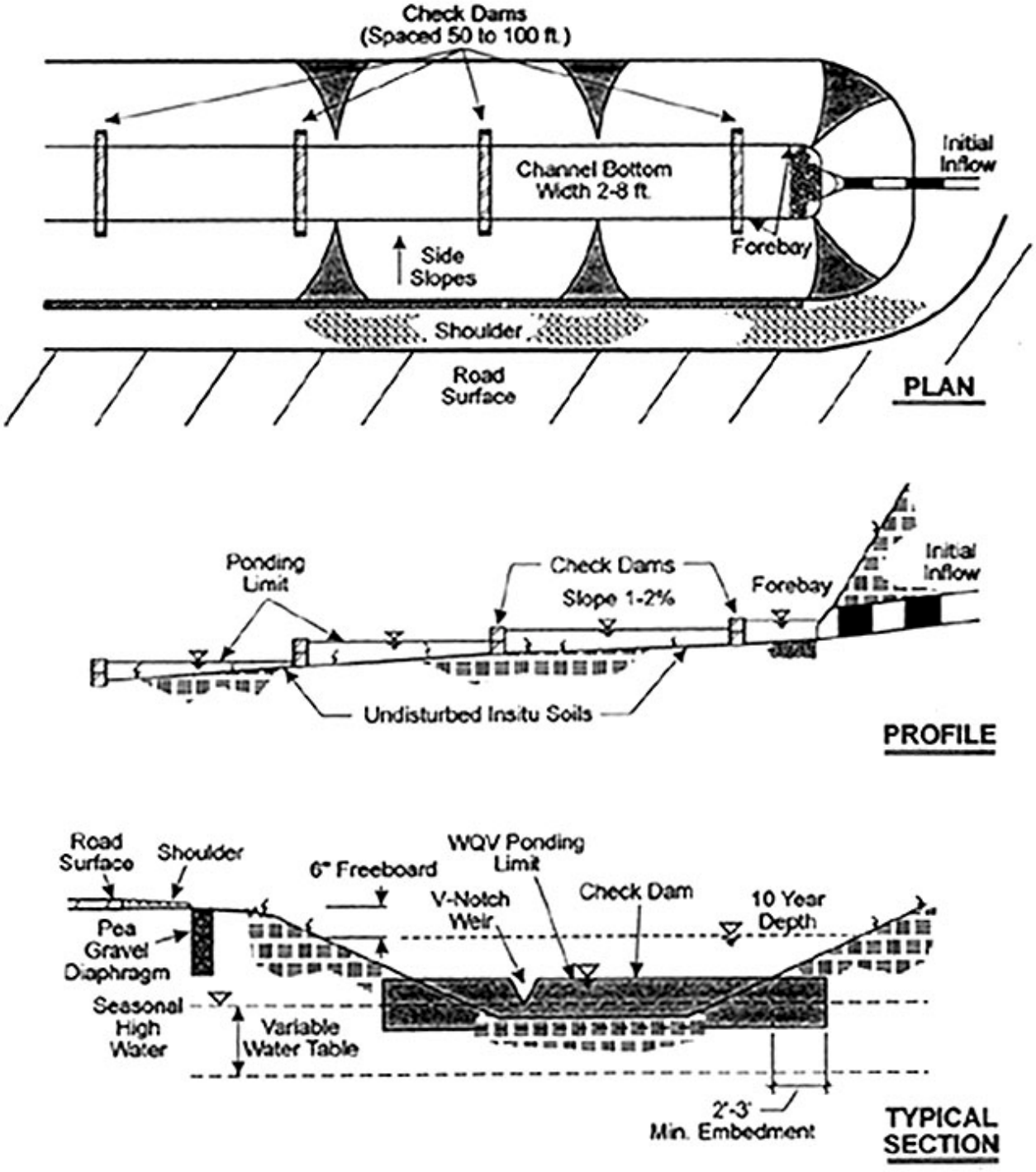


Figure 1. Wet Swale
Source: Center for Watershed Protection 1999

Wet Swales

Requirements

Design

The design approach for sizing wet swales is based on temporarily storing the Water Quality Volume (WQv) within a shallow linear ponding area. This methodology incorporates a **volume-based** sizing criteria for the WQv, and a rate based criteria for checking the erosive potential for the two-year frequency storm and capacity for the ten-year frequency storm (See Figure 1).

The following design specifications are summarized in Table 1.

Shape and Slopes

- The swales should generally be **trapezoidal in shape,** although a parabolic shape is also acceptable (provided the width is equal to or greater than, the design bottom width for a trapezoidal cross section). The criteria presented in this section assumes a trapezoidal cross section.
- For the trapezoidal cross section, size the **bottom width** between two and eight feet. The two feet minimum allows for construction considerations and ensures a minimum filtering surface for water quality treatment. The eight feet maximum reduces the likelihood of flow channelization within a portion of the bottom of the swale. Widths up to 16 feet may be used if separated by a dividing berm or structure to avoid braiding.
- The **side slopes** of the channel should be no steeper than 3:1 for maintenance and safety considerations. Flatter slopes are encouraged where adequate space is available to aid in providing pretreatment for lateral flows. Steeper maximum side slopes for the wet swales are permitted because these practices are designed to retain a storage volume versus being designed for a minimum residence time.
- The **longitudinal slope** of the swale should be moderately flat to permit the temporary ponding of the WQv within the channel without having excessively deep water at the downstream end. A slope between 1.0 percent and 2.0 percent is recommended. When natural topography necessitates, steeper slopes may be acceptable if check

Parameter	*Swale Design Criteria*
Pretreatment volume	.05" per impervious acre, at initial inflow point.
Preferred shape	Trapezoidal or parabolic.
Bottom width	2 feet minimum, 8 feet maximum widths up to 16 feet are allowable if a dividing berm or structure is used.
Side slopes	2:1 maximum, 3:1, or flatter preferred.
Longitudinal slope	1.0% to 2.0% without, check dams.
Sizing criteria	Length, width, depth, and slope needed to provide surface storage for WQV. Outlet structures sized to release WQV over 24 hours.
Underlying soil bed	Equal to swale width Dry Swale: Moderately permeable soils (USCS ML, SM, or SC) 30" deep with gravel/pipe underdrain system Wet Swale: Undisturbed soils, No underdrain system
Depth and capacity	▸ Surface storage of WQV with a maximum ▸ depth of 18 inches for water quality treatment (12" average depth). ▸ Safely convey 2 year storm with non-erosive velocity (≤ 4.0 to 5.0 ft/s) ▸ Adequate capacity for 10 year storm with 6" of freeboard

Table 1. Design Summary for Wet Swales
Source: Center for Watershed Protection 1999

Wet Swales

dams (vertical drops of 6 to 12 inches) are used. These structures will require additional energy dissipating measures and should be placed no closer than 50 to 100 feet intervals.

Design Size and Soils

- The detention/retention capacity of wet swales is governed by the runoff associated with the "water quality storm." The swale length, width, depth and slope should be designed to temporarily accommodate the WQv through surface ponding. The WQv is retained for 24 hours, but ponding may continue indefinitely depending on the depth and elevation to the water table. The WQv for high density residential, commercial and industrial land uses will most likely be too great to be accommodated with most swale designs. However, swales may be appropriate for pretreatment in association with other practices for these higher density land uses (See Figures 2 and 3).

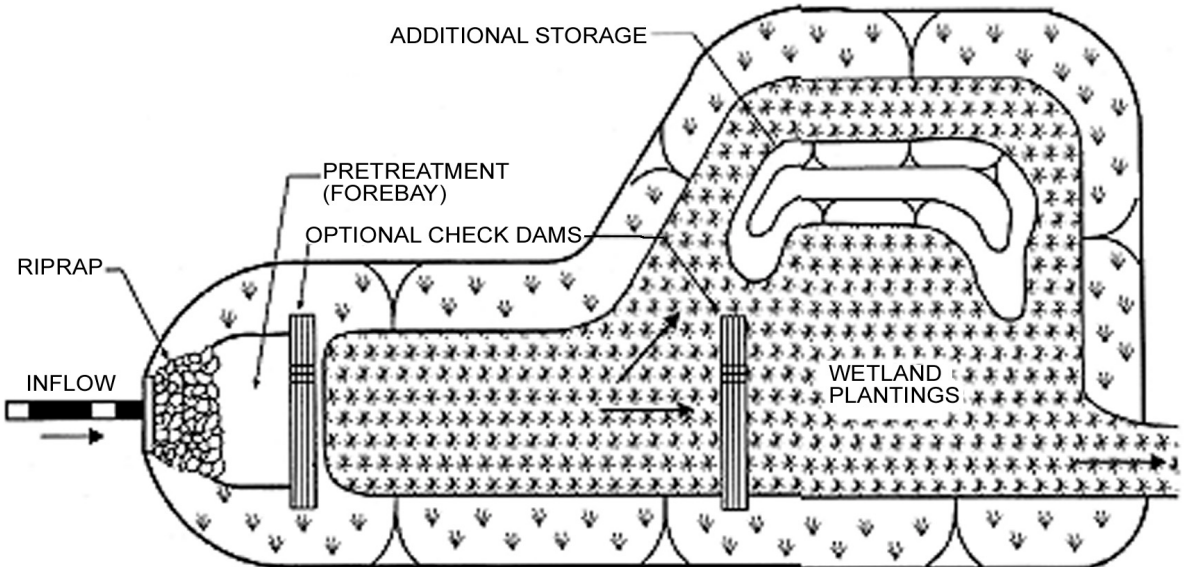


Figure 2. Wet Swale

- Design swales to provide a shallow ponding depth for the WQv (a maximum depth of 18 inches for the WQv is recommended), safely convey the 2 year storm with design velocities less than 4.0 fps, and provide adequate capacity for the 10 year storm with a minimum of 6 inches of freeboard.
- See that the soil bed below the wet swale consists of undisturbed soils. This area may be periodically inundated and remain wet for long periods of time.
- Do not construct wet swales in gravelly and coarse sandy soils that cannot easily support dense vegetations.
- In areas with steep slopes, employ vegetated swales in locations where they can be parallel to the contours.
- Size channels to convey 10-year storm volumes and design channel slopes to prevent erosion during 2-year storm events.

Wet Swales

Requirements Design (continued)

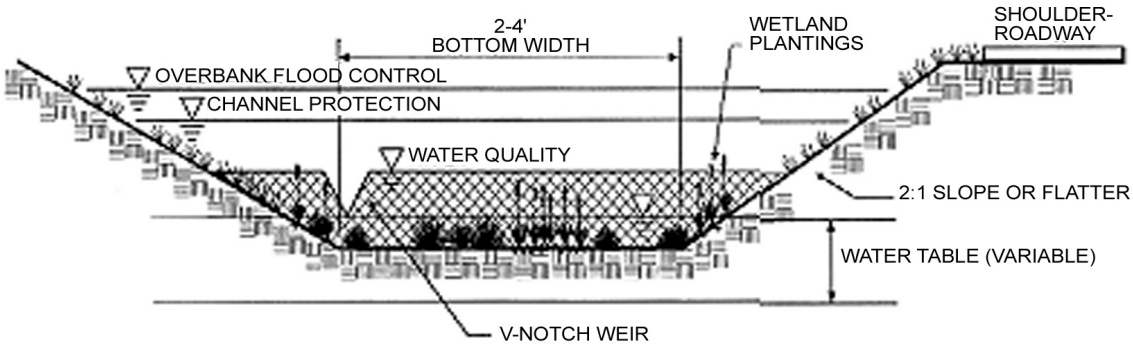


Figure 3. Wet Swale Cross Section
Source: Center for Watershed Protection. 2001

- Use outlet protection at any discharge point from water quality swales to prevent scour at the outlet.
- Provide minimum freeboard above 10 year storm water surface profile (6 inches minimum or as required by local ordinance).
- Specify vegetation required to meet design condition.
- Identify the swale bottom, width, depth, length, and slope necessary to store the WQv within a shallow ponding depth (approximate maximum depth of 18 inches).
- Compute the 2-year and 10-year frequency storm event peak discharges.
- Check the 10-year velocity for erosive potential (adjust swale geometry, if necessary and reevaluate WQv design parameters).
- Provide pretreatment to protect the filtering and infiltration capacity of the swale bed. Pretreatment can occur in a sediment forebay behind a checkdam with a pipe inlet.
- Use check dams in wet swales to achieve multiple cells. V-notched weirs in the check dams can be utilized to direct low flow volumes.
- Plant emergent vegetation or spread wetland soils on swale bottom for seed stock.
- Design wet swales with parabolic or trapezoidal cross-sections, and with side slopes no greater than 3:1 (horizontal:vertical) and bottom widths ranging from 2 to 8 feet.
- Specify grasses resistant to periodic inundation and periodic drought.
- Check permissible velocities of selected vegetation to ensure the 2-year frequency storm velocity is non-erosive.
- Compute the WQv drawdown time to ensure that it is less than 24 hours.

Wet Swales

Vegetative Cover

- Species selection will depend upon the duration of water inundation, soil type and amount of light.
- Desirable vegetative characteristics include species that form a dense sod with vigorous, upright growth. Species that have tendencies to mat down should not be used when sediment filtering is a desired outcome.
- Appropriate soil stabilization methods, such as mulch, blankets or mats should be used before establishment of vegetation. Seeding, sodding and other items related to establishing vegetation should be in accordance with accepted erosion-control and planting practices. (See Erosion Control BMP section.)

Construction

- Avoid soil compaction.
- Provide a bypass for high flows if the swale cannot be stable for the 10-year storm. The swale should adequately handle the 2-year storm at a minimum.

Maintenance

- Inspect wet swales on a semiannual basis for the first year, and after major storm events.
- The initial inflow forebay should be inspected annually for sediment buildup. Any excessive sediment, trash, and debris should be removed and disposed of in an appropriate location.
- The grass vegetation along the side slopes should be inspected for erosion rills or gullies, and corrected as needed. Bare areas should be seeded or sodded as necessary.
- Mowing may be necessary.

Annually or Semiannually

- Inspect swale several times the first few months to ensure grass cover is establishing well. If not, reseed or plant an alternative species. Once established, continue to inspect semiannually for erosion problems.
- At least annually inspect pea gravel diaphragm for clogging from excess sediment; remove sediment and correct associated problems.
- Remove trash and debris accumulated in the swale.

Wet Swales

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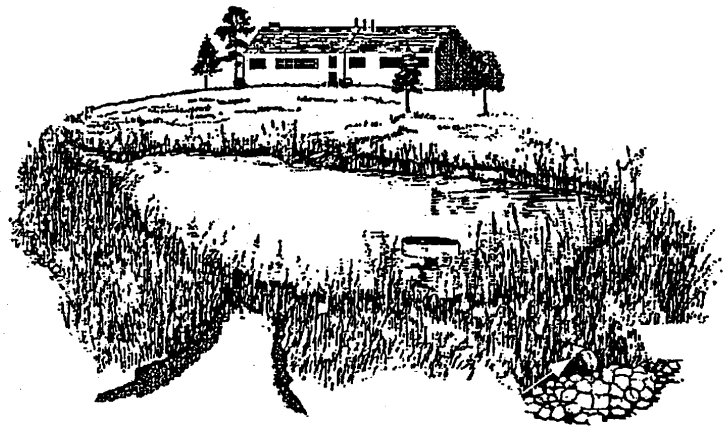
Wet Ponds



Description

A wet pond, also known as a wetpool, a retention basin, or a "NURP" pond (if the pond incorporates specific design parameters), is a constructed stormwater pond that retains a permanent pool of water. Wet ponds are generally on-line, end-of-pipe BMPs. The primary pollutant removal mechanism in a wet pond is sedimentation. Significant loads of suspended pollutants, such as metals, nutrients, sediments, and organics, can be removed by sedimentation. Dissolved contaminants are removed by a combination of processes: physical adsorption to bottom sediments and suspended fine sediments, natural chemical flocculation, bacterial decomposition, and uptake by aquatic plants and algae. Wet ponds have a moderate to high capacity for removing most urban pollutants, depending on how large the volume of the permanent pool is in relation to the runoff from the surrounding watershed. Figure 1 shows a schematic of a typical wet pond.

Generally, large contributing watersheds are required to maintain pool elevations. Minimum contributing watersheds should be at least 10 acres, but not more than one square mile. Sites with less than 10 acres of contributing watershed may be suitable if sufficient ground-water flow is available.

Wet ponds can be used at residential, commercial and industrial sites. Since wet ponds have the capability of removing soluble pollutants, they are suitable for sites where nutrient loadings are expected to be high.

Wet ponds may be single-purpose facilities, providing only runoff treatment, or they may be incorporated into an extended storage or a detention pond design to also provide flow control. Wet ponds themselves are generally ineffective in decreasing runoff volumes,

Purpose

Water Quantity	
Flow attenuation	■
Runoff volume reduction	□
Water Quality	
Pollution prevention	
Soil erosion	N/A
Sediment control	N/A
Nutrient loading	N/A
Pollution removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	◧
Floatables*	■
Oil and grease	◧
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

* Only if a skimmer is incorporated

Wet Ponds

Description (continued)

although some infiltration can occur (depending on groundwater depth and soil type), as well as evaporation in summer months.

Wet ponds work best when the water already in the pond is moved out en masse by incoming flows, a phenomena called "plug flow." Because treatment works on this displacement principle, the permanent pool of wet ponds may be provided below the groundwater level without interfering unduly with treatment effectiveness. Local authorities' regulations concerning groundwater should be consulted before constructing such a wet pond, however.

Removal efficiency is primarily dependent on the length of time that runoff remains in the pond, which is known as the pond's Hydraulic Residence Time (HRT). As discussed above, wet ponds can remove pollutants not only through sedimentation but also through biological uptake processes, whose removal of pollutants is proportional to the length of time runoff remains in the pond.

Studies have shown that more than 90 percent of the pollutant removal occurs during the quiescent period (the period between the rainfall events) (MD DEQ, 1986). However, some removal occurs during the dynamic period (when the runoff enters the pond). Modeling results have indicated that two-thirds of the sediment, nutrients and trace metal loads are removed by sedimentation within 24 hours. These projections are supported by the results of the EPA's 1993 Nationwide Urban Runoff Program (NURP) studies. However, other studies indicate that an HRT of two weeks is required to achieve significant phosphorus removal (MD DEQ, 1986). Researchers have developed design guidelines (discussed below) that are based in part on the influence of the HRT on a wet pond's treatment efficiency.

When properly designed and maintained, a wet pond can add recreation, open space, fire protection and aesthetic values to a project area.

Enhancement Options

Following the recommendations of this BMP section, by providing deep inlet and outlet zones or multiple pools, will usually result in designs that are robust enough to handle the winter and spring conditions without special considerations. However, runoff volume from spring snowmelt events can be very large, often the largest-volume event of the year. Ponds designed to function effectively in summer are often disrupted by winter and spring events. Inspection and maintenance during spring runoff should be a consistent feature of stormwater treatment systems in cold climates.

There are several common modifications that can be made to a wet pond to increase its pollutant removal effectiveness. These options are described below.

Varied Depths Throughout the Permanent Pool

Intermittent benches around the perimeter of the pond are recommended for safety and to promote vegetation. The safety bench should be designed to be at least 10 feet wide and located above normal pool elevations. The aquatic bench should be a minimum of ten feet wide and depths of 6-18 inches should be maintained at normal elevations to support aquatic vegetation. Deeper depths near the outlet will yield cooler bottom water discharges that may mitigate downstream thermal effects during the summer. Figure 2 shows a wet pond with both safety and aquatic benches.

Wet Ponds

Sediment Forebays

The settling area for incoming sediments can be increased through the addition of a sediment forebay. The use of a sediment forebay, however, is only recommended for wet ponds larger than 4,000 cubic feet. The forebay is an excavated settling basin or a section separated by a low weir at the head of the primary impoundment. Forebays serve to trap sediments before the runoff enters the primary pool, effectively enhancing removal rates and minimizing long term operation and maintenance problems. Periodic sediment removal from the forebay is easier and less costly than removal from the primary wet pond pool. Sediment forebays should be designed for ease of maintenance. Hard bottom forebays make sediment removal easier, and forebays should be accessible by heavy machinery, if necessary. About 10 to 25 percent of the surface area of the wet pond should be devoted to the forebay. The forebay can be distinguished from the remainder of the pond by one of several means: a lateral sill with rooted wetland vegetation, two ponds in series, differential pool depth, rock-filled gabions or retaining wall, or a horizontal rock wall filter placed laterally across the pond. Energy dissipation techniques should be used at the inlet to the sediment forebay to avoid erosion, to promote settling, and to minimize short-circuiting of flows. The length to width ratio of the forebay should be at least 2:1 to minimize short-circuiting. Figures 3a and 3b show a schematic of a wet pond that has a separate sediment forebay.

Pond Shape

To avoid reducing the pollutant removal capability and to maximize travel distance, the inflow points of the wet pond should be as far from the outlet as possible. To maximize stormwater contact and residence time in the pool, a length to width ratio of 3:1 is recommended. A minimum pool surface area of 0.25 acres is recommended. Performance of the wet pond may be enhanced by enlarging the surface area to increase volume, as opposed to deepening the pool.

Multi-Stage Outlets

Wet ponds may be designed with a multi-stage outlet structure to control discharges from different size storms. Usually the pond is designed to control multiple design storms (e.g. 2- and/or 10-year storms) and safely pass the 100-year storm event. However, the design storm may vary depending on local conditions and requirements.

Chemical Treatment

Addition of chemicals to precipitate phosphorus within the permanent pool (e.g. alum) can further enhance the removal of both particulate and dissolved forms of phosphorus entering the wet pond.

Aesthetic Enhancements

Many design features can be incorporated to enhance aesthetics where possible, such as:

- Providing pedestrian access to shallow pool areas enhanced with emergent wetland vegetation. This allows the pond to be more accessible without incurring safety risks.
- Providing side slopes that are sufficiently gentle to avoid the need for fencing (3:1 or flatter).
- Creating flat areas overlooking or adjoining the pond for seating that can be used by residents.
- Incorporating walking or jogging trails into the pond design.
- Including fountains or integrated waterfall features for privately maintained facilities.
- Providing visual enhancement with clusters of trees and shrubs.

Wet Ponds

Description (continued)

Establishing Aquatic Vegetation

Vegetative buffers around the perimeter of the wet pond are recommended for erosion control and additional sediment and nutrient removal. Establishing wetland vegetation on the aquatic bench will enhance removal of soluble nutrients, enhance sediment trapping, prevent sediment resuspension, provide wildlife and waterfowl habitat and conceal trash and debris that may accumulate near the outlet. Shallow depths near the inlet will concentrate sediment deposition in a smaller, more accessible area.

Advantages

- Capable of removing both solid and soluble pollutants.
- Depending on design, wet ponds can be an aesthetically pleasing BMP .
- Wildlife habitat is created when ponds are properly planted and maintained.

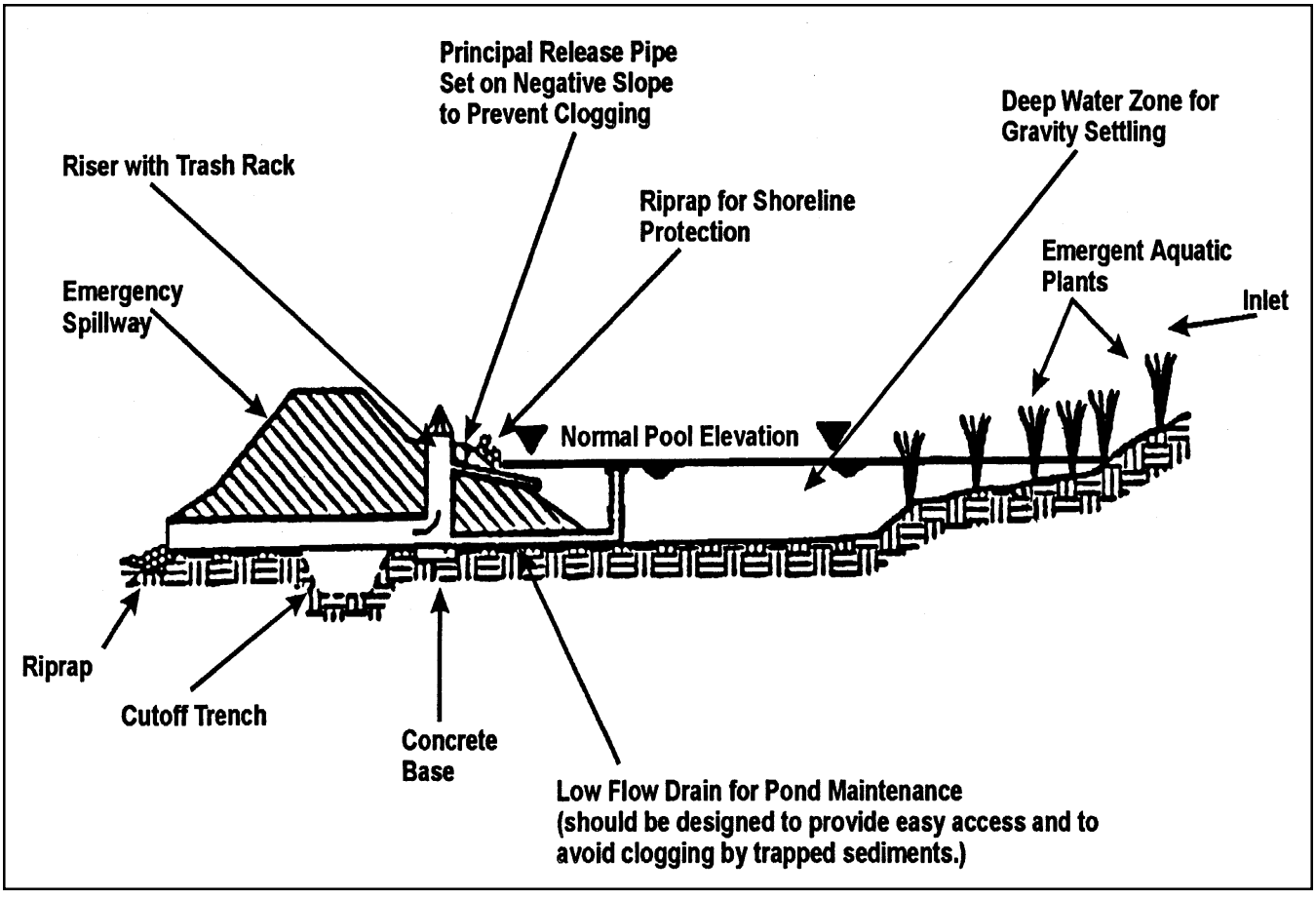


Figure 1: Typical Wet Pond Design
Source: Maryland Department of the Environment, 1986

Wet Ponds

- Can increase adjacent property values when planned, sited and designed properly.
- Pond sediment removal schedule is generally less frequent than for other BMPs.

Limitations

- Generally not prescribed for drainage areas smaller than 10 acres.
- More costly than extended storage ponds.
- Requires relatively large land area.
- Improperly designed or maintained ponds may result in stratification and anoxic conditions that can promote the release of nutrients and metals from the trapped sediments.
- Discharges from ponds usually consist of warm water, and thus pond use may be limited in areas where warm water discharges from the pond will adversely impact a cold water fishery.

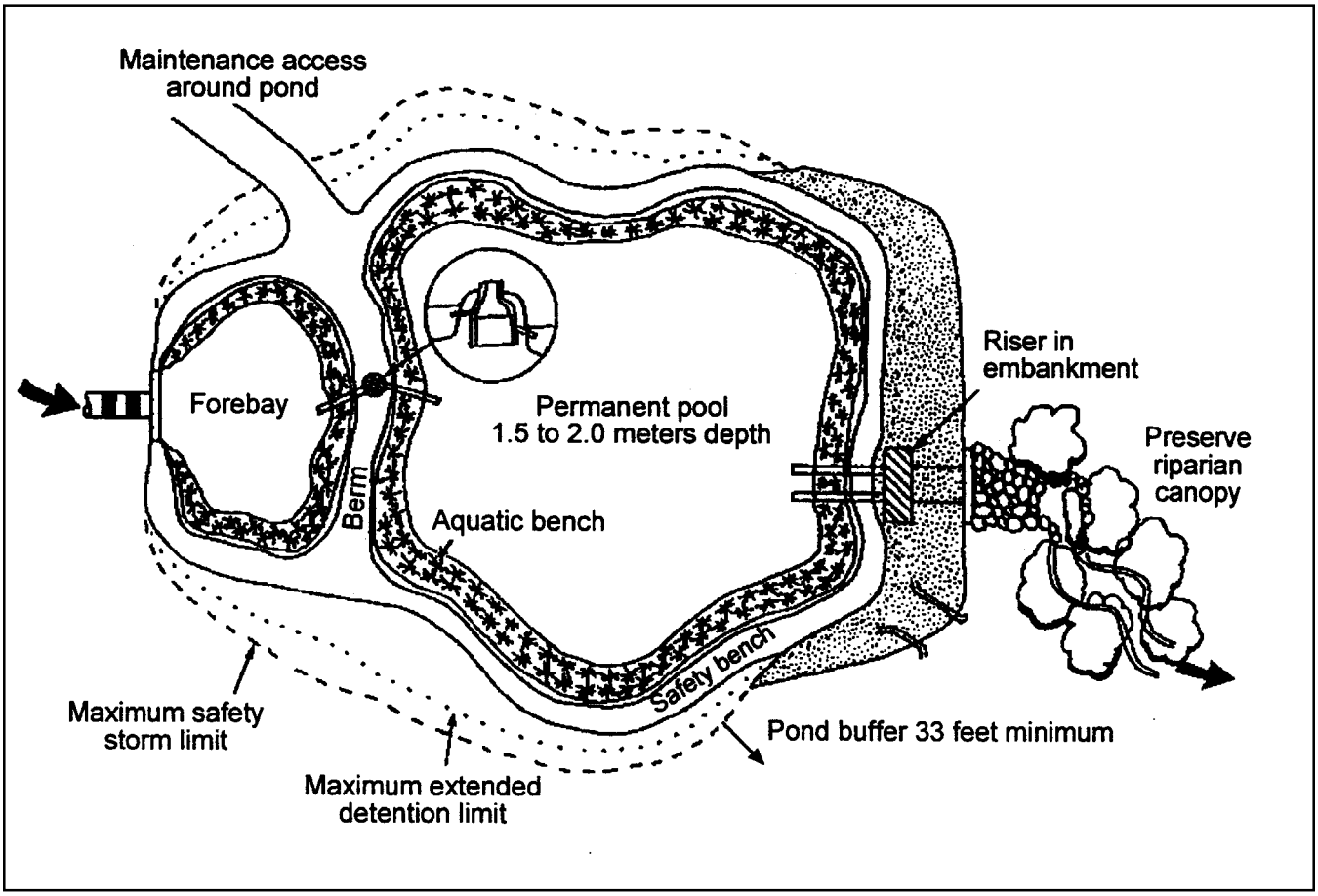


Figure 2: Schematic of a Wet Pond Showing Aquatic and Safety Benches
Source: Schueler, 1987

Wet Ponds

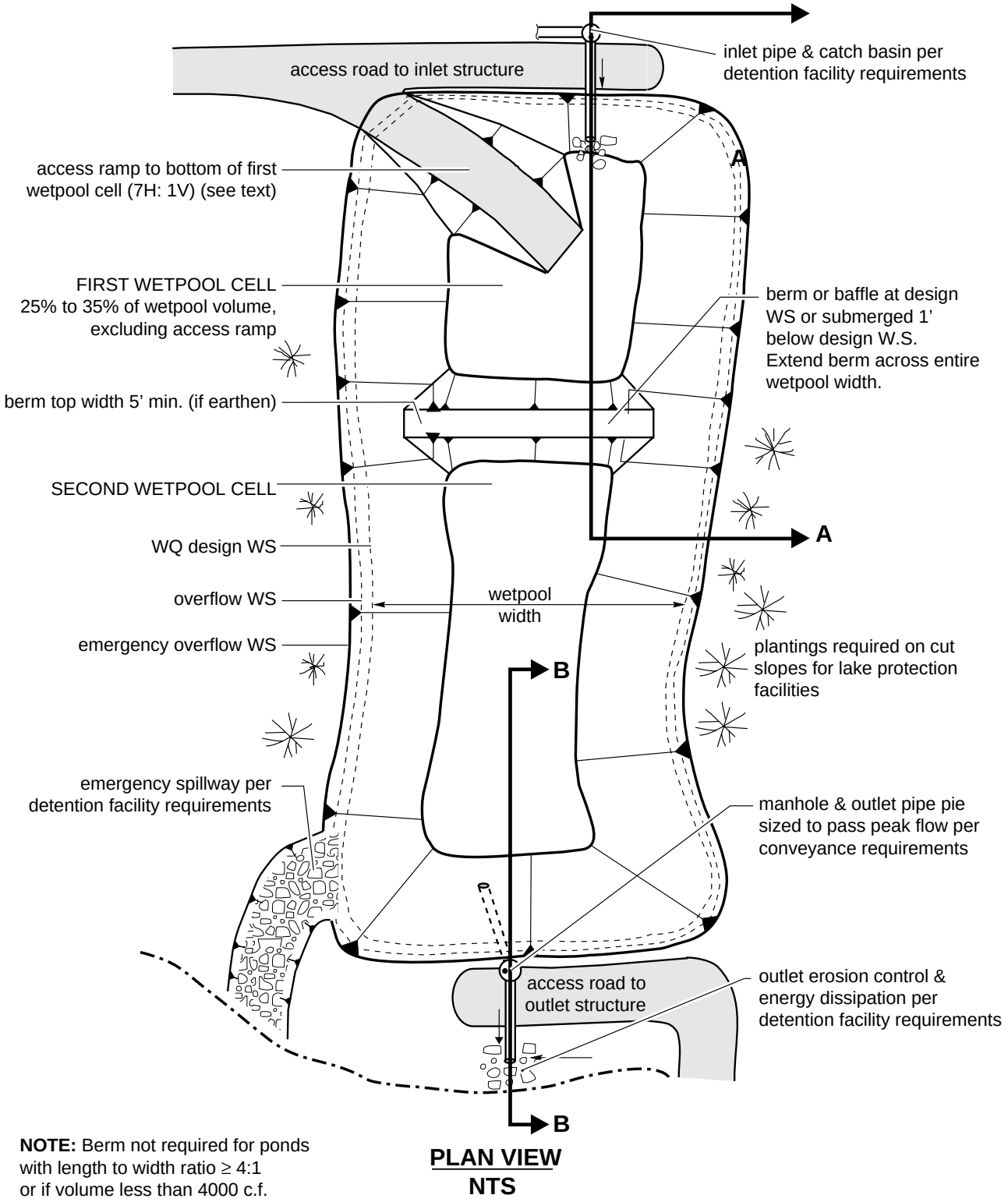
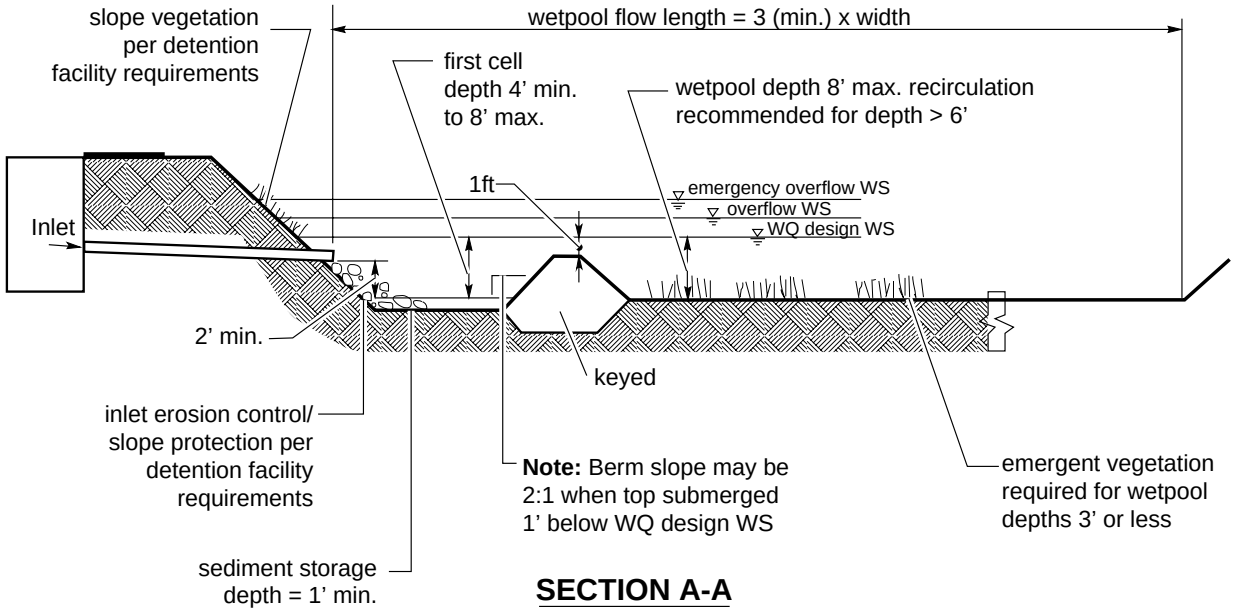


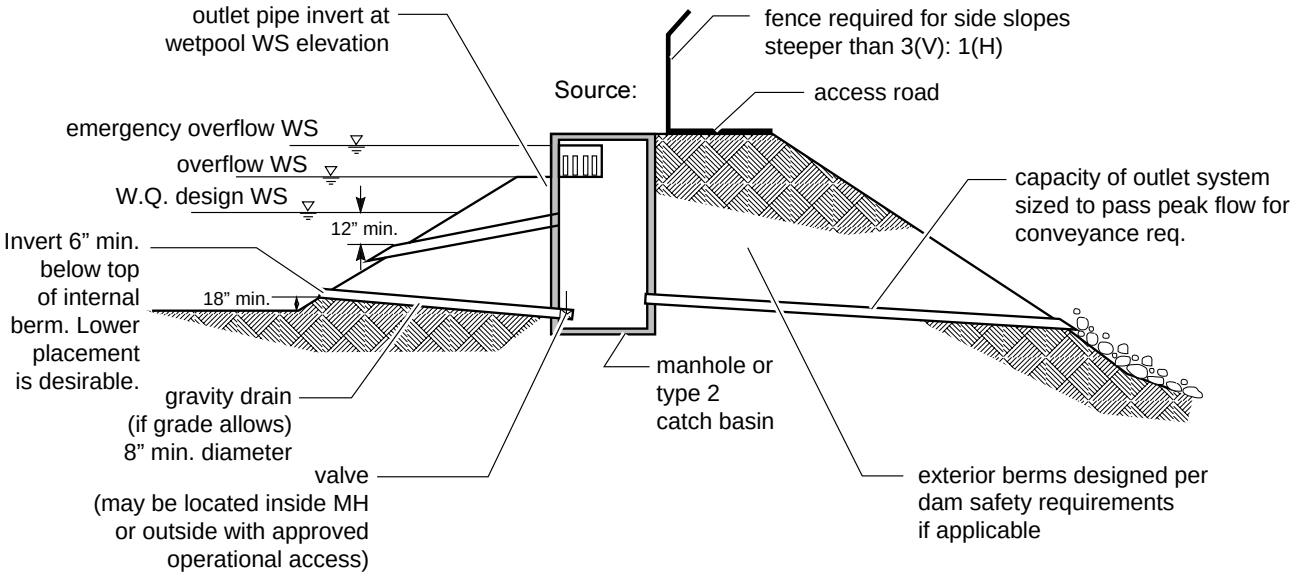
Figure 3a: Wet Pond Design with Separate Sediment Forebay (Plan View)

Source: Stormwater Management in Washington State, 2000

Wet Ponds



SECTION A-A
NTS
Caption



SECTION B-B
NTS

NOTE: See detention facility requirements for location and setback requirements.

Figure 3b: Wet Pond Design with Separate Sediment Forebay (Profile View)
Source: Stormwater Management in Washington State, 2000

Wet Ponds

Limitations (continued)

- The local climate during winter may affect the biological removal of pollutants in the pond. (Lower temperatures decrease the rate of biological activity). Also, formation of an ice layer may reduce the pond's treatment efficiency.
- Concern for mosquitoes and maintaining oxygen in ponds.
- Cannot be placed on steep unstable slopes.
- Depending on volume and depth, pond designs may require approval from dam safety authorities.

Requirements

Design

Pond Volume and Surface Area

Designing the volume of the permanent pool usually involves defining a rainstorm event called the "water quality event". For wet ponds, the runoff volume generated from the water quality event (called the "water quality volume") is equal to the volume of the wet pond. Local authorities will likely have their own definitions for the water quality event or the runoff volume that it generates. However, two published water quality event recommendations endorsed by the MPCA are the 1-year, 24-hour storm event (roughly 2 to 2.4 inches in Minnesota) and the 2.5-inch, 24-hour storm event (Walker, 1987). If the 1-year, 24-hour storm event is used, an additional volume for sediment storage must be added to the permanent pool design. If Walker's 2.5" storm is used, 25 years of sediment accumulation has already been incorporated into the pond volume.

The volume of runoff from the water quality event is best predicted by a combination of monitoring existing conditions and modeling future conditions. However, local authorities will likely have their own methods for calculating runoff volume from storm events. For design purposes, the water quality volume should be considered an instant flow to the pond, not an inflow-outflow calculation. In other words, this volume should be considered to arrive at the pond all at once, rather than over the course of several hours or days. The assumption of instant runoff is conservative, but it accounts for a great deal of the variability that occurs in both storm events and runoff conditions.

The 25-year sediment volume needed for the pond (if the 1-year, 24-hour storm is used as the water quality event) can be calculated with NRCS sediment storage calculation methods (see Sediment Management, below).

A minimum pool surface area of 0.25 acres is recommended based on the typical drainage area size required to sustain a permanent pool during summer months.

Pond Depth:

Pool depth is an important design factor, especially for sediment deposition. An average pool depth of 3 to 6 feet is recommended. Settling column studies and modeling analyses have shown that shallow ponds have higher solids removal than deeper ones. However, resuspension of settled materials by wind may be a problem in shallow ponds that are less than 2 feet in depth. Depths in excess of 10 feet may result in thermal stratification. Stratified pools tend to become anoxic (low or no oxygen) more often than shallower ponds. For wetpool depths in excess of 10 feet, it is recommended that some form of recirculation be provided in the summer, such as a fountain or aerator, to prevent stagnation and low dissolved oxygen conditions.

Wet Ponds

Varying depths throughout the pond are recommended. Intermittent benches around the perimeter of the pond are recommended to enhance public safety and to promote the growth of aquatic vegetation. Six to eighteen inches of water are needed for optimum wetland vegetation growth. Deeper depths near the riser will yield cooler water bottom discharges, which may mitigate downstream thermal effects.

Avoidance of short-circuiting and the promotion of plug flow:

To prevent short-circuiting, water is forced to flow, to the extent practical, to all potentially available flow routes, avoiding "dead zones" and maximizing the time water stays in the pond during the active part of a storm. Design features that encourage plug flow and avoid dead zones are:

- Providing a broad surface for water exchange across cells rather than a constricted area.
- Maximizing the flowpath between inlet and outlet, including the vertical path, also enhances treatment by increasing residence time. Baffles or islands can be added within the permanent pool to increase the flow path.
- The ratio of flowpath length to width from the inlet to the outlet should be at least 3:1. The flowpath length is defined as the distance from the inlet to the outlet, as measured at mid-depth. The width at mid-depth can be found as follows: width = (average top width + average bottom width)/2.
- All inlets should enter the first cell. If there are multiple inlets, the length-to-width ratio should be based on the average flowpath length for all inlets.
- Using a teardrop shape (as opposed to a rectangular one), as it minimizes dead zones caused by corners.

Pond Slopes:

The side slopes of the permanent pool should be no steeper than 3:1. Flatter slopes help to prevent erosion of the banks during larger storms and make routine bank maintenance tasks, such as mowing, easier. Flat slopes also provide for public safety, and allow easier access. Furthermore, the sides of the pool that extend below the safety and aquatic benches to the bottom of the pool should be at a slope that will remain stable, usually no steeper than 2:1 (horizontal: vertical). Slopes leading to the wet pond should be no steeper than 3:1.

Sediment Management:

A sediment forebay or similar pretreatment device is highly recommended to enhance pollutant removal and to prolong pond effectiveness in larger (>4,000 cubic feet) facilities.

The original design volume of the wet pond should take into account gradual sediment accumulation.

An access for maintenance, minimum width of 10 feet and a maximum slope of 15%, must be provided by public or private right-of-way. This access should never cross the emergency spillway, unless the spillway has been designed for that purpose.

An emergency drain (with a pipe sized to drain the pond in less than 24 hours) should be installed in all ponds to allow access for riser repairs and sediment removal (Schueler, 1987).

Wet Ponds

Design (continued)

Sediment Storage Design

Sediment volume should be at least the MPCA permit requirement of 250 cubic feet (ft^3) per acre of impervious surface in the tributary watershed. Alternatively, the wet pond can be built with capacity for about 25 years of storage. A detailed analysis of pond sediment storage volume may be helpful to determine cost-effective sediment control plans. Methods such as the NRCS use equations that address many of the sediment storage factors, but they should be evaluated by professionals on a site-specific basis. The basic equation and design considerations are:

$$Vol = A \times Y \times DR \times TE \times E / (217{,}800 \times G)$$

where: Vol = design sediment storage capacity,

E = average rate of erosion in the watershed in tons/acre/year,

A = area of the watershed in acres,

DR = sediment delivery ratio in percent,

G = estimated sediment density in the basin in pounds per cubic foot,

TE = trap efficiency, in percent, and

Y = design storage period in years.

It is important to remember that the Walker design (using a 2.5", 24-hour water quality event) already incorporates approximately 25 years of sediment storage in its design assumptions.

Pond Inlet/Outlet Structures and Pipes:

The outlet area should be a deeper micropool to provide final settling and prevent resuspension of sediments. The outlet device should be carefully designed, since it is important to the operation of the entire pond system.

Inflow points should be designed with energy dissipaters to reduce inflow velocity.

Several options that are available for pond outlets are discussed in the "Alternative Outlets" fact sheet. Two different outlet designs- one without and one with a riser, are shown in Figures 2 and 3, respectively.

In most cases, emergency spillways should be included in the pond design. Emergency spillways should be sized to safely pass flows that exceed the design storm flows. The spillway prevents pond water levels from overtopping the embankment, which could cause structural damage to the embankment. The emergency spillway should be located so that downstream buildings and structures will not be negatively impacted by spillway discharges. The pond design should include an emergency drain to assist in pond maintenance. The drain pipe should be designed for gravity discharge and should be equipped with an adjustable gate valve. Embankments and spillways should be designed in conformance with the state Dam Safety regulations and criteria.

The design of the wet pond embankment is another key factor to be considered. Proper design and construction of the embankments will prolong the integrity of the pond structure. Subsidence and settling will likely occur after an embankment is constructed. Therefore during construction, the embankment should be overfilled by at least 5

percent (SEWRPC, 1991). Seepage through the embankment can also affect the stability of the structure. Seepage can generally be minimized by adding drains, anti seepage collars, and core trenches. The embankment side slopes can be protected from erosion by using minimum side slopes of 3:1 and by covering the embankment with vegetation or riprap. The embankment should also have a minimum top width of 2 meters (6 feet) to aid in maintenance.

Scour Control:

Scour is the erosion of pond bottom or bank material due to high flow velocities. Scour control is important to maintain the function of the pond and reduce erosion, especially near the inlet. Inlet areas and inlet structures should be designed to control velocities at the inlet whether from large or small storm events.

Flow-diffusion devices, including plunge pools, directional berms or other specially created dissipation structures, are often recommended. For annual events, the velocity leaving the inlet area and entering the main treatment area should be less than 1 foot per second (fps). Decreasing velocity reduces scour and more importantly reduces mixing currents that reduce treatment efficiency.

The MPCA recommends that the following design storms be considered in the pond design (MPCA, 2000). Scour prevention can be achieved if velocities through the main treatment area are limited to the following maximums:

1 foot per second for the 1-yr 2.4” event:

3 feet per second for the 2-yr, 2.8” event:

5 feet per second for the 10-yr, 4.0” event and the 100-yr, 6.0” event

Velocities are calculated as outflow divided by the area of the critical cross-section. All events are considered to be the 24-hour NRCS distribution event.

Water Quantity Control Requirements:

Wet ponds should be designed to meet both storm water quality and quantity control requirements. Storm water quantity requirements are typically met by designing the pond to control post-development peak discharge rates to pre-development levels. Usually the pond is designed to control multiple design storms (e.g. 2- and/or 10-year storms) and safely pass the 100-year storm event. However, the design storm may vary depending on local conditions and requirements.

Design for Winter-Runoff Conditions

During the winter period, the design volume of the wet pond can be less than desired. Ground freezing throughout the tributary watershed effectively increases the watershed’s imperviousness, which increases the fraction of precipitation that reaches the pond. Moreover, the available volume in the permanent pool can be reduced by the formation of ice. Fortunately, winter rainfall and snowmelt events (as opposed to spring) typically produce lower volumes of runoff than summer storms and so most events will continue to be captured entirely (e.g. the volume of runoff will be less than the reduced volume of the wet pond). However, temperature regimes in the northern regions of Minnesota are such that ice cover may persist into the spring period when runoff rates and contaminant washoff rates are higher. In these areas, some authorities recommend that the wet pond volume be increased by an amount equal to the expected volume of the ice cover (Ontario Ministry of the Environment, 1999).

Wet Ponds

Requirements
Design (continued)

The thickness of ice can be estimated using Stefan's equation (Marsalek, 2000):

$$h = a\,(D_f)^{0.5}$$

where: h is the ice thickness in mm

a is a coefficient of ice growth

D_f is the sum of freezing degree-days

The values for the coefficient for ice growth are shown below.

Condition	a ($mm^{\circ}C^{-0.5}d^{-0.5}$)
Theoretical Maximum	34
Windy Lake with No Snow	27
Average Lake with Snow	17-24
Average River with Snow	14-17
Shelter River with Rapid Flow	7-14

Work done a pond in Kingston, Ontario, indicated that a coefficient value of 15 produced results close to measured values. The pond operated with a constant subsurface inflow, which tended to limit the buildup of ice. In general, it is expected that most ponds will be small enough and will receive sufficient inflow to behave more like a river (in terms of ice buildup) than a lake. Where possible however, the designer should consult with the local authorities concerning local knowledge on ice depths (Ontario Ministry of the Environment, 1999).

Snowmelt runoff events in Minnesota may convey high concentrations of urban runoff pollutants to stormwater ponds and other receiving waters. Recommendations to manage this potential influx of contaminated snow and ice melt include: incorporating extended storage (see the Extended Storage Ponds BMP Section) in the pond design, installing grass swales in the drainage system ahead of stormwater ponds, and storing contaminated snow and ice where debris and petroleum products are less likely to be transported to the pond (Oberts, 1991).

Water can flow over the ice in stormwater ponds during spring thaw, and may carry sediment directly out of the pond outlet. If this is a concern for a particular pond design, it is generally a good idea to incorporate extended storage capability of the pond. In this type of design, increasing the volume of the pond above the permanent pool can also enhance winter runoff treatment. One can also increase the depth of the pond below the water quality spillway, thus allowing more room for the ice to collapse into the pond. If the pond is located in an area with a high water table, it may not be feasible to make this design modification.

Standpipe outlets may be destroyed by ice movement in winter. Standpipes are not recommended unless they are designed to withstand ice movement.

In Minnesota's urban areas, snow piles are often created in parking lots, along streets and elsewhere. Store snow where debris oil and other materials cannot readily enter waters of the state. Discharge of such materials directly to waters of the state is prohibited. So, snow-storage areas that minimize surface-water impacts should be planned.

Wet Ponds

Following the recommendations of this BMP section, by providing deep inlet and outlet zones or multiple pools, will usually result in designs that are robust enough to handle the winter and spring conditions without special considerations. However, runoff volume from spring snowmelt events can be very large, often the largest-volume event of the year. Ponds designed to function effectively in summer are often disrupted by winter and spring events. Inspection and maintenance during spring runoff should be a consistent feature of stormwater treatment systems in cold climates.

Sequencing

- Wet ponds may be constructed in the early phases of a development project, in order to treat site runoff during construction.
- If the basin is used as a sediment trap during construction, all sediment deposited during construction should be removed before normal operation begins.

Construction

- As with other stormwater BMPs, soils, depth to bedrock, and depth to water table must be investigated before designing a wet pond. At sites where bedrock is close to the surface, high excavation costs may make wet ponds infeasible. If the soils on site are relatively permeable or well drained, it will be difficult to maintain a permanent pool. In this situation, it may be necessary to line the bottom of the wet pond to reduce infiltration.
- All local, state and federal permit requirements should be established prior to initiating the pond design. Depending on the location of the pond, required permits and certifications may include wetland permits, water quality certifications, dam safety permits, sediment and erosion control plans, waterway permits, local grading permits, land use approvals, etc. Since many states and municipalities are still in the process of developing or modifying storm water permit requirements, the applicable requirements should be confirmed with the appropriate regulatory authorities.
- Pond systems can perform well in cold climates because many modification options are available to increase their effectiveness in frigid and snowy conditions. Many of these modifications address the problems associated with pipe freezing (Oberts, 1991 and CWP, 1997).

Maintenance

- Maintenance is required for the proper operation of wet ponds. Plans for wet ponds should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule for wet ponds.
- Once constructed, the wet pond should be inspected after several storm events to confirm drainage system functions, bank stability, and vegetation growth. Problems should be addressed immediately.
- Accumulated trash and debris should be removed from the side slopes, embankment, emergency spillway and weird trash gates as often as needed (at least twice during the growing season). Accumulated sediment in the forebay should be inspected at the same time.
- Wet ponds should be inspected at least twice per year during the growing season to ensure that they are operating as designed. Potential problems that should be checked include: subsidence, erosion, cracking or

Requirements
Maintenance (continued)

tree growth on the embankment; damage to the emergency spillway; sediment accumulation around the outlet; and erosion within the basin and banks. Any necessary repairs should be made immediately. During inspections, changes to the wet pond or the contributing watershed should be noted, as these may affect basin performance.

- Sediment should be removed from the pond as necessary, and at least once every 5 to 25 years (usually more frequently than once every 25 years). The frequency of sediment removal depends on the years of sediment accumulation that were incorporated into the design volume of the wet pond's permanent pool and forebay and on the occurrence of any high-loading events.
- In most cases, no specific limitations have been placed on disposal of sediments removed from wet detention ponds. Studies to date indicate that pond sediments are likely to meet toxicity limits and can be safely landfilled. On-site sediment disposal is always preferable (if local authorities permit) as long as the sediments are deposited away from the shoreline to prevent their reentry into the pond and away from recreation areas, where they could possibly be ingested by young children.
- Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.
- Mosquito control, if necessary.

Wet Ponds

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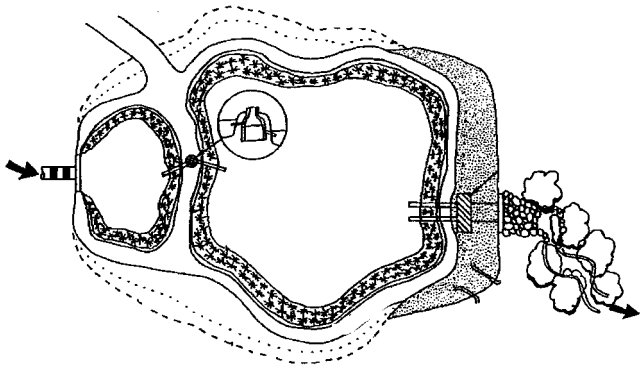
Extended Storage Ponds



Description

Extended storage ponds (also known as extended detention ponds) are stormwater basins that are designed to provide temporary storage for runoff from multiple design events. Extended storage ponds are typically on-line, end-of-pipe BMPs. Extended storage ponds are not just flood-control measures, but are designed to use detention time as their primary method to allow the physical settling of pollutants. Extended storage allows particulate material and debris to settle out of the water column while drawing the pond down for additional storm event storage. Ponds that use this method can be dry, designed with a shallow marsh or have a permanent pool.

An extended storage pond is typically designed with three distinct stages:

- The top stage of the pond should have the capacity to regulate peak flow rates of large, infrequent storms (10-, 25- or 100-year), and will generally remain dry between storms. The volume in the stage is called the "flood storage volume".
- The middle stage of the pond is designed to detain smaller storms for a sufficient period of time to remove pollutants from the runoff. The volume in this stage is called the "water quality volume". The water quality volume is a design term that refers to the volume of water to be treated by the BMP. For extended storage ponds, the water quality volume is typically the runoff from the 0.3-year storm event, since a large fraction of the annual pollutant load is delivered by small, frequent storm events (like the 0.3-year storm).
- A third, bottom stage of extended storage ponds (below the outlet elevation) is optional. It can be designed to be managed in one of several ways. The lower stage can either have a permanent pool of water, have a shallow marsh, or be normally dry between

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	□

Water Quality

Pollution prevention

Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**

Pollution removal

Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	◧
Floatables*	■
Oil and grease	◧
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

* Only if a skimmer is incorporated into the outlet design.

Extended Storage Ponds

Description (continued)

storm events (for the purpose of sediment storage). Only the first option (an extended storage pond that includes a permanent pool in its lower stage) is discussed in this document. A permanent pool in an extended storage pond functions like a wet pond (see the Wet Pond BMP Section for a more detailed description of wet ponds). Extended storage ponds with a permanent pool of water typically are more effective for pollutant removal than those that are normally dry. The permanent pool of water provides a much higher removal efficiency of suspended solids for very small runoff events by providing sediment storage and a relatively long residence time between storms for settling.

Figure 1 illustrates the difference between the flood storage volume, the water quality volume and the permanent pool in an extended storage pond. Figures 2 and 3 are examples of some typical extended storage pond designs.

For storms with a recurrence interval of about one year, the maximum bounce (water elevation increase) above the permanent pool usually should not exceed 3 ft. The extended storage volume should be drawn down in one to two days after a storm event to prevent destruction of adjacent vegetation by inundation, and to help assure the basin is ready for the next storm. In the Minneapolis-St. Paul area, the time between rainfall events is typically 87 hours.

It should be noted that the recommended drawdown time of 24 to 48 hours for a full pond is based on very limited laboratory data. A few extended storage ponds have been monitored and generally provide a TSS removal efficiency of 60 to 80% with a drawdown time of 24 hours. Forty hours is recommended in order to settle out the finer clay particles in runoff that typically adsorb toxic pollutants.

Sediment and its associated pollutants, such as trace metals and nutrients, are the pollutants most effectively controlled by extended storage ponds. If the pond's outlet is designed as a skimmer, floating debris and organic matter can also be effectively trapped. If a permanent pool or shallow marsh area is included in the design, some removal of fine sediment and soluble nutrients can be achieved.

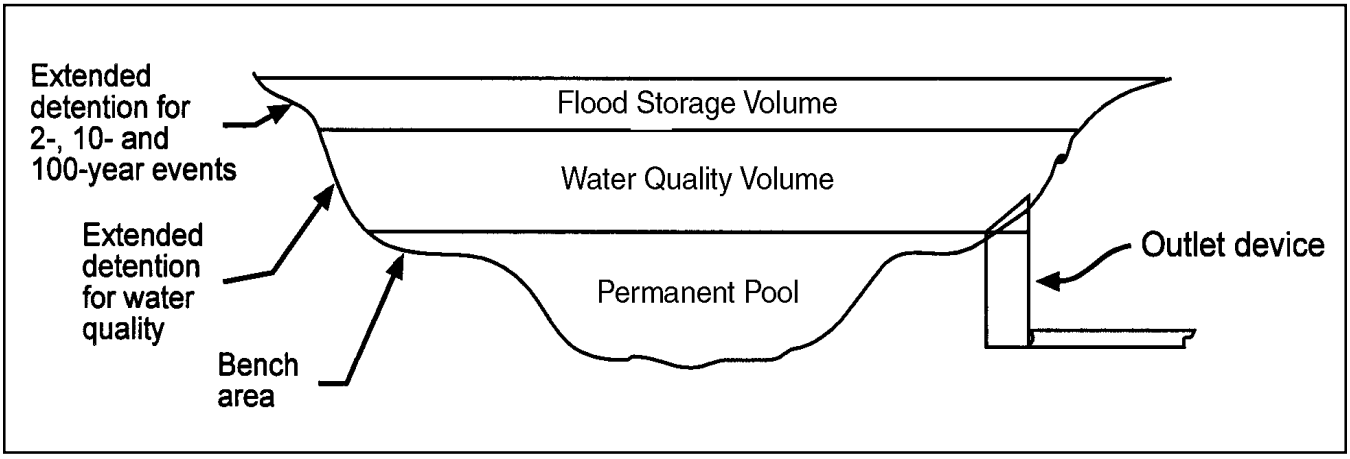


Figure 1: Extended Pond Cross-Section
Source: Adapted from Wet Detention Ponds, Pitt, 1998

Extended Storage Ponds

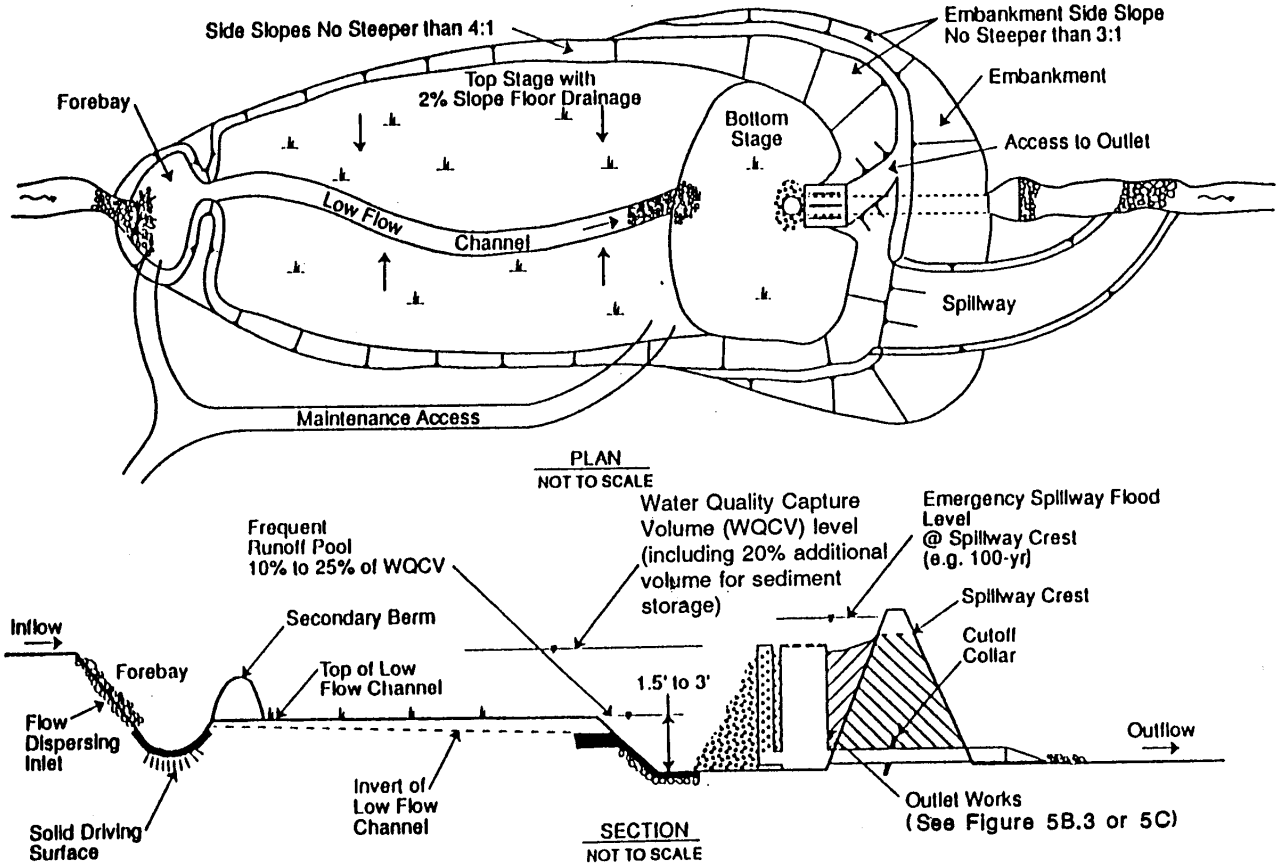


Figure 2: Schematic of an Extended Storage Pond

Source: *"Used by Permission", UDFCD, 1992*

Extended storage ponds are some of the best facilities for treating spring and winter runoff, because of the way that ice conditions effect the flows. Ponds without extended storage may have minimal storage above the ice surface; therefore, treatment could be bypassed. In addition, extended storage ponds are very effective in controlling peak discharges, an important factor in reducing downstream streambank erosion and sediment loads.

Generally, extended storage ponds are not practical if the contributing watershed area is less than 10 acres. Four acres of watershed area are recommended for each acre-foot of storage in the pond.

The efficiency of an extended storage pond depends largely upon the surface overflow rate (defined as the pond outflow rate divided by the pond surface area) (Barfield et al., 1986).

Extended Storage Ponds

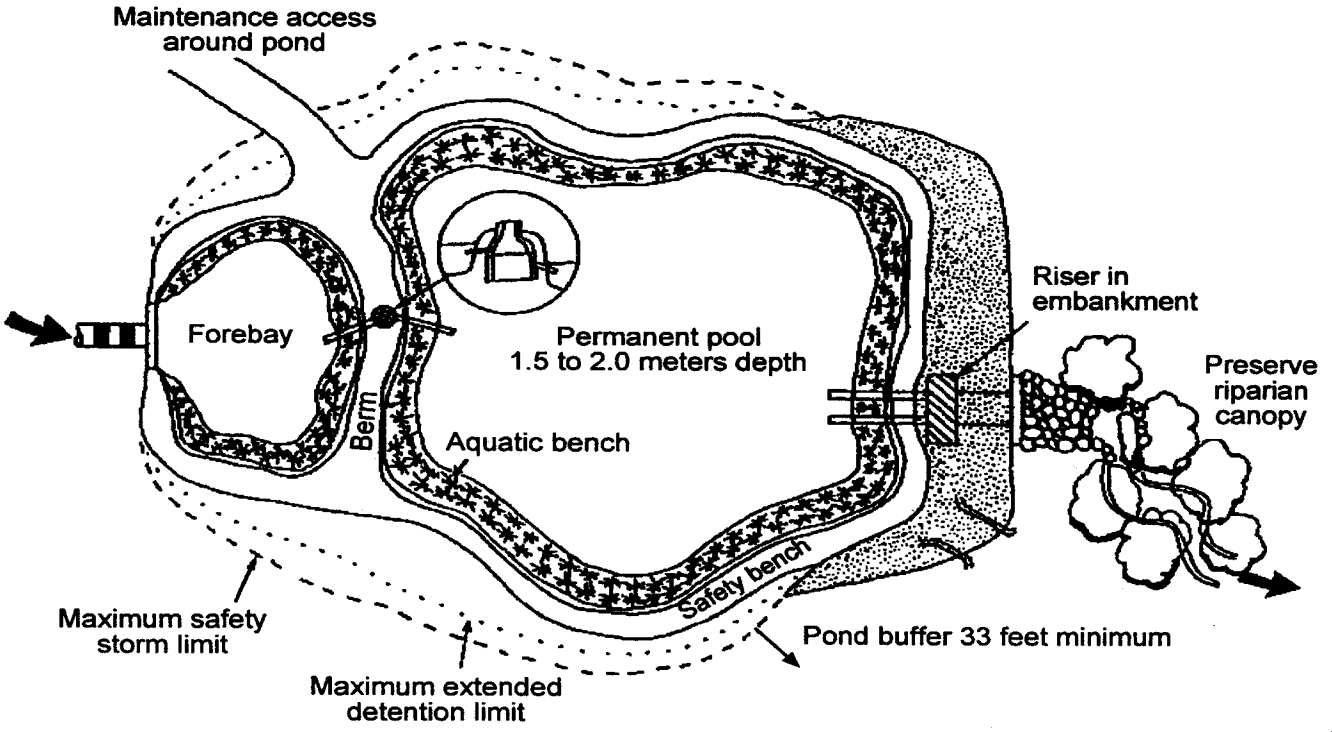


Figure 3: Schematic of an Extended Storage Pond with a Sediment Forebay

Source: Schueler, 1992

Enhancement Options

There are several common modifications that can be made to an extended storage pond to increase its pollutant removal effectiveness. These options are described below.

Adding a shallow wetland

Removal of soluble pollutants can be enhanced in the lower stage of the basin, if it is maintained as a shallow wetland. Establishing wetland vegetation in a shallow marsh component or on an aquatic bench in the lower stage of the detention basin will enhance removal of soluble nutrients, increase sediment trapping, prevent sediment resuspension, and provide wildlife and waterfowl habitat. Proper soils and surface or groundwater depth are needed to maintain wetland vegetation. The degree of removal by such wetlands appears to be dependent upon wetland size in relation to loading.

Sediment forebays

The settling area for incoming sediments can be increased through the addition of a sediment forebay. The use of a sediment forebay, however, is only recommended for wet ponds larger than 4,000 cubic feet. The forebay is an

Extended Storage Ponds

excavated settling basin or a section separated by a low weir at the head of the primary impoundment. Forebays serve to trap sediments before the runoff enters the primary pool, effectively enhancing removal rates and minimizing long term operation and maintenance problems. Periodic sediment removal from the forebay is easier and less costly than removal from the primary wet pond pool. Sediment forebays should be designed for ease of maintenance. Hard bottom forebays make sediment removal easier, and forebays should be accessible by heavy machinery, if necessary. About 10 to 25% of the surface area of the wet pond should be devoted to the forebay.

The forebay can be distinguished from the remainder of the pond by one of several means: a lateral sill with rooted wetland vegetation, two ponds in series, differential pool depth, rock-filled gabions or retaining wall, or a horizontal rock wall filter placed laterally across the pond. Energy dissipation techniques should be used at the inlet to the sediment forebay to avoid erosion, to promote settling, and to minimize short-circuiting of flows. The length to width ratio of the forebay should be at least 2:1 to minimize short-circuiting.

Low flow channels

A low flow channel routes the last remaining runoff, dry weather flow and groundwater to the permanent pool and outlet. A low flow channel should be installed in the upper stage of the basin to ensure that the basin dries out completely. Low flow channels also serve to prevent erosion of the upper stage of the pond outside as runoff first enters the pond.

Pond shape

The inlet and outlet should be positioned in such a way that short-circuiting in the basin is minimized. Ponds that are considerably longer than wide (e.g. length equal to three times the width) will likely provide additional detention time for settling and biological treatment. Baffles and curved flow paths can also be used to increase settling efficiency.

Advantages

- Least costly BMP that controls both stormwater quantity and quality (in terms of construction costs).
- Can perform well in cold climates.
- Good retrofitting option for existing basins.
- Extended storage ponds that include a dead storage pool can remove significant levels of sediment and sorbed pollutants.
- Potential for beneficial terrestrial and aquatic habitat (depends on design).
- Less potential for hazards than deeper permanent pools
- Can provide excellent streambank erosion protection and treatment of stormwater when used in combination with other stormwater control practices such as wetlands or when retrofitted with permanent pools.

Limitations

- Generally not prescribed for drainage areas smaller than 10 acres.
- Requires relatively large land area.

Extended Storage Ponds

- Removal of soluble pollutants is minimal if a permanent pool is not incorporated into the design.
- Discharges from ponds can consist of warm water, and thus their use may be limited in areas where warm water discharges will adversely impact a cold-water fishery.
- Sediment can be resuspended in the first stage of the pond after large storms if not removed.
- Cold winter climates may affect the biological removal of pollutants in the pond. (Lower temperatures decrease the rate of biological activity).
- Can often be considered unattractive by residents. Poorly maintained basins can create nuisance odors and collect trash.
- Erosion and resuspension of sediments may occur in the pond if the upper stage is not properly vegetated.
- Depending on their volume and depth, pond designs may require approval from dam safety authorities.

Design

In determining the size of the basin, the two most critical parameters are the pond volume and the maximum rate of runoff released from the basin.

Pond Volume and Surface Area

Flood Storage Volume

The flood storage volume can be estimated in a number of ways. A typical approach is to limit the peak outflow rate to some predetermined level, such as the pre-development peak level. Local authorities may also have their own requirements that will dictate the magnitude of the flood storage volume. This volume must be situated above the groundwater table.

Water Quality Volume

When designing an extended storage pond, it's important to recognize that small storms (typically less than 1.25-inch events or 0.3-year return frequency events) that produce less than 0.5 inch of runoff) deliver the majority of the pollutants throughout an average year (Pitt, 1994 and 1998). If small storms are not considered in the design, their effects may not be adequately treated.

Therefore, the minimum recommended water quality volume for extended storage is the total volume of runoff from a 1.25-inch event (a storm with a return frequency of once in about 0.3 years). This should be calculated as an instant runoff volume. In other words, this volume should be considered to arrive at the pond all at once, rather than over the course of several hours or days.

In some urban areas, the water quality volume is often considered as 0.5 inch of runoff for all impervious areas in the watershed (MPCA, Construction Storm Water Permit). The 0.5-inch criterion is intended to be a simplified calculation of the runoff volume from the 1.25-inch event in residential areas. If you are required to meet other regulatory requirements, the MPCA recommends calculating both the 1.25-inch and other regulatory volumes, then using the larger measure for the water quality volume in the design. This volume must be situated above the groundwater table.

Extended Storage Ponds

Permanent Pool Volume

The design requirements outlined in the Wet Ponds BMP section are pertinent to the design of the permanent pool in the lower stage of an extended storage pond. The only significant difference between a wet pond and the permanent pool in an extended storage pond is that the wet pond's volume must encompass the entire water quality volume (a wet pond design relies on only its permanent pool for treatment, whereas the permanent pool in an extended storage pond acts more like a "polishing" stage of the pond).

A minimum average depth of 3 feet is recommended in the permanent pool. The surface area of the permanent pool should be larger than 0.25 acres. Site constraints will likely play a role in determining the surface area of the permanent pool. Other sizing parameters will be determined by scour prevention requirements (see Scour Control, below).

Water Quantity Control Requirements:

Extended storage pond design must account for large, infrequent storm events for runoff quantity control, as well as small, frequent storm events for runoff quality control. This is usually achieved through the use of a multiple-stage outlet design. The Alternative Outlets BMP Section will cover the design of extended storage outlets in more detail.

Large storm events

Local authorities will likely have their own runoff control requirements for large storm events. Many watersheds require that the post-development peak runoff rate must equal the peak runoff rate from the 10- and 100- year pre-development events. In addition, low floor elevations of structures are typically required to be at least 0.3 to 3 feet above the 100-year flood elevation. These rates and elevations need to be considered in the pond-design phase, in addition to the water quality treatment and erosion control design.

Small storm events

Typically, the first flush of runoff contains the highest concentrations of pollutants. Thus, extended storage ponds should be designed to maximize the detention time for the most frequent storms. Routing calculations for a range of storms should provide the designer with the optimal basin size. Generally, most particulates settle within the first 12 hours of detention; however, additional time is required to settle finer particulates. Twenty-four hours is the minimum detention time necessary for optimal pollutant removal.

The design detention time can be achieved by adjusting the outflow rate from the basin. As the outflow rate is decreased, the detention time and the required temporary storage volume will be increased.

Although detention time is widely used in design, problems are often encountered in defining detention time in the case of intermittent stormwater flows. It is essentially impossible to define a detention time for stormwater flows (US EPA, 1983). To provide 90% overall removal, a design criterion has been established which will provide reasonable treatment given the assumptions about storm events, particle size distribution and settling velocities. To standardize design methods, the MPCA has selected an outflow rate of 5.66 cfs per surface acre of treatment pond. This outflow rate has been selected to provide 90% removal of TSS for a volume equal to the runoff from the 0.3-year return frequency event. This is about 1.25 inches of precipitation in the Minneapolis/St. Paul area.

Extended Storage Ponds

Design (continued)

The outlet device can therefore be designed to provide the desired outflow rate of 5.66 cfs per acre of pond surface area for the water quality volume (Pitt, 1994 and 1998) and appropriate rates for the two-, 10- and 100 year events

Pond Depth

Maximum depth of an extended storage pond may range from 3 to 12 feet (above the permanent pool). The depth of the basin may be limited by groundwater conditions or by soils. Extended storage ponds should be above normal groundwater elevation (i.e. should not intercept groundwater).

The depth of the permanent pool should be designed with other considerations in mind (see the Wet Pond BMP section for more detail).

Avoidance of Short-Circuiting and the Promotion of Plug Flow:

To prevent short-circuiting, water is forced to flow, to the extent practical, to all potentially available flow routes, avoiding "dead zones" and maximizing the time water stays in the pond during the active part of a storm. Design features that encourage plug flow and avoid dead zones are:

- Providing a broad surface for water exchange across cells rather than a constricted area.
- Maximizing the flowpath between inlet and outlet, including the vertical path, also enhances treatment by increasing residence time. Baffles or islands can be added within the permanent pool to increase the flow path.
- The ratio of flowpath length to width from the inlet to the outlet should be at least 3:1. The flowpath length is defined as the distance from the inlet to the outlet, as measured at mid-depth. The width at mid-depth can be found as follows: width = (average top width + average bottom width)/2.
- All inlets should enter the first cell. If there are multiple inlets, the length-to-width ratio should be based on the average flowpath length for all inlets.
- Using a teardrop shape (as opposed to a rectangular one), as it minimizes dead zones caused by corners.

Pond Slopes

The side slopes of the permanent pool should be no steeper than 3:1. Flatter slopes help to prevent erosion of the banks during larger storms and make routine bank maintenance tasks, such as mowing, easier. Flat slopes also provide for public safety, and allow easier access. Furthermore, the sides of the pool that extend below the safety and aquatic benches to the bottom of the pool should be at a slope that will remain stable, usually no steeper than 2:1 (horizontal: vertical). Slopes leading to the wet pond should be no steeper than 3:1.

Sediment Management

Adequate sediment storage should be provided, usually to hold five to 25 years of sediment accumulation. A forebay at the inlet to the sediment basin can be used to trap coarse sediments, such as road sand, and large debris, such as leaves and branches. If sediment is removed from the forebay or the entire basin on a more ffrequent basis, the sediment storage volume in the basin may be reduced. A common (and recommended)

Extended Storage Ponds

maintenance cycle is five years. Sediments can be resuspended by the incoming runoff. Therefore, it is recommended that there is either an additional plunge pool at the inlet (forebay) of the basin or sufficient measures such as riprap to dissipate the energy.

A sediment forebay or similar pretreatment device is highly recommended to enhance pollutant removal and to prolong pond effectiveness in larger (>4,000 cubic feet) facilities.

An access for maintenance, minimum width of 10 feet and a maximum slope of 15%, must be provided by public or private right-of-way. This access should never cross the emergency spillway, unless the spillway has been designed for that purpose.

An emergency drain (with a pipe sized to drain the pond in less than 24 hours) should be installed in all ponds to allow access for riser repairs and sediment removal (Schueler, 1987).

Sediment Storage Design

The original design volume of the wet pond should take into account gradual sediment accumulation. Sediment volume should be at least the MPCA permit requirement of 250 cubic feet (ft^3) per acre of impervious surface. Another alternative is to design the permanent pool with a capacity for a certain number of years of storage. A detailed analysis of pond sediment storage volume may be helpful to determine cost-effective sediment control plans. Methods such as the NRCS use equations that address many of the sediment storage factors, but they should be evaluated by professionals on a site-specific basis. The basic equation and design considerations are:

$$Vol = A \times Y \times DR \times TE \times E / (217{,}800 \times G)$$

where: Vol = design sediment storage capacity,

E = average rate of erosion in the watershed in tons/acre/year,

A = area of the watershed in acres,

DR = sediment delivery ratio in percent,

G = estimated sediment density in the basin in pounds per cubic foot,

TE = trap efficiency, in percent, and

Y = design storage period in years.

Pond Inlet/Outlet Structures and Pipes

The pond should be designed in such a way that turbulence in the main treatment area is minimized. For example, inflow points should be designed with energy dissipaters to reduce inflow velocity. Reducing the turbulence will reduce the chance that previously deposited materials will be resuspended. It will also result in conditions more conducive to settling while the pond is filling.

The outlet area should be a deeper micropool to provide final settling and prevent resuspension of sediments. The outlet device should be carefully designed, since it is important to the operation of the entire pond system.

Several options that are available for pond outlets are discussed in the “Alternative Outlets” BMP Section.

In most cases, emergency spillways should be included in the pond design. Emergency spillways should be sized to safely pass flows that exceed the design storm flows. The spillway prevents pond water levels from overtopping

Extended Storage Ponds

Design (continued)

the embankment, which could cause structural damage to the embankment. The emergency spillway should be located so that downstream buildings and structures will not be negatively impacted by spillway discharges. The pond design should include an emergency drain to assist in pond maintenance. The drain pipe should be designed for gravity discharge and should be equipped with an adjustable gate valve. Embankments and spillways should be designed in conformance with the state Dam Safety regulations and criteria.

The design of the wet pond embankment is another key factor to be considered. Proper design and construction of the embankments will prolong the integrity of the pond structure. Subsidence and settling will likely occur after an embankment is constructed. Therefore during construction, the embankment should be overfilled by at least 5 percent (SEWRPC, 1991). Seepage through the embankment can also affect the stability of the structure. Seepage can generally be minimized by adding drains, anti seepage collars, and core trenches. The embankment side slopes can be protected from erosion by using minimum side slopes of 3:1 and by covering the embankment with vegetation or riprap. The embankment should also have a minimum top width of 2 meters (6 feet) to aid in maintenance.

Low-Flow Channels

A low flow channel routes the last remaining runoff, dry weather flow and groundwater to the permanent pool and outlet. A low flow channel should be installed in the upper stage of the basin to ensure that the basin dries out completely. Low flow channels also serve to prevent erosion of the upper stage of the pond outside as runoff first enters the pond. Pervious or impervious channel lining may be used. A pervious lining allows interaction of the runoff with the soil and grass, resulting in increased sorption of pollutants. Design velocities in pervious low flow channels should be high enough to prevent sedimentation and low enough to prevent scouring and erosion. No minimum low flow channel velocity is needed if a forebay is utilized prior to the low flow channel. The maximum flow velocity is dependent on the nature of the material used to line the channel.

Scour Control

Scour is the erosion of pond bottom or bank material due to high flow velocities. Scour control is important to maintain the function of the pond and reduce erosion, especially near the inlet. Inlet areas and inlet structures should be designed to control velocities at the inlet whether from large or small storm events.

Flow-diffusion devices, including plunge pools, directional berms or other specially created dissipation structures, are often recommended. For annual events, the velocity leaving the inlet area and entering the main treatment area should be less than 1 ft per second (fps). Decreasing velocity reduces scour and more importantly reduces mixing currents that reduce treatment efficiency.

The MPCA recommends that the following design storms be considered in the pond design (MPCA, 2000). Scour prevention can be achieved if velocities through the main treatment area are limited to the following maximums:

1 foot per second for the 1-year, 2.4-inch event:

3 feet per second for the 2-year, 2.8-inch event:

5 feet per second for the 10-year, 4.0-inch event and the 100-year, 6.0-inch event

Extended Storage Ponds

Velocities are calculated as outflow divided by the area of the critical cross-section. All events are considered to be the 24-hour NRCS distribution event.

Design for Winter Runoff Conditions

During the winter period, the design volume of the wet pond can be less than desired. Ground freezing throughout the tributary watershed effectively increases the watershed's imperviousness, which increases the fraction of precipitation that reaches the pond. Moreover, the available volume in the permanent pool can be reduced by the formation of ice. Fortunately, winter rainfall and snowmelt events (as opposed to spring) typically produce lower volumes of runoff than summer storms and so most events will continue to be captured entirely (e.g. the volume of runoff will be less than the reduced volume of the wet pond). However, temperature regimes in the northern regions of Minnesota are such that ice cover may persist into the spring period when runoff rates and contaminant washoff rates are higher. In these areas, some authorities recommend that the wet pond volume be increased by an amount equal to the expected volume of the ice cover (Ontario Ministry of the Environment, 1999).

The thickness of ice can be estimated using Stefan's equation (Marsalek, 2000):

$$h = a\,(D_f)^{0.5}$$

Where: h is the ice thickness in mm

a is a coefficient of ice growth

D_f is the sum of freezing degree-days

The values for the coefficient for ice growth are shown below.

Condition	a ($mm^{\circ}C^{-0.5}d^{-0.5}$)
Theoretical Maximum	34
Windy Lake with No Snow	27
Average Lake with Snow	17-24
Average River with Snow	14-17
Shelter River with Rapid Flow	7-14

Work done a pond in Kingston, Ontario indicated that a coefficient value of 15 produced results close to measured values. The pond operated with a constant subsurface inflow, which tended to limit the buildup of ice. In general, it is expected that most ponds will be small enough and will receive sufficient inflow to behave more like a river (in terms of ice buildup) than a lake. Where possible however, the designer should consult with the local authorities concerning local knowledge on ice depths (Ontario Ministry of the Environment, 1999).

Snowmelt runoff events in Minnesota may convey high concentrations of urban runoff pollutants to stormwater ponds and other receiving waters. Recommendations to manage this potential influx of contaminated snow and ice melt include: incorporating extended storage (see the Extended Storage Ponds BMP Section) in the pond design, installing grass swales in the drainage system ahead of stormwater ponds, and storing contaminated snow and ice where debris and petroleum products are less likely to be transported to the pond (Oberts, 1991).

Extended Storage Ponds

Design (continued)

Water can flow over the ice in stormwater ponds during spring thaw, and may carry sediment directly out of the pond outlet. If this is a concern for a particular pond design, it is generally a good idea to incorporate extended storage capability of the pond. One can also increase the depth of the pond below the water quality spillway, thus allowing more room for the ice to collapse into the pond. If the pond is located in an area with a high water table, it may not be feasible to make this design modification.

Standpipe outlets may be destroyed by ice movement in winter. Standpipes are not recommended unless they are designed to withstand ice movement.

In Minnesota's urban areas, snow piles are often created in parking lots, along streets and elsewhere. Store snow where debris oil and other materials cannot readily enter waters of the state. Discharge of such materials directly to waters of the state is prohibited. So, snow-storage areas that minimize surface-water impacts should be planned.

Following the recommendations of this BMP section, by providing deep inlet and outlet zones or multiple pools, will usually result in designs that are robust enough to handle the winter and spring conditions without special considerations. However, runoff volume from spring snowmelt events can be very large, often the largest-volume event of the year. Ponds designed to function effectively in summer are often disrupted by winter and spring events. Inspection and maintenance during spring runoff should be a consistent feature of stormwater treatment systems in cold climates.

Sequencing

- Extended storage ponds may be constructed in the early phases of a development project, in order to treat site runoff during construction.
- If the basin is used as a sediment trap during construction, all sediment deposited during construction should be removed before normal operation begins.

Construction

- As with other stormwater BMPs, soils, depth to bedrock, and depth to water table must be investigated before designing an extended storage pond. At sites where bedrock is close to the surface, high excavation costs may make wet ponds infeasible. If the soils on site are relatively permeable or well drained, it will be difficult to maintain a permanent pool. In this situation, it may be necessary to line the bottom of the wet pond to reduce infiltration.
- All local, state and federal permit requirements should be established prior to initiating the pond design. Depending on the location of the pond, required permits and certifications may include wetland permits, water quality certifications, dam safety permits, sediment and erosion control plans, waterway permits, local grading permits, land use approvals, etc. (Schueler, 1992). Since many states and municipalities are still in the process of developing or modifying storm water permit requirements, the applicable requirements should be confirmed with the appropriate regulatory authorities.
- Pond systems can perform well in cold climates because many modification options are available to increase their effectiveness in frigid and snowy conditions. Many of these modifications address the problems associated with pipe freezing.

Extended Storage Ponds

- To be effective in reducing peak runoff rates, the basin must be located where it can intercept most of the runoff from the site. Usually, this location is found at the lowest elevation of the site.

Maintenance

- Maintenance is required for the proper operation of extended storage ponds. Plans for extended storage ponds should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule for extended storage ponds.
- Once constructed, the extended storage pond should be inspected after several storm events to confirm drainage system functions, bank stability, and vegetation growth. The outlet structure should be inspected for evidence of clogging or outflow release velocities that are greater than design flow. Problems should be addressed immediately.
- At least twice during the growing season, accumulated trash and debris should be removed from the side slopes, embankment, emergency spillway and outflow trash racks. Accumulated sediment in the forebay should be inspected at the same time.
- All extended storage outlet devices should be protected from clogging. All devices should have above-ground access for cleanout, should this be necessary.
- Extended storage ponds should be inspected at least once per year to ensure that they are operating as designed. Potential problems that should be checked include: subsidence, erosion, cracking or tree growth on the embankment; damage to the emergency spillway; sediment accumulation around the outlet; inadequacy of the inlet/outlet channel erosion control measures; changes in the condition of the pilot channel; and erosion within the basin and banks. Any necessary repairs should be made immediately. During inspections, changes to the extended storage pond or the contributing watershed should be noted, as these may affect basin performance.
- Sediment should be removed from the pond as necessary, and at least once every 5 to 25 years (usually more frequently than once every 25 years). The frequency of sediment removal depends on the years of sediment accumulation that were incorporated into the design of the volume of the wet pond's permanent pool and forebay.
- In most cases, no specific limitations have been placed on disposal of sediments removed from wet detention ponds. Studies to date indicate that pond sediments are likely to meet toxicity limits and can be safely landfilled. On-site sediment disposal is always preferable (if local authorities permit it) as long as the sediments are deposited away from the shoreline to prevent their re entry into the pond.
- Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.
- Mosquito control, if necessary.

Extended Storage Ponds

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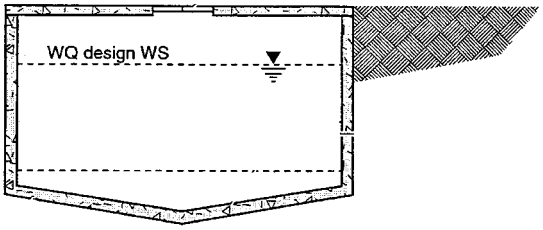
Wet Vaults



Description

A wet vault is a subterranean structure designed to provide temporary and permanent storage for stormwater runoff from a specified storm event. Wet vaults have a permanent pool of water which dissipates energy and improves the settling of particulate stormwater pollutants. Wet vaults are typically on-line, end-of-pipe BMPs. Wet vaults can be distinguished from grit chambers in two ways: 1) wet vaults are typically on-line structures (grit chambers are typically off-line) and 2) a wet vault's primary treatment feature is its permanent pool for sedimentation (acting essentially like an underground wet pond), whereas a grit chamber has a relatively smaller permanent pool as just one step in its treatment process (see the Grit Chamber BMP Section for more information). Figure 1 shows a typical wet vault design.

Pollutant removal mechanisms for particulate pollutants in wet vaults are similar to wet ponds. The primary pollutant removal mechanism in a wet vault is sedimentation. Significant loads of suspended pollutants, such as metals, nutrients, sediments, and organics, can be removed by sedimentation. However, in a wet vault, the permanent pool of water is covered by a lid which blocks sunlight from entering the facility, limiting light-dependent biological activity. Consequently, biological pollutant removal mechanisms that function in surface wet ponds are not a part of storm water treatment in a wet vault.

Wet vaults are typically used for commercial, industrial, or roadway projects if there are space limitations precluding the use of other treatment BMPs.

Wet vaults are not widely used and therefore little information has been published with regard to their design, applicability and usefulness.

Enhancement Options

Vault Shape: To avoid reducing the pollutant removal capability and to maximize travel distance, the inflow points of the wet vault should be as far from the outlet as possible. To maximize stormwater contact and residence time in the vault, a length to width ratio of 3:1 is recommended.

Purpose

Water Quantity

Flow attenuation	◧
Runoff volume reduction	☐

Water Quality

Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollution removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	◧
Floatables	■
Oil and grease	◧
Other	
Fecal coliform	☐
Biochemical oxygen demand (BOD)	☐

■ Primary design benefit
◧ Secondary design benefit
☐ Little or no design benefit

Wet Vaults

Advantages

- Good for areas with limited space for BMPs.
- Efficient removal of sediment and particulate pollutants.
- Pond sediment removal schedule is generally less frequent than for other BMPs.
- Can be designed to provide trapping of oils and floatables.
- Insulated from freezing

Limitations

- Considerably more expensive than many other BMPs.
- Wet vaults are believed to be ineffective in removing dissolved pollutants such as soluble phosphorus or metals such as copper.
- There is some concern that oxygen levels in a wet vault will decline, especially in warm summer months, because of limited contact with air and wind. However, the extent to which this potential problem occurs has not been documented.
- Maintenance of wet vaults requires special equipment.
- No biologic activity to increase stormwater treatment.
- Accumulated sediment and stagnant conditions may cause noxious gases to form and accumulate in the vault if regular maintenance is neglected.

Design

Wet Vault Volume

As in wet pond design, the primary design factor that determines the removal efficiency of a wet vault is the volume of its permanent pool. In general, the larger the volume of the permanent pool, the higher the vault's potential for pollutant removal. The volume of the permanent pool in a wet vault can be calculated in the same manner as a wet pond, by defining a rainstorm event called the "water quality event". The runoff volume generated from the water quality event (called the "water quality volume") is equal to the volume of the permanent pool of the wet vault. Some authorities recommend a water quality volume that is three times the volume of runoff from the mean annual storm event (King County, 1998). Two other water quality event recommendations endorsed by the MPCA are the 1-year, 24-hour storm event (2-2.4" in Minnesota) and the 2.5", 24-hour storm event (Walker, 1987).

The volume of runoff from the water quality event is best predicted by a combination of monitoring existing conditions and modeling future conditions. However, local authorities will likely have their own methods for calculating runoff volume from storm events. For design purposes, the water quality volume should be considered an instant flow to the vault, not an inflow-outflow calculation. In other words, this volume should be considered to

Wet Vaults

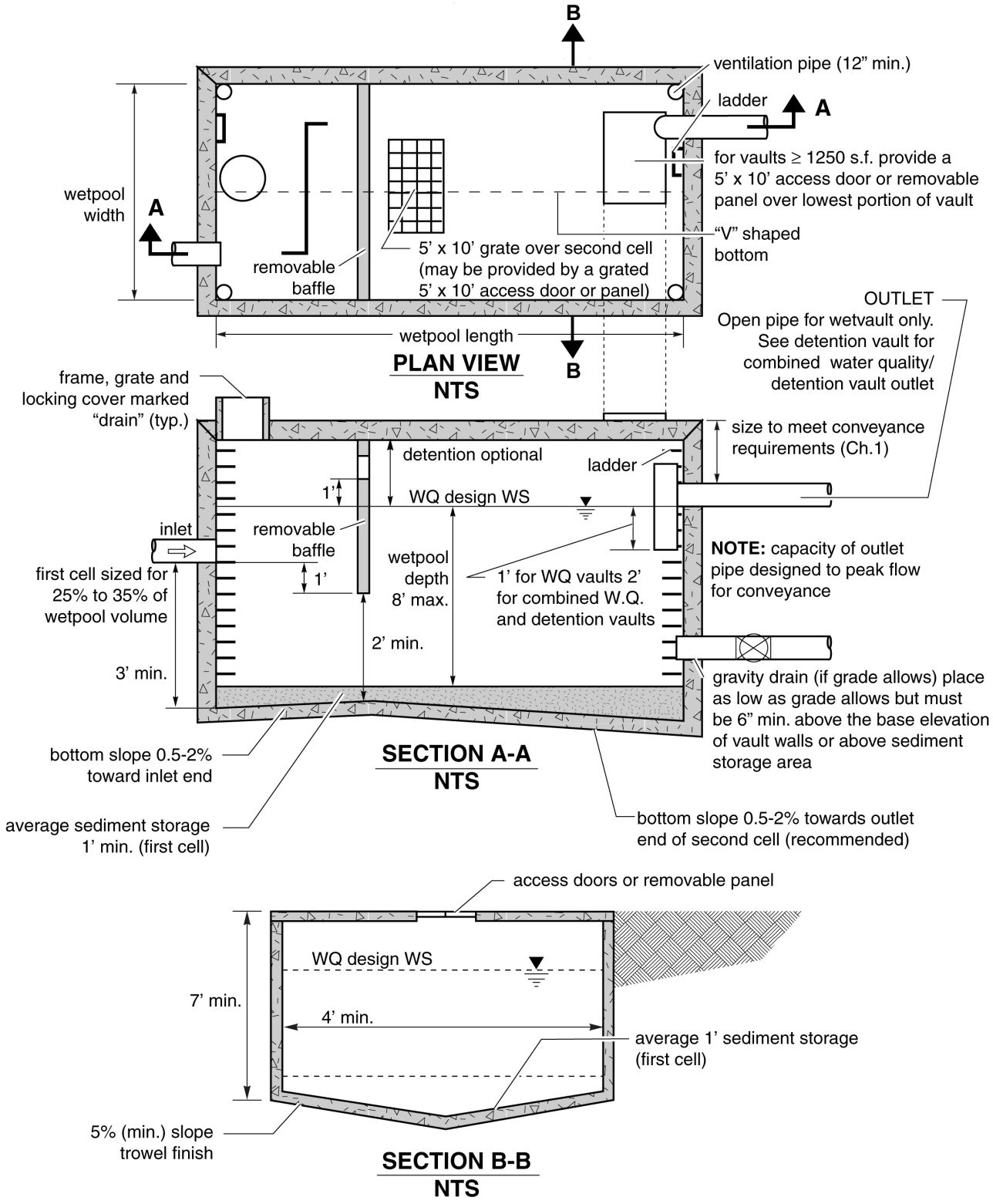


Figure 1: Schematic of a Typical Wet Vault

Source: King County, 1998

Wet Vaults

Design (continued)

arrive at the vault all at once, rather than over the course of several hours or days. The assumption of instant runoff is conservative, but it accounts for a great deal of the variability that occurs in both storm events and runoff conditions.

Avoidance of short-circuiting and the promotion of plug flow:

To prevent short-circuiting, water is forced to flow, to the extent practical, to all potentially available flow routes, avoiding "dead zones" (like corners) and maximizing the time water stays in the vault during the active part of a storm. Design features that encourage plug flow and avoid dead zones are:

- Providing a broad surface for water exchange across cells rather than a constricted area.
- Maximizing the flowpath between inlet and outlet, including the vertical path, also enhances treatment by increasing residence time.
- The ratio of flowpath length to width from the inlet to the outlet should be at least 3:1.
- All inlets should enter the first cell. If there are multiple inlets, the length-to-width ratio should be based on the average flowpath length for all inlets.
- Flow rates should be uniform to the extent possible and not increased between cells.

Vault Structure

The King County Surface Water Management Plan (1998) contains a detailed description of wet vault structure design, as follows:

- The vault should be separated into two cells by a wall or a removable baffle. If a wall is used, a 5 foot by 10 foot removable maintenance access should be provided for both cells. If a removable baffle is used, the following criteria apply:

1) The baffle should extend from a minimum of 1 foot above the design water surface to a minimum of 1 foot below the invert elevation of the inlet pipe.

2) The lowest point of the baffle should be a minimum of 2 feet from the bottom of the vault, and greater if feasible.

However, if the vault is less than 2,000 cubic feet (inside dimensions), or if the length to-width ratio of the vault pool is 5:1 or greater, the baffle or wall may be omitted and the vault may be one-celled.

- The bottom of the first cell should be sloped toward the access opening. Slope should be between 0.5 percent (minimum) and 2 percent (maximum). The second cell may be level (longitudinally) sloped toward the outlet, with a high point between the first and second cells. The intent of sloping the bottom is direct the sediment accumulation to the closest access point for maintenance purposes. Sloping the second cell towards the access opening for the first cell is also acceptable.
- The second cell shall be a minimum of 3 feet deep since planting cannot be used to prevent resuspension of sediment in shallow water as it can in open ponds.

Wet Vaults

- The vault bottom shall slope laterally a minimum of 5% from each side towards the center, forming a broad "v" to facilitate sediment removal. Note: More than one "v" may be used to minimize vault depth. *Exception*: The vault bottom may be flat if removable panels are provided for openings over the entire vault. Removable panels should be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel.
- The highest point of a vault bottom should be at least 6 inches below the gravity drain outlet elevation to provide for sediment storage over the entire bottom.

Pond Inlet/Outlet Structures and Pipes

- The inlet to the wet vault shall be submerged with the inlet pipe invert a minimum of 3 feet from the vault bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible. The submerged inlet is intended to dissipate energy of the incoming flow. The distance from the bottom is to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.
- Unless designed as an off-line facility, the capacity of the outlet pipe and available head above the outlet pipe should be designed to convey flows larger than the water quality design flow for developed site conditions without overtopping the vault. The available head above the outlet pipe should be a minimum of 6 inches.
- The outlet pipe should be back-sloped or have tee section, the lower arm of which should extend 1 foot below the water quality design water surface to provide for trapping of oils and floatables in the vault.
- A gravity drain for maintenance is recommended if grade allows. Gravity drains should be as low as the site situation allows; however, the invert shall be no lower than the average sediment storage depth. At a minimum, the invert shall be 6 inches above the base elevation of the vault side walls. This placement prevents highly sediment-laden water from escaping when the vault is drained for maintenance. A lower placement is allowed than for wet ponds since the v-shaped vault bottom will capture and retain additional sediments.
- Wet vaults may be constructed using arch culvert sections provided the top area at the design water surface is, at a minimum, equal to that of a vault with vertical walls designed with an average depth of 6 feet. This is to prevent decreasing the surface area available for oxygen exchange.
- Galvanized materials should be avoided whenever possible.
- Lockable grates instead of solid manhole covers are recommended to increase air contact with the wetpool.

Sediment Storage

The sediment storage in the first cell (Section B-B in Figure 1) should be limited to 1 foot. Because of the v-shaped bottom, the depth of sediment storage needed above the bottom of the side wall is roughly proportional to vault width according to the schedule at right.

Vault Width (feet)	**Sediment Depth** (inches from bottom of side wall)
15	10
20	9
40	6
60	4

Wet Vaults

Requirements

Sequencing

- Wet vaults may be constructed in the early phases of a development project, in order to treat site runoff during construction.
- Sediment that has accumulated in the vault should be removed after construction in the drainage area is complete.

Construction

- Operational access to the valve that controls the gravity drain should be provided to the finished ground surface. The valve location should be accessible and well marked with one foot of paving placed around the box. It must also be protected from damage and unauthorized operation.
- Local permitting authorities may require a bypass/shutoff valve to enable the vault to be taken off-line for maintenance.

Maintenance

- Sediment should be removed when the 1-foot (average) sediment zone is full. Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.
- Facilities should be inspected annually. Floating debris and accumulated petroleum products should be removed as needed, but at least annually. The floating oil should be removed from wet vaults used as oil/water separators when oil accumulation exceeds one inch.
- Vault maintenance procedures must meet OSHA confined space entry requirements, which includes clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser(s), just under the access lid.

Sources

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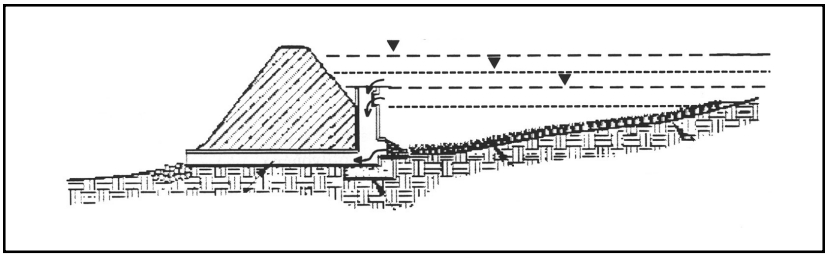
Dry Ponds



Description

Dry ponds, also called "detention ponds," are stormwater basins that are designed to intercept a volume of stormwater runoff and temporarily impound the water for gradual release to the receiving stream or storm sewer system. Dry ponds are typically on-line, end-of-pipe BMPs. Dry ponds are designed to completely empty out between runoff events, and therefore provide mainly runoff rate control as opposed to water quality control. Dry ponds can provide limited settling of particulate matter, but a large portion of this material can be resuspended by subsequent runoff events. Therefore, dry ponds should be considered mainly as practices used to reduce the peak discharge of stormwater to receiving streams to limit downstream flooding and to provide some degree of channel protection.

Most dry ponds are designed to empty in a time period of less than 24 hours, resulting in lower contaminant removal (the inter-event settling time does not exist) than wet ponds. If water quality treatment is the intended goal of the pond, a wet or extended storage pond design should be considered (see the Wet Pond and Extended Storage Pond BMP Sections for more information on these systems).

Detention basins can limit downstream scour and loss of aquatic habitat by reducing the peak flow rate and energy of stormwater discharges to the receiving stream. Typically, dry ponds are designed so that release rates are comparable to pre-development flow rates.

As a general rule dry ponds should be implemented for drainage areas greater than 10 acres. This area requirement is purely a function of the outlet sizing to ensure that the outlet does not become clogged.

A diagram of a typical detention basin is shown in Figure 1.

Modeling studies have indicated that substantial improvement can be made in removal efficiency if a 48-hour detention time can be employed. While achieving this for smaller drainage areas can be difficult (because of outlet orifice size considerations), the use of dry

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	□

Water Quality

Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollutant removal	
Total suspended sediment (TSS)	◧
Total phosphorus (P)	□
Nitrogen (N)	□
Heavy metals	□
Floatables	◧
Oil and grease	□
Other	
Fecal coliform	□
Biochemical oxygen demand (BOD)	□

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Dry Ponds

ponds in larger catchments (especially in retrofit situations) may have greater potential than previously thought, especially if infiltration occurs. There are no documented performance monitoring data for dry ponds with longer detention times however, and re-suspension of settled material remains a concern. As such, the use of dry ponds (for water quality control) remains largely restricted to retrofit situations, situations where temperature is an overriding concern and situations where other more effective BMP types are infeasible. Dry ponds may be used as part of an overall treatment train approach.

Enhancement Options

Sediment Forebay

The treatment efficiency of a dry pond can be increased by incorporating a forebay into the pond design. A sediment forebay facilitates maintenance and improves pollutant removal by trapping larger particles near the inlet of the pond. The forebay should include a deep permanent pool (greater than 3 feet) to minimize the potential for scour and re-suspension.

Extended Storage

Traditional dry ponds have rarely been considered acceptable ponds from a water-quality perspective. The potential for scour and small detention times almost always eliminates these ponds from consideration as a water-quality BMP. However, designs that eliminate scour by controlling the flow through the pond can provide acceptable treatment. Enhanced swales and dry ponds that utilize extended storage principles can serve to meet water quality goals; however, they must be carefully and properly designed, implemented and maintained. To operate properly, these treatment systems need outlet controls with filters, weirs or other energy-dissipation and flow-spreading devices constructed as part of the pond. The Extended Storage and Permeable Weirs BMP Sections provide more detailed information on this type of pond design.

Micropool at the Outlet

The performance of a dry pond can be enhanced through the provision of a micropool at the outlet. The micropool is typically relatively shallow and undrained. Its purpose is to concentrate finer sediment and reduce re-suspension. The micropool is normally planted with hardy wetland species such as cattails. Figure 2 illustrates a micropool in a dry pond, facilitated by the use of a reversed slope outlet pipe.

Pond Shape

To maximize the treatment potential of the pond, the inlet and outlet should be positioned in such a way that short-circuiting in the basin is minimized. Ponds that are considerably longer than wide (e.g. length equal to three times width) will likely provide additional detention time for settling and biological treatment. Baffles and curved flow paths can also be used to increase settling efficiency.

Low flow Channels

Low flow channels serve two purposes: to prevent erosion as runoff first enters the pond during a storm event, and to route the last remaining runoff to the outlet after the event, ensuring that the basin dries completely.

Dry Ponds

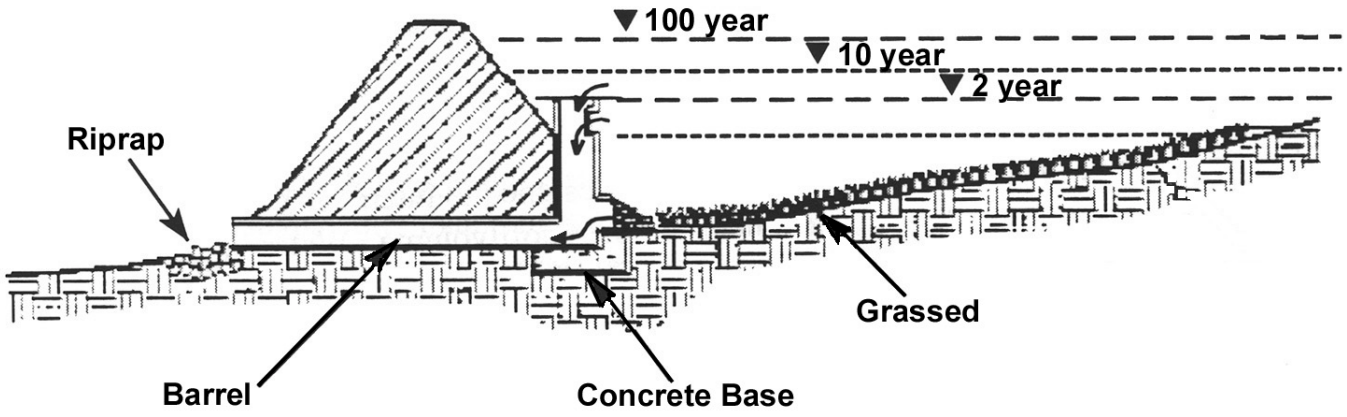


Figure 1: Typical Dry Pond
Source: NVPDC, 1992.

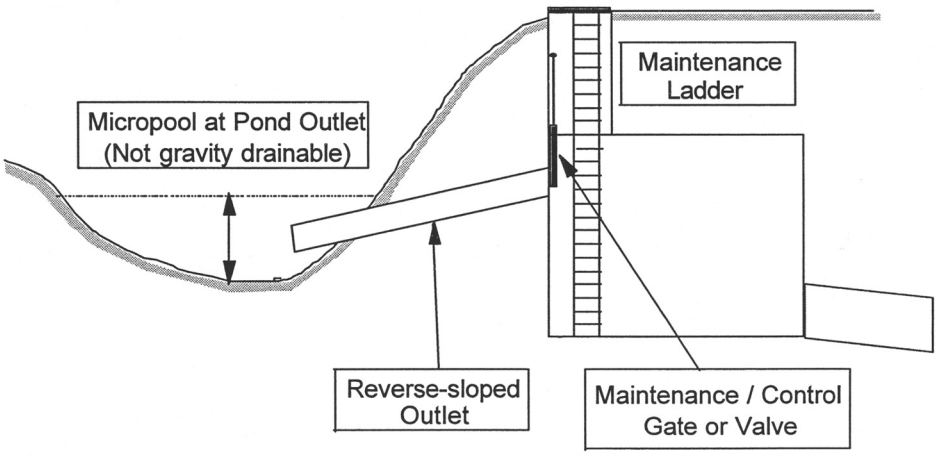


Figure 2: Dry Pond Micropool and Reversed-Slope Outlet Pipe
Source: Ontario Ministry of the Environment, 1999.

Dry Ponds

Advantages

- Can perform well in cold climates.
- Can limit downstream scour and loss of aquatic habitat by reducing the peak flow rate and energy of stormwater discharges to receiving streams.
- Can be used as recreational areas (ex. athletic fields) if not needed for water too often and if designed properly.

Limitations

- Generally not prescribed for drainage areas less than 10 acres.
- Provides only marginal removal of stormwater pollutants.
- Potential for clogging of outlets
- Sediments can be resuspended in the pond if not removed between storm events.
- Can be considered unattractive by residents. Poorly maintained basins can create nuisance odors and weed growth and collect trash.
- Depending on their volume and depth, pond designs may require approval from dam safety authorities.

Design

Drainage Area

As a general rule dry ponds should be implemented for drainage areas greater than 10 acres. This area requirement is purely a function of the outlet sizing to ensure that the outlet does not become clogged. Smaller drainage areas may be considered (subject to minimum orifice sizing and hence reduced detention times) if the dry pond is used as part of an effective treatment train approach.

Pond Volume and Water Quantity Control Requirements

The required volume of the dry pond (sometimes called the "flood storage volume," or "live storage") will be dependent on local conditions and policies. Normally, sufficient storage will be required to ensure that post development peak flows can be controlled to pre-development levels for storms ranging from a 2-year through 100-year return period. In some situations where downstream flooding is a concern, control of more frequent events may be required. Direction should be sought from the local municipality and/or conservation authority for requirements at specific locations.

Detention Time

A minimum detention time of 24 hours should be targeted in all instances, unless the potential for clogging the outlet is high. Where possible, a detention time of 48 hours should be employed to improve suspended solids removal (as discussed in the Enhancement Options section, above). In cases where the outlet is susceptible to clogging (i.e. drainage areas less than 20 acres) the detention time can be reduced to a minimum of 12 hours.

The preferred minimum orifice size is equivalent to a 4-inch-diameter opening. In instances where a perforated

riser outlet is designed, the orifice is protected by the other smaller perforations in the riser and a minimum orifice size equivalent to a 2-inch-diameter opening is acceptable. Where small orifices are required, consideration should be given to providing an overflow outlet which would operate in the event there is blockage of the primary orifice.

Pond Slopes

The grading in a dry pond is less critical than a wet pond since there is no permanent pool. The typical extended detention time of 24 to 48 hours, however, indicates that water will be present in these facilities for a reasonable period of time. Therefore, the grading of the pond side slopes should be terraced with an average slope of 3:1 or flatter. Flatter slopes help to prevent erosion of the banks during larger storms and make routine basin tasks, such as mowing, easier. Flat slopes also provide for public safety, and allow easier access. Steeper slopes may result in fencing requirements, creating unsightly conditions.

Length to Width Ratio

All stormwater servicing should be conveyed to one inlet location at the pond if possible. In order to provide the longest flow path through the pond, the inlet to the pond should be located as far away from the pond outlet as possible. The desired flow path in a pond is generally described by the length to width ratio recognizing that a specific storage volume is to be provided in the pond . A pond with a length to width ratio > 3:1 will have an acceptable flowpath. Preferred length to width ratios range from 4:1 to 5:1. An acceptable design feature to increase the length to width ratio is berming to redirect flows at certain elevations. This practice increases the pond performance by ensuring that short circuiting cannot occur. One drawback associated with berming within the pond is that additional land will be required to fulfill the storage requirements for water quality, erosion, and/or quantity control.

Live Storage Depth

The maximum depth of the water in the pond (also called the "bounce") should be limited to 6 to 10 feet. This maximum applies to all extended detention objectives (i.e. water quality, erosion, and quantity control). If a planting strategy is proposed for the dry pond, these maximum depths may be reduced. However, planting options in a dry pond are somewhat limited due to harsh growing conditions in the basin (frequent wetting/drying) hindering the establishment of plants.

Winter Operation

Dry ponds are normally the least affected by winter/spring conditions because there is no permanent pool and the pond's function is not dependent on infiltration. Precautions can be taken to guard against freezing of pipes and orifices (Oberts 1991), and a bypass (flow-splitter) can be employed to limit inflow (and hence scouring of accumulated sediment) by major spring storms. Otherwise, dry ponds do not require special consideration of winter conditions.

Pond Inlet/Outlet Structures and Pipes

The pond should be designed in such a way that turbulence in the main treatment area is minimized. For example, inflow points should be designed with energy dissipaters to reduce inflow velocity. Reducing the turbulence will reduce the chance that previously deposited materials will be resuspended. It will also result in conditions more conducive to settling while the pond is filling. Energy dissipation at inflow points can also be accomplished with micropools or flow spreaders.

Dry Ponds

Design (continued)

The outlet area should be a deeper micropool to provide final settling and prevent resuspension of sediments. The outlet device should be carefully designed, since it is important to the operation of the entire pond system. There are numerous outlet configurations possible for dry ponds, such as perforated risers and reversed-slope pipes. The outlet should be located in the pond embankment wherever possible for ease of maintenance and aesthetics. Several options for dry pond outlets are discussed in the Alternative Outlet Designs BMP Section. A pond outlet with a micropool and a reversed-slope pipe are shown in Figure 2.

In most cases, emergency spillways should be included in the pond design. Emergency spillways should be sized to safely pass flows that exceed the design storm flows. The spillway prevents pond water levels from overtopping the embankment, which could cause structural damage to the embankment. The emergency spillway should be located so that downstream buildings and structures will not be negatively impacted by spillway discharges. The pond design should include a low flow drain to assist in pond maintenance. The drain pipe should be designed for gravity discharge and should be equipped with an adjustable gate valve. Embankments and spillways should be designed in conformance with the state Dam Safety regulations and criteria.

The design of the pond embankment is another key factor to be considered. Proper design and construction of the embankments will prolong the integrity of the pond structure. Subsidence and settling will likely occur after an embankment is constructed. Therefore during construction, the embankment should be overfilled by at least 5 percent (SEWRPC, 1991). Seepage through the embankment can also affect the stability of the structure. Seepage can generally be minimized by adding drains, anti seepage collars, and core trenches. The embankment side slopes can be protected from erosion by using minimum side slopes of 3:1 and by covering the embankment with vegetation or riprap. The embankment should also have a minimum top width of 2 meters (6 feet) to aid in maintenance.

Low-Flow Channels

A low flow channel routes the last remaining runoff, dry weather flow and groundwater to the permanent pool and outlet. A low flow channel should be installed in the basin to ensure that the basin dries out completely between storm events. Low flow channels also serve to prevent erosion of the pond as runoff first enters the pond. Pervious or impervious channel lining may be used. A pervious lining allows interaction of the runoff with the soil and grass, resulting in increased sorption of pollutants. Design velocities in pervious low flow channels should be high enough to prevent sedimentation and low enough to prevent scouring and erosion. (See specific recommendations below under Scour Control.) No minimum low flow channel velocity is needed if a forebay is utilized prior to the low flow channel. The maximum flow velocity is dependent on the nature of the material used to line the channel.

Scour Control

Scour is the erosion of pond bottom or bank material due to high flow velocities. Scour control is important to maintain the function of the pond and reduce erosion, especially near the inlet. Inlet areas and inlet structures should be designed to control velocities at the inlet whether from large or small storm events.

Flow-diffusion devices, including plunge pools, directional berms or other specially created dissipation structures, are often recommended. For annual events, the velocity leaving the inlet area and entering the main treatment area should be less than 1 foot per second (fps). Decreasing velocity reduces scour and more importantly reduces mixing currents that reduce treatment efficiency.

Dry Ponds

The MPCA recommends that the following design storms be considered in the pond design. Scour prevention can be achieved if velocities through the main treatment area are limited to the following maximums:

1 foot per second for the 1-yr 2.4" event:

3 feet per second for the 2-yr, 2.8" event:

5 feet per second for the 10-yr, 4.0" event and the 100-yr, 6.0" event

Velocities are calculated as outflow divided by the area of the critical cross-section. All events are considered to be the 24-hour NRCS distribution event.

Sequencing

- Dry ponds may be constructed in the early phases of a development project, in order to treat site runoff during construction.
- If the basin is used as a sediment trap during construction, all sediment deposited during construction should be removed before normal operation begins.

Construction

- As with other stormwater BMPs, soils, depth to bedrock, and depth to water table must be investigated before designing a dry pond. At sites where bedrock is close to the surface, high excavation costs may make wet ponds infeasible. The storage in a dry pond must be located above the seasonally high groundwater table.
- All local, state and federal permit requirements should be established prior to initiating the pond design. Depending on the location of the pond, required permits and certifications may include wetland permits, water quality certifications, dam safety permits, sediment and erosion control plans, waterway permits, local grading permits, land use approvals, etc. (Schueler, 1992). Since many states and municipalities are still in the process of developing or modifying stormwater permit requirements, the applicable requirements should be confirmed with the appropriate regulatory authorities.
- Pond systems can perform well in cold climates because many modification options are available to increase their effectiveness in frigid and snowy conditions. Many of these modifications address the problems associated with pipe freezing.
- To be effective in reducing peak runoff rates, the basin must be located where it can intercept most of the runoff from the site. Usually, this location is found at the lowest elevation of the site.

Maintenance

- Maintenance is required for the proper operation of dry ponds. Plans for dry ponds should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule for extended storage ponds.
- Once constructed, the dry pond should be inspected after several storm events to confirm drainage system functions, bank stability, and vegetation growth. The outlet structure should be inspected for evidence of clogging or outflow release velocities that are greater than design flow. Problems should be addressed immediately.

Dry Ponds

- At least twice during the growing season, accumulated trash and debris should be removed from the side slopes, embankment and emergency spillway. Accumulated sediment in the forebay should also be inspected at this time.
- All dry pond outlet devices should be protected from clogging. All devices should have above-ground access for clean out, should this be necessary.
- Dry ponds should be inspected at least once per year to ensure that they are operating as designed. Potential problems that should be checked include: subsidence, erosion, cracking or tree growth on the embankment; damage to the emergency spillway; sediment accumulation around the outlet; inadequacy of the inlet/outlet channel erosion control measures; changes in the condition of the pilot channel; and erosion within the basin and banks. Any necessary repairs should be made immediately. During inspections, changes to the dry pond or the contributing watershed should be noted, as these may affect basin performance.
- Sediment should be removed from the pond as necessary, and at least once every 5 to 25 years (usually sooner rather than later). The frequency of sediment removal depends on the years of sediment accumulation that were incorporated into the design of the pond's forebay.
- Because these types of basins do not have as much sediment storage volume as a typical wet detention basin, they need to be maintained more regularly, especially if extended detention is incorporated into the dry pond design. This usually increases the maintenance cost of the project.
- In most cases, no specific limitations have been placed on disposal of sediments removed from dry ponds. Studies to date indicate that pond sediments are likely to meet toxicity limits and can be safely landfilled. On-site sediment disposal is always preferable (if local authorities permit it) as long as the sediments are deposited away from the shoreline to prevent their re-entry into the pond and away from recreation areas where people could inhale resulting dust.
- Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.

Dry Ponds

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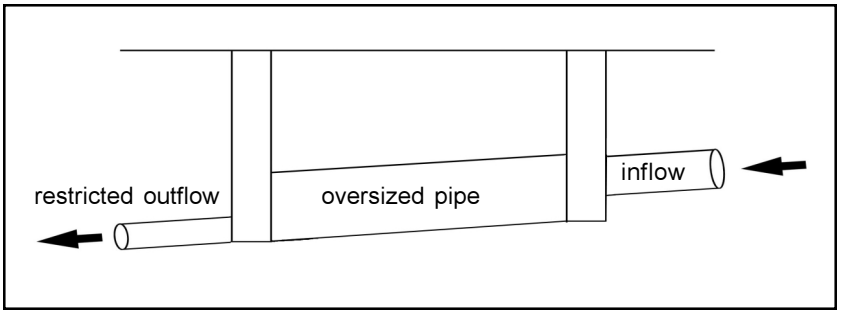
Oversized Pipes



Description

Oversized pipes are designed to reduce peak flow rates by providing temporary, subsurface storage of stormwater runoff. An oversized pipe system is essentially a large pipe that has a small outlet at its invert. When inflow rates are larger than the outflow rates in this pipe series, runoff is detained within the pipes. Generally, detention times are in the order of a few hours. Like detention basins, oversized pipes are designed to empty out between runoff events so that storage capacity is available for subsequent runoff events.

Oversized pipes are designed to drain dry and therefore significant water quality improvements should not be expected; only some of the coarser sediment particles will settle out in the pipes, but can be resuspended by incoming flows if they are not removed before the next storm event. If water quality improvements are also desired, the designer should reference the Wet Vaults BMP.

Oversized pipes are a retrofit alternative for existing storm drains in the upper portions of the drainage system. They lower the peak discharge rate and provide a limited amount of additional temporary storage volume. However, a careful analysis of the storm drainage system is necessary in order to prevent water backup and flooding in the upper reaches of the drainage area.

Generally, oversized pipes are utilized for small development sites where there is insufficient surface space to construct detention facilities. Other underground structures, such as underground detention vaults, can be used to accomplish the same objectives.

Some proprietary versions of this BMP exist in the form of manifold pipe systems. In this type of system, water flows from a catchbasin or stormsewer pipe into several pipes in parallel before outflowing to the larger system, as illustrated in Figure 1.

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	□

Water Quality

Pollution prevention	
Soil erosion	N/A
Sediment control	N/A
Nutrient loading	N/A
Pollutant removal	
Total suspended sediment (TSS)	□
Total phosphorus (P)	□
Nitrogen (N)	□
Heavy metals	□
Floatables	□
Oil and grease	□
Other	
Fecal coliform	□
Biochemical oxygen demand (BOD)	□

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Oversized Pipes

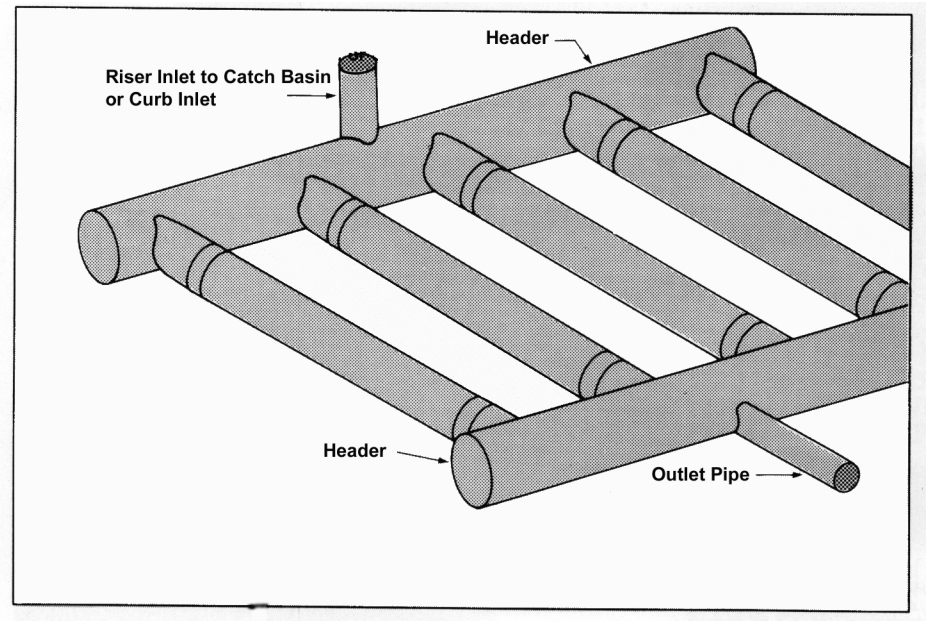


Figure 1: Manifold Underground Detention System
Source: Used with permission from Contech Construction Products, Inc.

Advantages

- Can be very effective in reducing peak runoff flows from small sites.
- Can be used in sites with insufficient space to construct larger, traditional types of detention facilities.
- Can be useful in retrofit projects.

Limitations

- Provides little or no water quality treatment of runoff.
- High material costs relative to traditional surface storage facilities.
- Must be located in areas where the pipes can be easily accessed for maintenance.

Oversized Pipes

Requirements

Design

Location:

Oversized pipes should be installed where the pipes can be easily accessed for maintenance. Subsurface locations include parking lots, grassed swales, adjacent to property boundaries, upper portion of catchment areas, etc. Oversized pipes should not be constructed under structures that cannot be excavated.

Inlets and Outlets:

Inlets and outlets must be sized for each structure. Outflow rates should be defined in a drainage plan or a storm sewer analysis. Generally, inlets are sized to convey frequent runoff events from paved surfaces, as in the typical stormwater design. Outlets are much smaller pipes. The size and configuration of the outlet should be designed to restrict flows to the allowable discharge rate. The allowable discharge rate will be determined by local authorities' requirements and stormwater management goals.

Pipe Diameter (inches)	Storage (ft^3/ft)
72	28.3
84	38.5
96	50.3
108	63.6
120	78.5

Table 1: Reinforced Concrete Round Pipe Storage
(per linear foot)

Length and Diameter:

The length and diameter of the oversized pipe will be a function of the storage required to meet the allowable discharge rates. Generally, sizing the oversized pipe involves a standard hydraulic analysis- comparing the incoming flow to the desired outgoing flow to obtain the storage needed in the pipe. Maximum pre-manufactured diameters are approximately 10 feet and are generally dependent on the diameter that can be transported by truck to the site. Minimum diameters should be approximately 72 inches as smaller sizes are difficult to clean. Some municipalities have established minimum sizes to facilitate cleaning.

Some examples of the storage available in circular pipes (RCP) of several different diameters are presented in Table 1.

Slope:

Slopes of the oversized pipe should be approximately 0.2%, as a slight slope must be maintained to completely drain the pipe. Slopes should be kept to a minimum as steep slopes will reduce the amount of storage available within the pipe.

Emergency Overflows:

Emergency surface overflow paths should be located and sized to convey the 100-year runoff in case the oversized pipe (inlet/outlet) becomes plugged or inoperable.

Access Points:

- At a minimum, personnel access points should be located at the upstream and downstream ends of the oversized pipe. Additional, intermediate locations (approximately every 100 feet depending on the cleaning method) should be included.

Oversized Pipes

Requirements

Sequencing

- Sequencing for installation of the oversized pipes should progress with the installation of the storm sewer system.
- Inlet protection for sediment control should be installed immediately after each storm sewer inlet is completed. This will minimize costs and delays of removing large quantities of sediment from the pipes during construction.

Construction

- Oversized pipes should not be placed under structures that cannot be excavated.
- Placing the oversized pipe at some minimum slope is important to ensure that the pipe will completely drain between storm events.

Maintenance

- At a minimum, personnel access points should be located at the upstream and downstream ends of the oversized pipe. Additional, intermediate locations (approximately every 100 feet depending on the cleaning method) should be included.
- For safety, confined space entry procedures must be followed by maintenance personnel when removing sediments.
- Whenever possible, sediment removal should be by mechanical means other than flushing. Sediment should be removed from the pipe and not flushed downstream.
- If flushing is the only cleaning option, special care should be taken to trap and remove sediment before it moves downstream.

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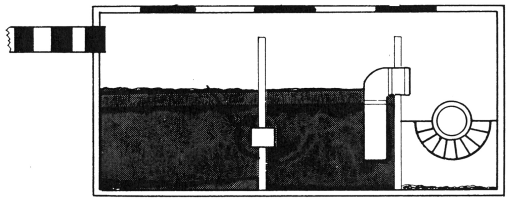
Oil/Grit Separators



Description

Oil/grit separators, also called oil and water separators, are systems designed to remove trash, debris, and some amount of sediment, oil and grease from stormwater runoff. Oil/grit separators operate based on the principles of sedimentation for the grit, and phase separation for the oil. There is minimal attenuation of flow in oil/grit separators since they are not designed with significant detention storage.

Because grit chambers and deep sump catch basins have limited storage capacity and detention time, these systems cannot be expected to have significant water quality treatment capabilities. While they can trap trash, oil and grease and other floatables, they are not effective at removing pollutants such as nutrients or metals. In terms of sediments, only coarse sediments are likely to be trapped. Resuspension of the sediments is likely, unless an aggressive maintenance program is followed. Therefore, pollutants are not actually removed from oil/grit separators until they are cleaned out.

There are a variety of both proprietary and non proprietary oil/grit separators on the market ranging from chambered designs to manhole-types. Many of these systems are "drop-in" systems, and incorporate some combination of filtration media, hydrodynamic sediment removal, oil and grease removal, or screening to remove pollutants from stormwater.

Non-proprietary systems include:

- Grit Chambers, also called "water quality inlets"
- Deep Sump Catch Basins

Proprietary hydrodynamic separator systems include:

- CDS Technologies
- Stormceptor ®
- Vortechs™
- Downstream Defender™

Purpose

Water Quantity	
Flow attenuation	☐
Runoff volume reduction	☐
Water Quality	
Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollutant removal	
Total suspended sediment (TSS)	◧
Total phosphorus (P)	☐
Nitrogen (N)	☐
Heavy metals	☐
Floatables	■
Oil and grease	■
Other	
Fecal coliform	☐
Biochemical oxygen demand (BOD)	☐

■ Primary design benefit
◧ Secondary design benefit
☐ Little or no design benefit

Oil/Grit Separators

These systems represent only some of the systems currently available. Their presentation in this BMP section in no way reflects an endorsement.

Recent studies indicate that oil/grit separators are best used as pretreatment devices for other technologies. The benefits of pretreatment are many, including extension of the operational life of stormwater management facilities adversely impacted by sediment, extension of maintenance intervals for ponds and improvement of visual appeal of ponds and wetlands by prevention of oil sheen and large sediment deposits by the inlet.

Proprietary separator systems include enhanced features that can increase their treatment potential. However, one of the main problems facing the use of proprietary systems is the lack of peer-reviewed performance data for these systems. However, EvTEC (Environmental Technology Evaluation Center) may be including these systems in a series of proprietary BMP evaluations scheduled for 2001. For more information, see EvTEC's website at www.cerf.org/evtec/evals.htm

Oil/grit separators are often used in retrofit situations, to provide some water quality treatment for small urban lots where larger BMPs are not feasible due to site constraints. Oil/grit separators are best used in commercial, industrial and transportation types of land use (impervious areas that are expected to receive high sediment and hydrocarbon loadings). However, oil/water separators cannot be used for the removal of dissolved or emulsified oils such as coolants, soluble lubricants, glycols, and alcohols.

Oil/grit separators should be designed and constructed as off-line systems only. Also, it is recommended that the contributing area to any individual inlet be limited to one acre or less of impervious cover.

Runoff in excess of the prescribed water quality treatment volume should be routed around (bypass) the pretreatment BMP. The inflow pipe should be sized and constructed to pass the design storm volume into the water quality inlet or deep sump, and excess flows should be directed to another BMP of sufficient capacity to meet the water quantity requirements or directed to a storm drain system.

Oil/grit separators are available as pre-manufactured units or can be cast in place. Reinforced concrete should be used to construct below-grade systems. In addition, oil/grit separators should be watertight to prevent possible groundwater contamination.

Advantages

- Can be used for retrofitting small urban lots where larger BMPs are not feasible or where above-ground BMPs are not an option.
- Provides pretreatment of runoff before it is delivered to other BMPs.
- Easily accessed for maintenance.
- Longevity is high, with proper maintenance.
- Standardized designs allow for relatively easy installation.
- Compatible with storm drain systems.

Oil/Grit Separators

Limitations

- Limited pollutant removal
- No volume control
- Frequent maintenance is necessary
- Proper disposal of trapped sediment and oil and grease required
- Expensive to install and maintain, compared to other types of BMPs (usually used where the cost of land would be prohibitive or where resources are sensitive or valuable).
- Cannot be used for the removal of dissolved or emulsified oils such as coolants, soluble lubricants, glycols, and alcohols
- Contributing area limited to one acre or less of impervious cover

Design

Grit Chambers (also called Water Quality Inlets)

Grit chambers come in a variety of shapes and sizes. They typically consist of three bays; forebay, separator section, and the afterbay. Figures 1 and 2 illustrate typical three-bay grit chamber designs.

Runoff enters the top of the first chamber, which contains a permanent pool of water (minimum depth of four feet). Pollutants are removed in this first chamber by trapping floatable debris (leaves and litter) and by gravity settling of sediment. Stormwater flows through screened orifices to the second chamber, which also contains a permanent pool of water (minimum depth of 4 feet). The stormwater must then pass through the bottom opening of an inverted pipe into the third chamber. The opening of this pipe is located at least three feet below the second chamber permanent pool. Oil and grease float on the permanent pool water, and are trapped in the second chamber. Eventually the oil and grease will attach to sediment and settle out. If the outlet of the third chamber is above the chamber floor, then a permanent pool will form, providing another settling area. Otherwise, there will be little pollutant removal in the third chamber. Lastly, stormwater is routed out of the third chamber into the storm drain system or into another BMP.

To achieve consistent removal of pollutants, the volume of the permanent pools in the chambers of the inlets should be maximized. The combined volume of these pools should equal at least 400 cubic feet per acre of contributing impervious area. The pools should be at least four feet deep for settleability. Where feasible, the third chamber should also be used as a permanent pool. Vertical baffles at the bottom of the permanent pools can help to minimize sediment resuspension.

A trash rack or screen should cover the discharge outlets (including between the chambers). To trap hydrocarbons in the water quality inlets, an inverted elbow pipe should be located between the second and third chambers and the bottom of the pipe should be at least three feet below the second chamber permanent pool. Manholes should be included for each chamber to provide access for cleaning.

Oil/Grit Separators

Design (continued)

A variation on this basic design is the coalescing plate (CP) type (Figure 3) using a gravity mechanism for separation. CP separators need considerably less space for separation of the floating oil due to the shorter travel distances between parallel plates. Coalescing units are made from oil-attracting materials, such as polypropylene or other materials. These units attract small oil droplets which begin to concentrate until they are large enough to float to the surface and separate from the storm water. Without these units the oil and grease particles must concentrate and separate naturally, requiring a much larger surface area. For inflows from small drainage areas (fueling stations, maintenance shops, etc.) a coalescing plate (CP) type separator is typically considered, due to space limitations. However, if plugging of the plates is likely, then the baffle-type designs shown in Figures 1 and 2 may be more appropriate.

Deep Sump Catch Basins

(also known as Sump Pits, Oil and Grease Catch Basins or Hooded Catch Basins:

Functioning as a modified catch basin, the deep sump design has the stormwater runoff inflow at the top of the basin. The discharge point is located at least 4 feet below the inflow point. Generally, the volume rule is to size the sump four times the diameter of the inflow pipe. Stormwater flows through screened orifices to the chamber, which may contain a permanent pool of water. The stormwater must pass through the bottom opening of an inverted pipe. Oil and grease float on the permanent pool water, and are trapped in the chamber. Eventually, the oil and grease will attach to sediment and settle out.

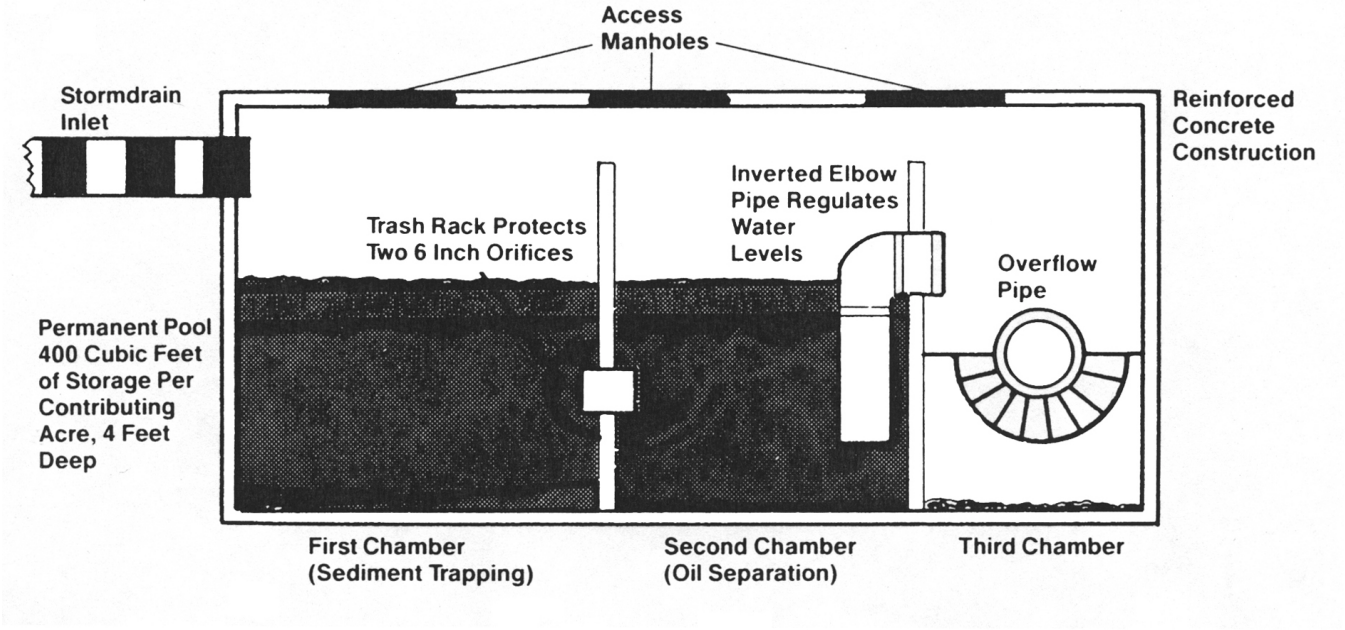


Figure 1: Typical Grit Chamber Design

Source: Schueler, 1987.

Oil/Grit Separators

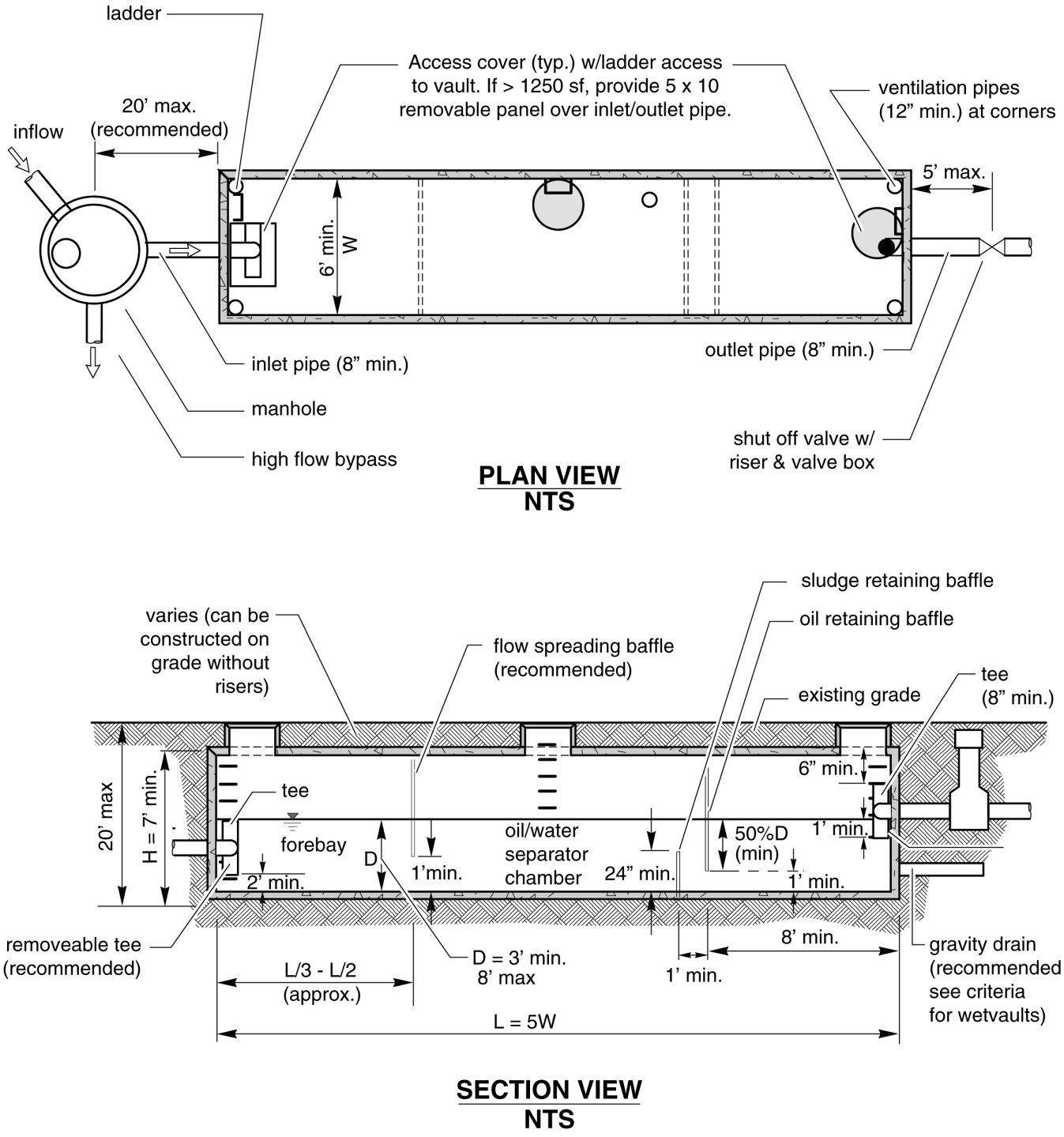
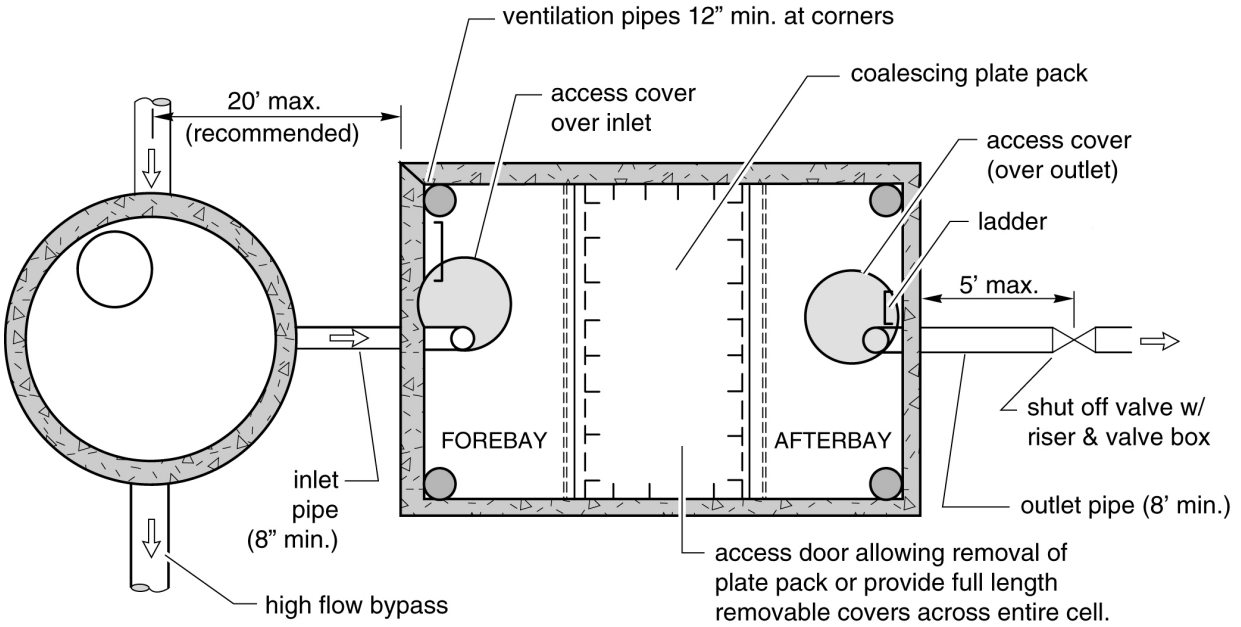


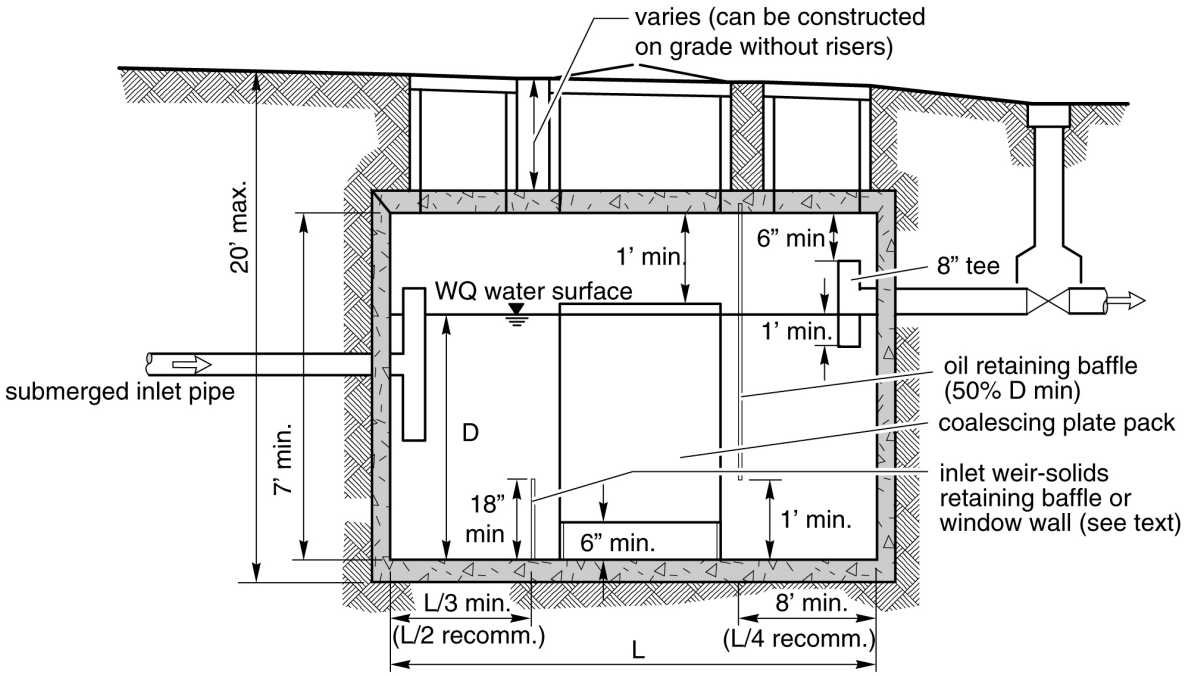
Figure 2: Typical API-Type (Baffle) Grit Chamber

Source: Washington Department of Ecology, 1999

Oil/Grit Separators



PLAN VIEW
NTS



SECTION VIEW
NTS

Figure 3: Typical CP-Type Oil/Grit Separator
Source: Washington Department of Ecology, 1999

Oil/Grit Separators

Design (continued)

Figure 4 illustrates a deep sump catch basin.

Continuous Deflective Separation (CDS) Technologies

CDS hydrodynamic separator technology* is suitable for gross pollutant removal. The system utilizes the natural motion of water to separate and trap sediments by indirect filtration. As the storm water flows through the system, a very fine screen deflects the pollutants, which are captured in a litter sump in the center of the system. Floatables are retained separately. This non-blocking separation technique is the only proprietary technology covered in this fact sheet that does not rely on secondary flow currents induced by vortex action.

The processing capacities of CDS units vary from 3 to 300 cubic feet per second (cfs), depending on the application. Precast modules are available for flows up to 62 cfs, while higher flow processing requires cast-in-place construction. Every unit requires a detailed hydraulic analysis before it is installed to ensure that it achieves optimum solids separation.

Stormceptor ®

Stormceptor Corporation, based in Canada, has licensed manufacturers throughout Canada and the United States. Stormceptor* is designed to trap and retain a variety of nonpoint source pollutants, using a bypass chamber and treatment chamber. The company claims that its device is capable of removing 50 to 80 percent of the total sediment load when used properly.

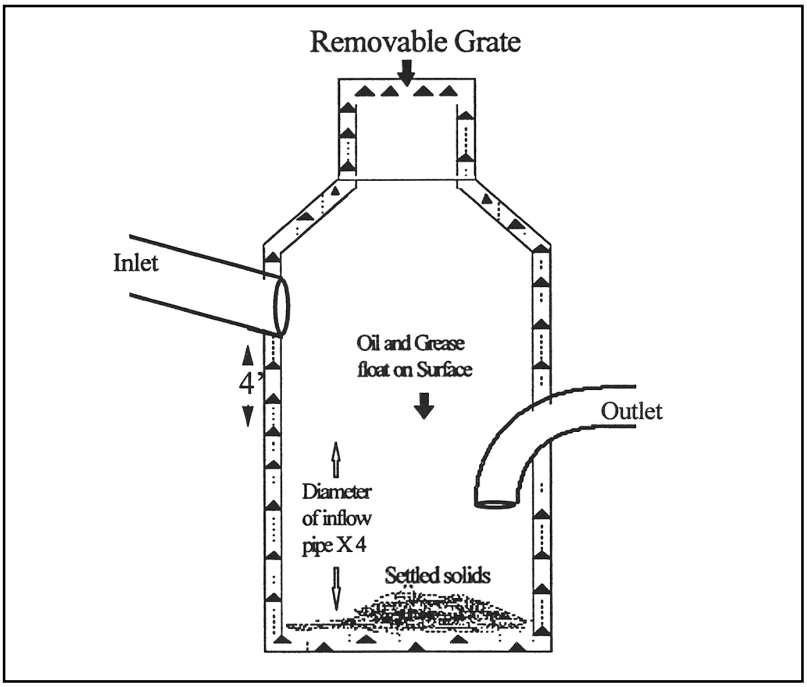


Figure 4: Typical Deep Sump Catch Basin
Source: Massachusetts Department of Environmental Protection, 1997

* *This mention does not constitute an endorsement of product.*

Design (continued)

Stormceptor units are available in prefabricated sizes up to 12 feet in diameter by 6 to 8 feet deep. Customized units are also available for limited spaces. Stormceptor recommends its units for the following areas:

- Redevelopment projects of more than 2,500 square feet where there was no previous storm water management (even if the existing impervious area is merely being replaced).
- Projects that result in doubling the impervious area.
- Projects that disturb at least half of the existing site.

Vortechs™

The Vortechs™ storm water treatment system,* manufactured by Vortechnics, Inc. of Portland, Maine, has been available since 1988. Like the other hydrodynamic separators, Vortechs removes floating pollutants and settleable solids from surface runoff. This system combines swirl concentrator and flow-control technologies to separate solids from the flow. Constructed of precast concrete, Vortechs uses four structures to optimize storm water treatment through its system. These are:

- Baffle wall: Situated permanently below the water line, this structure helps to contain floating pollutants during high flows and during clean outs.
- Circular grit chamber: This structure aids in directing the influent into a vortex path. The vortex action encourages sediment to be caught in the swirling flow path and to settle out later, when the storm event is complete.
- Flow control chamber: This device helps keep pollutants trapped by reducing the forces that encourage resuspension and washout. This chamber also helps to eliminate turbulence within the system.
- Oil chamber: This structure helps to contain floatables. Vortechnics manufactures nine standard-sized units. These range from 9 by 3 feet to 18 by 12 feet. The unit sizes depend on the estimated runoff volume to be treated. For specific applications, dimensions of the runoff area are used to customize the unit. Vortechnics claims that Vortechs systems are able to treat runoff flows ranging from 1.6 cfs to 25 cfs.

Downstream Defender™

The Downstream Defender™,* manufactured by H.I.L. Technology, Inc., regulates both the quality and quantity of storm water runoff. The Downstream Defender is designed to capture settleable solids, floatables, and oil and grease. It utilizes a sloping base, a dip plate and internal components to aid in pollutant removal. As water flows through the unit, hydrodynamic forces cause solids to begin settling out. A unique feature of this unit is its sloping base (see Figure 5), which is joined to a benching skirt at a 30-degree angle. This feature helps solids to settle out of the water column. The unit's dip plate encourages solids separation and aids in the capture of floatables and oil and grease. All settled solids are stored in a collection facility, while flow is discharged through an outlet pipe. H.I.L. Technology claims that this resulting discharge is 90 percent free of the particles greater than 150 microns that originally entered the system.

The Downstream Defender comes in predesigned standard manhole size, typically ranging from 4 to 10 feet in diameter. These units have achieved 90 percent removal for of solids for flows from 0.75 cfs to 13 cfs. To meet

* *This mention does not constitute an endorsement of product.*

Oil/Grit Separators

specific performance criteria, or for larger flow applications, units may be custom designed up to 40 feet in diameter. (These are not able to fit in conventional manholes.)

Maintenance

The actual removal of sediments, associated pollutants and trash occurs only when oil/grit separators are cleaned out. Therefore, aggressive maintenance plans are required to reduce the risk of resuspension of sediments during large storm events. Most studies have linked the failure of inlets to the lack of regular maintenance.

- Ideally, in areas of high sediment loading, inlets should be inspected and cleaned after every major storm event, and inspected monthly.
- Typically, oil/grit separators need to be cleaned every one to six months.

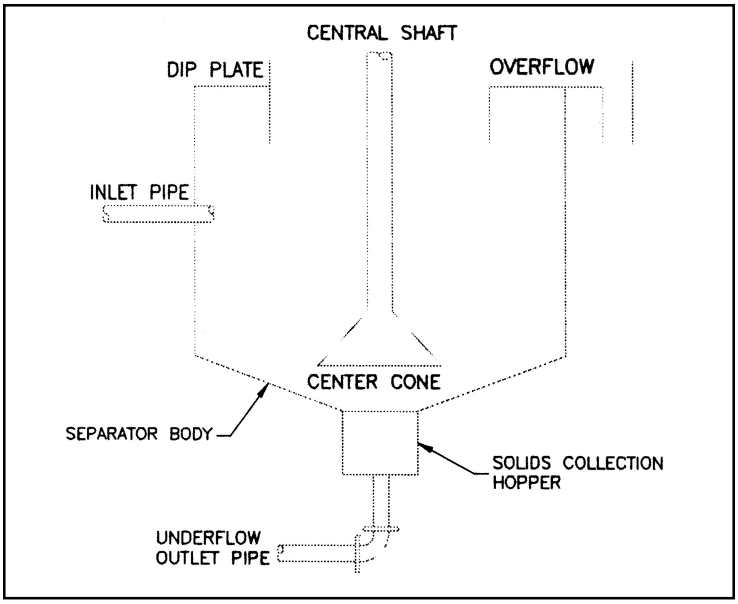


Figure 5: Generalized Hydrodynamic Separator
Source: Tyack and Fenner, 1997.

- Ordinary catch basin cleaning equipment (vacuum pumps available to most public works departments) can be used to clean oil/grit separators. Manual removal of sediments may be necessary, as well. Confined space entry procedures should be followed.
- Storm sewer maintenance crews should document how much material they remove from each of the chambers so they know how often to clean them.
- Proprietary systems may have their own, specific maintenance requirements.
- Disposal of the accumulated sediment and hydrocarbons must be in accordance with applicable local, state, and federal guidelines and regulations. In most cases, these residuals are not "hazardous waste." However, the material is contaminated well beyond levels associated with the raw stormwater itself with a wide array of inorganic and organic pollutants. Disposal without proper precautions would not be recommended regardless of the source of the residue.

Oil/Grit Separators

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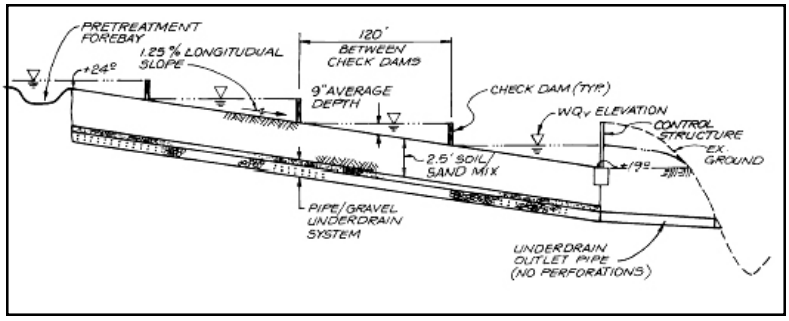
Dry Swales



Description

The dry swale (also called a grassed swale) is a type of open vegetated channel used to treat and attenuate the water quality volume of stormwater runoff as well as convey excess stormwater downstream. In dry swales, the entire water quality volume of a given storm is temporarily held in a pool or series of pools created by permanent checkdams or ditchblocks. This holding time serves to settle pollutants, especially sediment.

Dry swales are good options in residential settings, as they discourage long-standing water, thus making it possible to mow the area even shortly after a rainfall. Dry swales are typically located in a drainage easement at the back or side of a residential lot or along roadsides in place of curb and gutter.

Dry swales may be treated as an extension to a mown lawn or be planted in native grasses and allowed to grow longer (though still mown at least annually), potentially increasing filtration/infiltration as well as habitat value. Unless existing soils are highly permeable, they are replaced with a sand/soil mix that meets minimum permeability requirements.

An underdrain system is also installed under the soil bed. Typically, the underdrain system is created by a gravel layer which encases a perforated pipe. Stormwater treated by the soil bed flows into the underdrain, which conveys treated stormwater back to the storm drain system. The dry swale is related to the wet swale, though the latter does not have an underlying filtering bed.

Advantages

- Traps sediment and other pollutants.
- Controls peak discharges by reducing runoff velocity and promoting infiltration.

Purpose

Water Quantity	
Flow attenuation	◧
Runoff volume reduction	☐
Water Quality	
Pollution prevention	
Soil erosion	N/A
Sediment control	N/A
Nutrient loading	N/A
Pollutant removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	■
Nitrogen (N)	■
Heavy metals	■
Floatables	☐
Oil and grease	◧
Other	
Fecal coliform	☐
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
☐ Little or no design benefit

Dry Swales

- Provides some groundwater recharge if their design and location allows adequate infiltration.
- Good option for small-area stormwater retrofits, replacing existing drainage ditches.
- Good option for residential or institutional areas of low to moderate density, and may also be used in parking lots to break up impervious areas.
- Linear nature makes them work well for treating highway or residential road runoff.

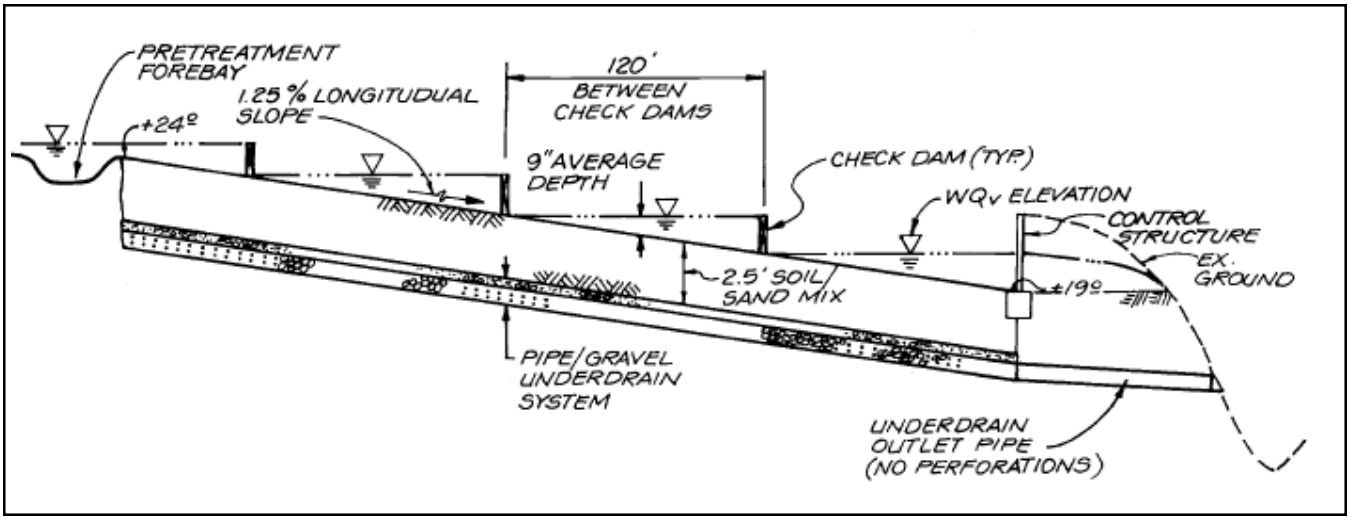


Figure 1: Dry Swale Longitudinal Section

Source: Maryland, 2000

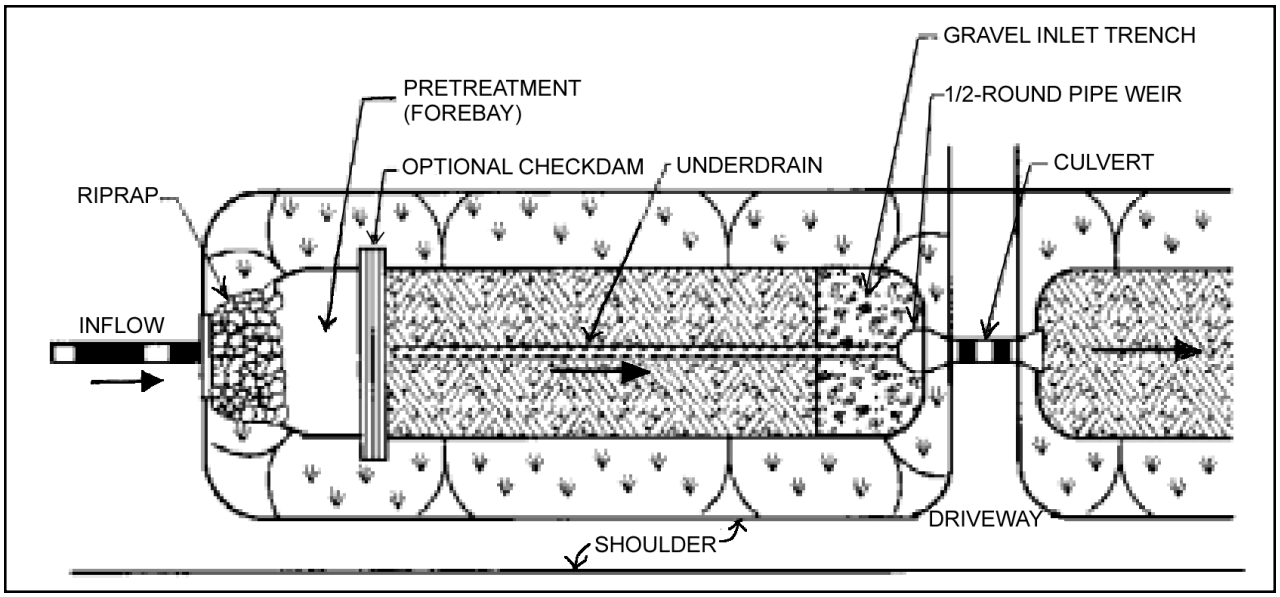


Figure 2: Dry Swale Plan View

Source: CWP, 2000

Dry Swales

- Rapidly dewater and have shallow slopes that are easy to mow.
- Since runoff ponds for only a short time in a dry swale, water temperatures do not significantly increase, making this an appropriate practice for use in watersheds with cold-water trout streams
- They are generally less expensive to build than curb-and-gutter systems.

Limitations

- If designed or installed improperly (e.g., if proper slopes or sufficiently dense vegetation are not achieved) dry swales will not effectively remove sediment and pollutants.
- Individual dry swales can treat only a small area.
- May not be applicable to sites with many driveway culverts or extensive sidewalk systems.
- Do not appear to be effective in reducing bacteria levels in stormwater, and appear to remove only modest amounts of phosphorous. Few studies are available to gauge their effectiveness.
- Require more maintenance than curb and gutter systems.
- Roadside dry swales are subject to damage from off-street parking and snow removal.

Design

Siting

- Individual dry swales should be designed to treat relatively small, flat drainage areas. If the swales employ slopes steeper that four percent or if they are used to treat areas larger than five acres, the flow velocity becomes too great for effective treatment and erosion of the channel is more likely.
- Dry swales can be sited on most soils. Native soils with low permeability, however, will need to be amended or replaced to increase infiltration.
- The bottom of the swale should be at least three feet above groundwater in order to prevent the swale bottom from remaining moist or groundwater from being contaminated.
- If used in areas with steep slopes, dry swales must generally run parallel to contours in order to be effective.

Channel Profile and Size

- The swale should have a trapezoidal or parabolic cross section with relatively flat side slopes (less than 3:1 horizontal:vertical). This maximizes the wetted perimeter—the length along the edge of the channel cross-section that is in contact with the runoff—and thus enhances treatment.
- Shallow side slopes also allow any runoff entering the swale from the side to receive some treatment. A filter strip or other vegetated buffer should be located on both sides of the swale, particularly if nearby impervious surfaces drain into the swale.
- The flat channel bottom should be between two and eight feet wide, the minimum to ensure sufficient filtering surface for water quality treatment, the maximum to minimize the formation of small channels within the swale bottom.

Dry Swales

Design Requirements (continued)

- Typically, the dry swale accommodates runoff from a two-year storm to flow through without causing erosion, but it should have the capacity to handle larger flows (usually a ten-year storm).
- The longitudinal slope of the dry swale is generally between one and two percent (Fig. 2), which, along with dense vegetative cover, helps reduce flow velocity, prevent erosion and filter runoff. If slopes exceed 4 percent, checkdams can be installed to reduce the effective slope to below four percent. The grade should be continuous and uniform.

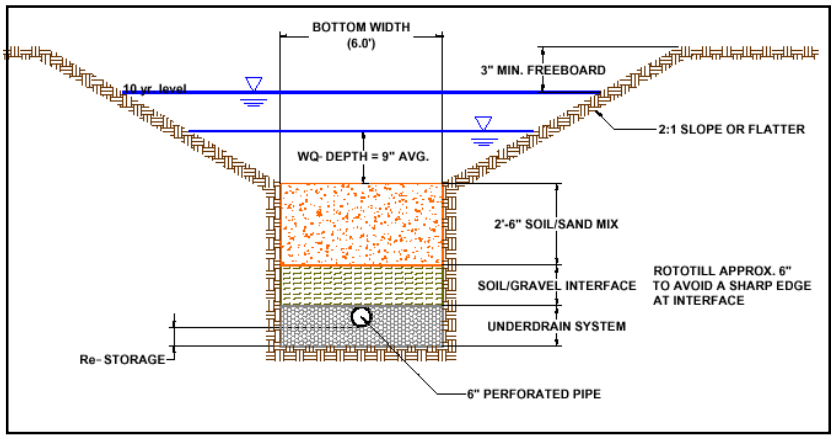


Figure 3: Dry Swale Trapezoidal Section
Source: Maryland, 2000.

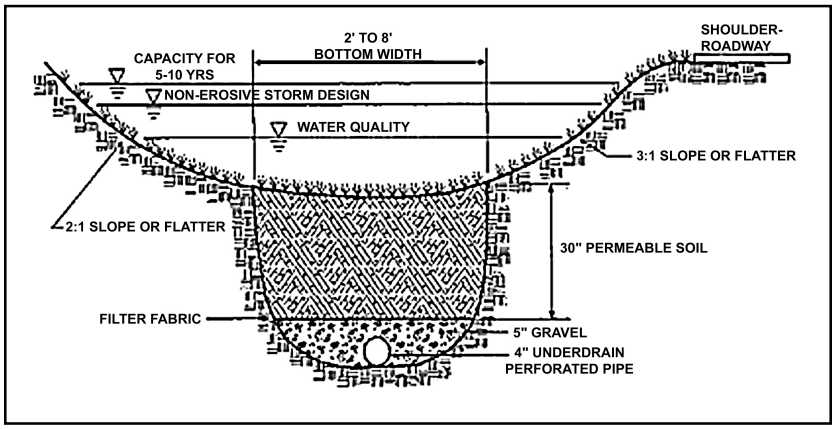


Figure 4: Dry Swale Parabolic Section
Source: Center for Watershed Protection, 2000.

Design Process

The following steps are detailed in Chapters 2 and 7 of *Design of Stormwater Filtering Systems* (Schueler, 1996.)

1. Compute the Water Quality Treatment Volume (WQV) for the given land surfaces as required by the local permitting agency.

2. Identify the required swale bottom width, depth, length and slope necessary to store the WQV within a shallow ponding depth (18 inches maximum).

4. Compute the WQV drawdown time to ensure that it is less than 24 hours.

5. Compute the 2-year and 10-year frequency storm event peak discharges.

6. Check the 2-year velocity for erosive potential (adjust swale geometry, if necessary, and reevaluate WQV design parameters).

7. Check the 10-year depth and velocity for capacity (adjust swale geometry, if necessary, and reevaluate WQV and 2-year design parameters

8. Provide minimum freeboard above 10-year stormwater surface profile (6-inch minimum recommended).

Dry Swales

Structures and Soils

- A forebay large enough to accommodate 25 percent of the water quality volume is created by installing a checkdam between the inlet and the main body of the swale (See Figure 2). The checkdam should overlay a stone base to prevent downstream scour. The area just downstream of the checkdam should be protected from scouring with riprap or channel lining.
- The checkdam may be constructed of timber or concrete (see Figures 5 and 6). Timber may be pressure-treated 6- by 6-inch or 8- by 8-inch, atop a rock base and embedded at least 3 feet into side slopes.
- A checkdam may also be installed at the downstream end of the swale, along with an optional pea gravel window to route water to the underdrain in the event that surface soils become clogged. See Figure 2.
- Unless existing soils are highly permeable, they are replaced with a 30-inch depth of a sand/soil mixture (approximately 50/50 mix) to ensure infiltration.
- Beneath the soil layer, install an underdrain system, typically a gravel layer encasing a longitudinal perforated pipe.

Vegetation

Depending on the swale location, grasses may be designed to be mown like a typical lawn or only annually. Native grasses are best for enhancing biodiversity and wildlife habitat, and their extensive root systems enhance infiltration and drought-tolerance. They do, however, take longer to become well-established, so a cover crop or other soil stabilization method will be important.

Grass species should be selected for vigorousness; rigid, upright habit (even during flow times); and, if located along a high-volume

Parameter	*Swale Design Criteria*
Pretreatment volume	.05" per impervious acre, at initial inflow point.
Preferred shape	Trapezoidal or parabolic.
Bottom width	2 feet minimum, 8 feet maximum widths up to 16 feet are allowable if a dividing berm or structure is used.
Side slopes	2:1 maximum, 3:1, or flatter preferred.
Longitudinal slope	1.0% to 2.0% without, check dams.
Sizing criteria	Length, width, depth, and slope needed to provide surface storage for WQV. Outlet structures sized to release WQV over 24 hours.
Underlying soil bed	Equal to swale width Dry Swale: Moderately permeable soils (USCS ML, SM, or SC) 30" deep with gravel/pipe underdrain system Wet Swale: Undisturbed soils, No underdrain system
Depth and capacity	▸ Surface storage of WQV with a maximum ▸ depth of 18 inches for water quality treatment (12" average depth). ▸ Safely convey 2 year storm with non-erosive velocity (≤ 4.0 ft/s). ▸ Adequate capacity for 10 year storm with 6" of freeboard

Table 1: Design Criteria for Dry (and Wet) Swale Systems

Source: Claytor & Schueler, 1996

Dry Swales

Requirements Design (continued)

roadside, ability to tolerate salt. (One salt-tolerant choice is creeping bentgrass—Agrostis palustris.) If mowing regularly, use park grade Kentucky bluegrass or fescue. Otherwise, use native species such as switchgrass, big bluestem, little bluestem, Indian grass or side-oats grama. *Do not* use reed canary grass, which is highly invasive.

Check permissible velocities of selected vegetation to ensure the two-year frequency storm velocity is nonerosive.

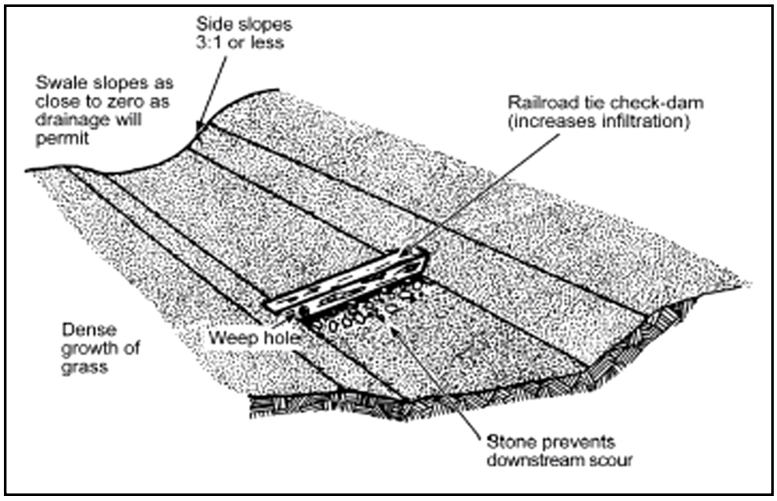


Fig 5: Timber Checkdam
Source: Schueler, 1987

Construction

- Accuracy in grading is essential, as departure from design slopes will easily affect effectiveness of treatment.
- Temporary erosion and sediment BMPs should be utilized during construction.
- After seeding, immediately install erosion control blanket. This is essential in order to stabilize the channel before turf has become established.

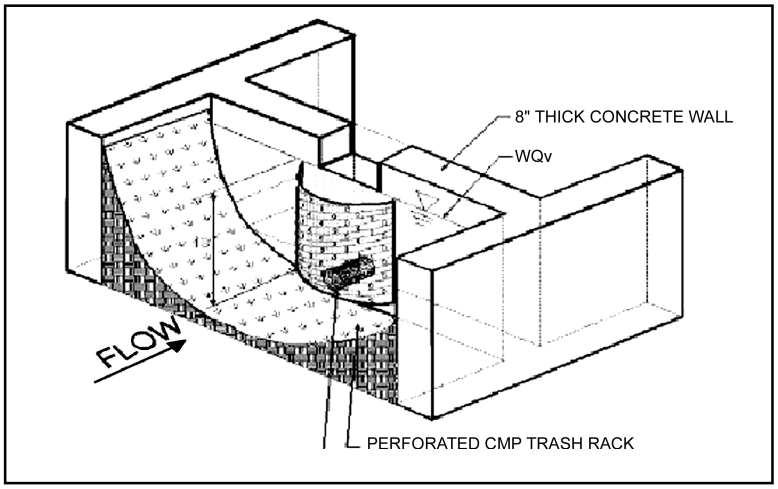


Figure 6: Concrete Checkdam
Source: Maryland Stormwater Design Manual, 2000

Maintenance

Dry swales must be maintained in order to function properly. Plans should include a detailed inspection and maintenance plan, identify owners and indicate those responsible for maintenance.

Annually or Semiannually

- Inspect swale several times the first few months to ensure grass cover is establishing well. If not, reseed or plant an alternative species. Once established, continue to inspect semiannually for erosion problems.
- At least annually inspect pea gravel diaphragm for clogging from excess sediment; remove sediment and correct associated problems.
- Remove trash and debris accumulated in the swale.

Dry Swales

As Needed (frequent)

- Mow turf grass to a height of about four inches. If native grasses are used, mow only once a year in early spring to remove dead vegetation. Mowing the native grasses the first year is critical in order to eliminate competition from annual weeds.
- With infrequent mowings, remove the clippings.

As Needed (infrequent)

- Remove sediment buildup on the bottom of swale once it has accumulated to 25 percent of the original design volume.
- Reseed as necessary to maintain dense vegetation.
- Grass in the swales should be fertilized rarely, if at all, to avoid unnecessary export of nutrients. If an application of lime or fertilizer is deemed necessary on the basis of soil tests, it should be done only in cool spring or fall weather and only with a no phosphorus fertilizer.

Sources

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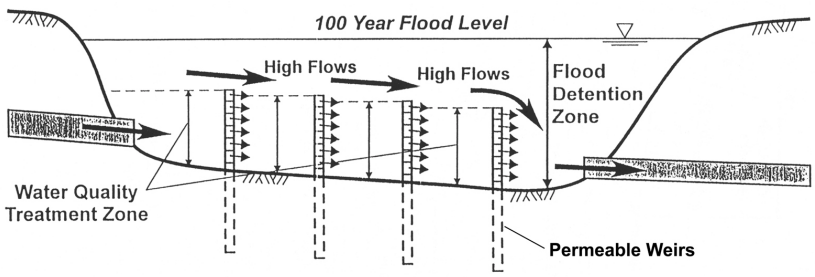
Permeable Weirs



Description

Permeable weirs are a relatively new BMP concept. As such, information regarding their application and design is limited in the current body of literature on BMP systems.

Permeable weirs are typically constructed from treated lumber, stacked with spaces between each timber to provide long, narrow openings that slowly pass stormwater. They have the appearance of a wooden fence. Under low flow conditions, water ponds behind the permeable weir and slowly seeps through the openings between the timbers, functioning like a dry extended storage pond. Under high flow conditions, water flows both over and through the weir.

Permeable weirs are generally used in low-quality wetland areas or constructed water quality treatment ponds. They promote sedimentation by slowing flow velocities as water ponds behind the weir. They also provide a means of spreading runoff as it is discharged, helping to decrease concentrated flow and reduce velocities as the water travels downstream.

Currently, permeable weirs are most often used in large drainage areas as regional BMPs. Figure 1 shows an example of a regional permeable weir. Figure 2 shows another type of permeable weir—a perforated sheetpile wall.

The permeable weir concept could be applied to smaller sites as well. In this case, a permeable weir would act as a wooden check dam, placed in a ditch or swale. Or, it may be used as a control structure in a dry extended detention area. Figure 3 shows how permeable weirs can be incorporated into a dry pond design (See the Dry Ponds BMP Section for more information on this type of BMP).

Purpose

Water Quantity	
Flow attenuation	■
Runoff volume reduction	□
Water Quality	
Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollutant removal	
Total suspended sediment (TSS)	◧
Total phosphorus (P)	□
Nitrogen (N)	□
Heavy metals	□
Floatables	◧
Oil and grease	□
Other	
Fecal coliform	□
Biochemical oxygen demand (BOD)	□

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Permeable Weirs

Requirements

Design

Permeable weir design generally includes considering the long, narrow openings as orifices to estimate the flow that passes through them at different water elevations. The 2-year runoff event is commonly chosen as the storage volume behind the weir, with 100 percent of the 2-year runoff passing through gaps in the weir. The length of the weir and the gaps between the boards should be designed so that the 2-year storm event is retained behind the weir approximately 1 to 2 days before fully draining down to normal conditions. Also, a structural analysis of the weir should be conducted and the length of piles should be designed to prevent overturning of the weir under the force of the inflowing stormwater (as shown in Figure 1).

Maintenance

The biggest maintenance concern of permeable weirs is that the timbers can swell, decreasing the size of the opening between each timber. Clogging, therefore, is a prime concern and must be accounted for in the design. Sediment removal from behind the permeable weir is also an important maintenance activity; otherwise, sediment resuspension is likely.

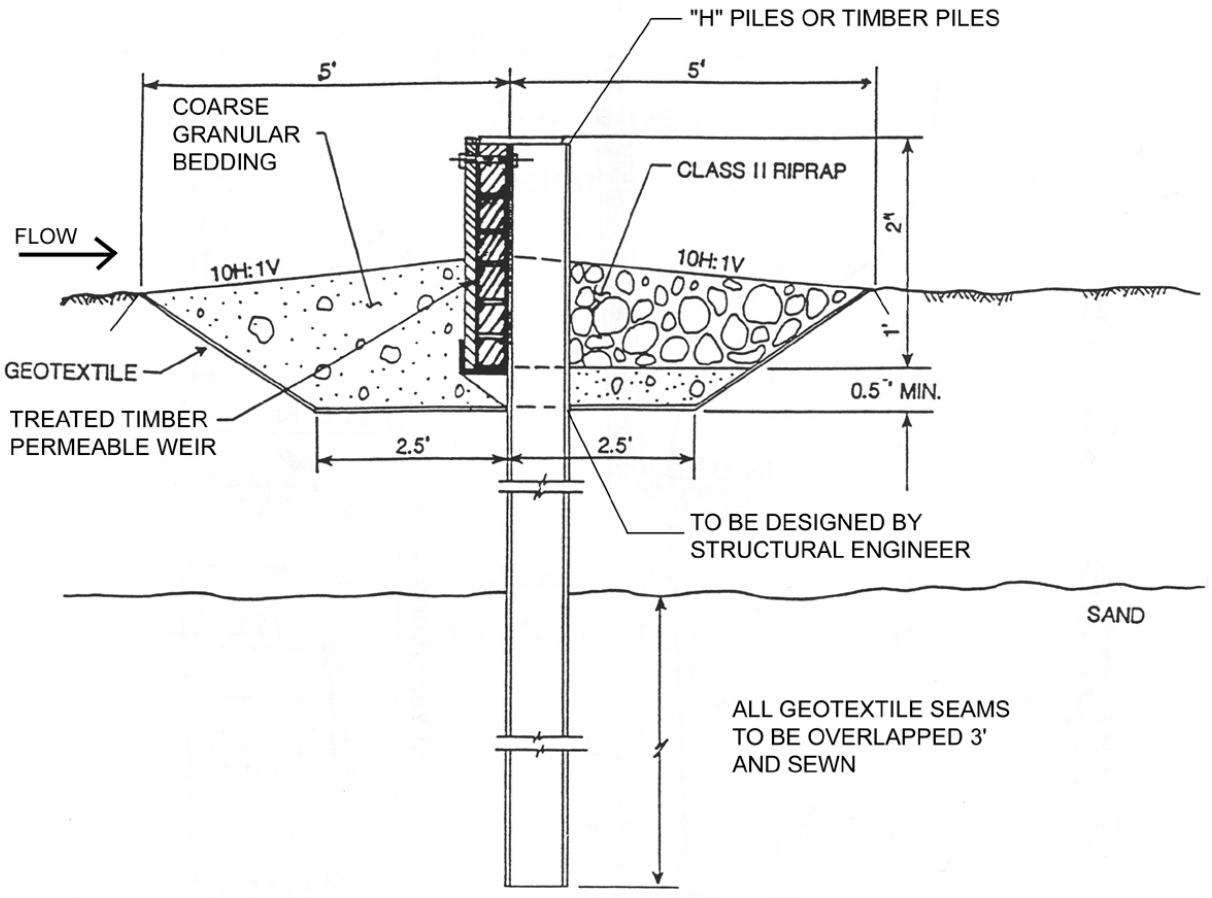


Figure 1: Typical Permeable Weir Section
Source: Klein, 1997

Permeable Weirs

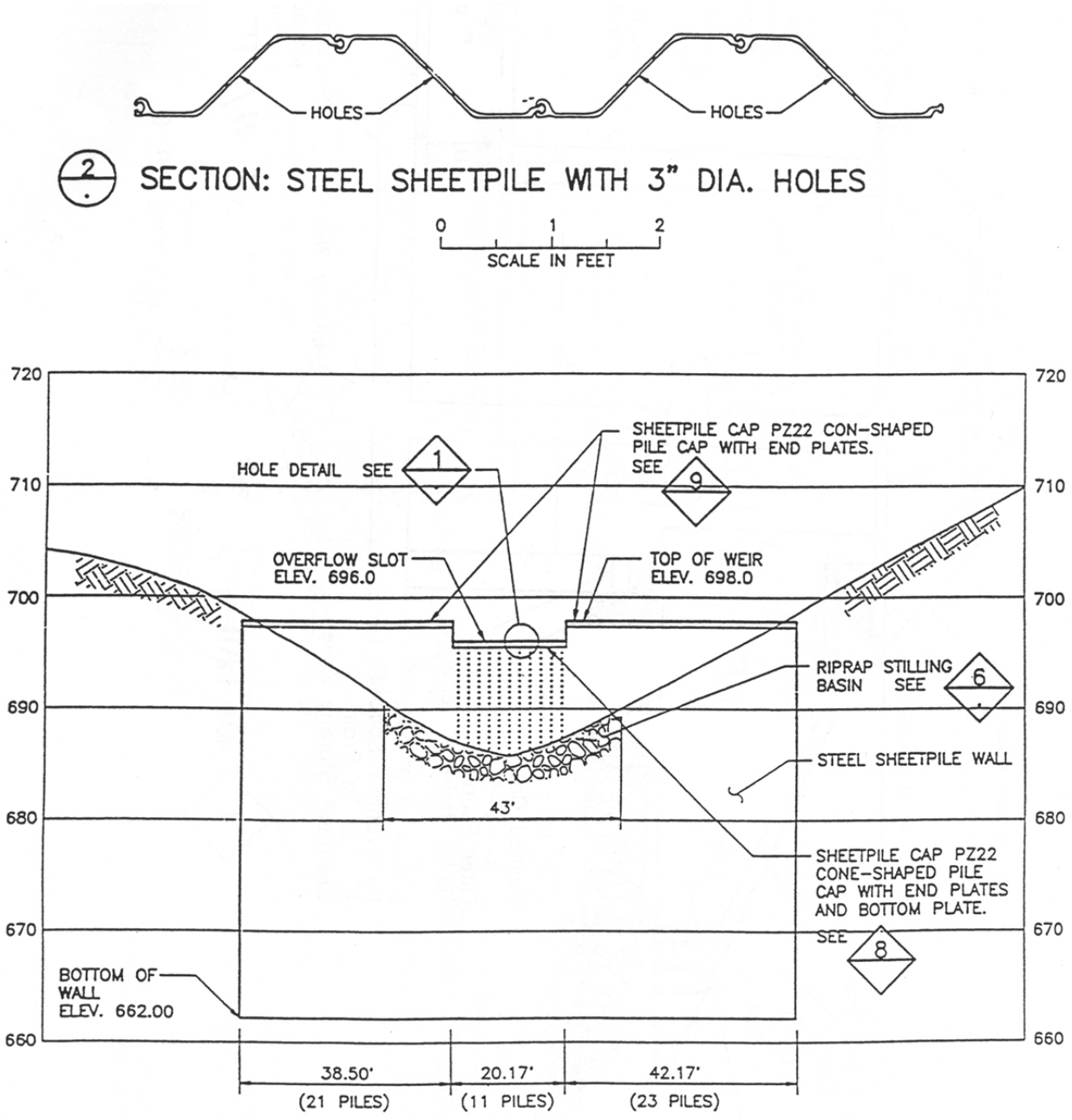


Figure 2: Perforated Sheetpile Wall
Source: Klein, 1997

Permeable Weirs

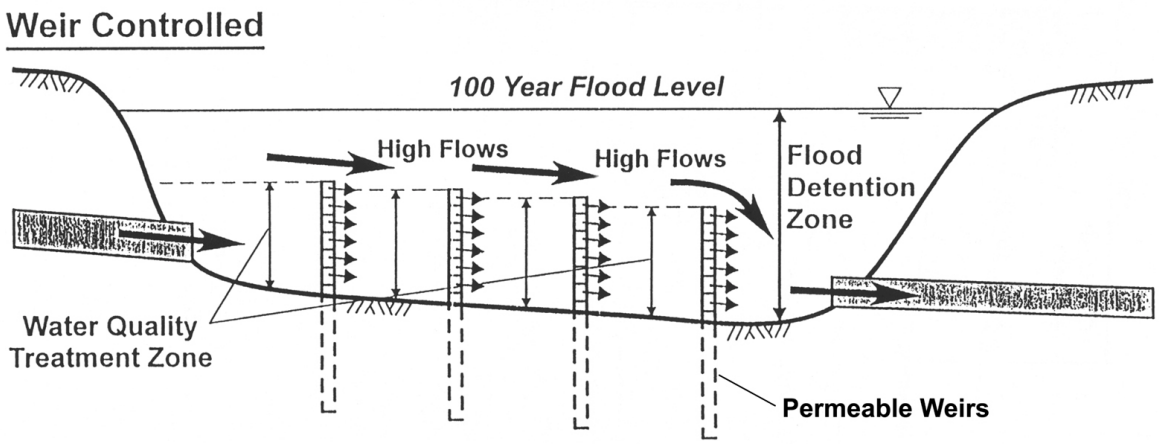


Figure 3: Dry Pond with Permeable Weir Control
Source: Klein, 1997

Sources

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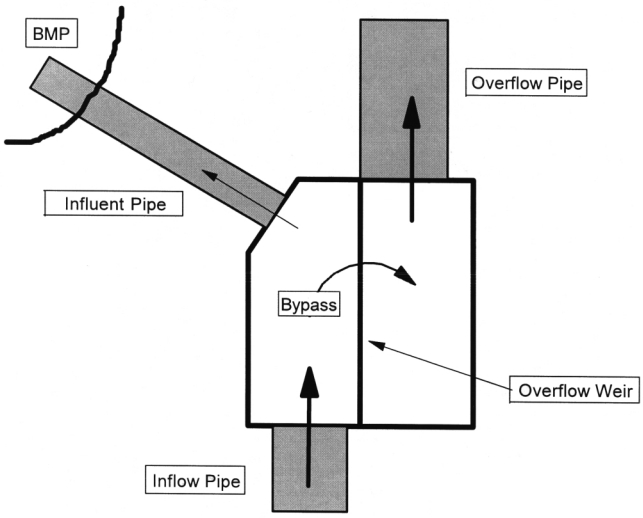
2. Klein, Steve M., Barr Engineering Company. 1997. "Alternatives to Wet Detention Basins" presentation at 30th Annual Water Resources Conference. Minneapolis.

3. Minnesota Pollution Control Agency. 2000. *Protecting Water Quality in Urban Areas: Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban and Developing Areas of Minnesota.* St. Paul.

Flow Splitters



Purpose

	Water Quantity
Flow attenuation	N/A
Runoff volume reduction	N/A
	Water Quality
Pollution prevention	N/A
Pollutant removal	N/A

Description

For off-line BMPs it is often necessary to restrict stormwater flows and bypass them around the facility because they are designed to only treat water from small storm events. Bypassing larger flows helps prevent resuspension of sediment, hydraulic overload, or erosion of the BMP.

Flow splitters are used to direct the first fraction of runoff (commonly called the "first flush") into an end-of-pipe BMP facility, while bypassing excess flows from larger events around the facility into a bypass pipe or channel. The bypass typically enters a detention pond or the downstream receiving drainage system, depending on flow control requirements.

Examples of off-line BMP systems that may require a flow-splitter include:

- Extended Storage Ponds (without a forebay)
- Constructed Wetlands (without a forebay)
- Infiltration Basins
- Infiltration Trenches
- Oil/Grit Separators
- Filters

In any of these systems, water is conveyed to the BMP facility via the facility's influent pipe. As shown in Figure 1, once the facility

Flow Splitters

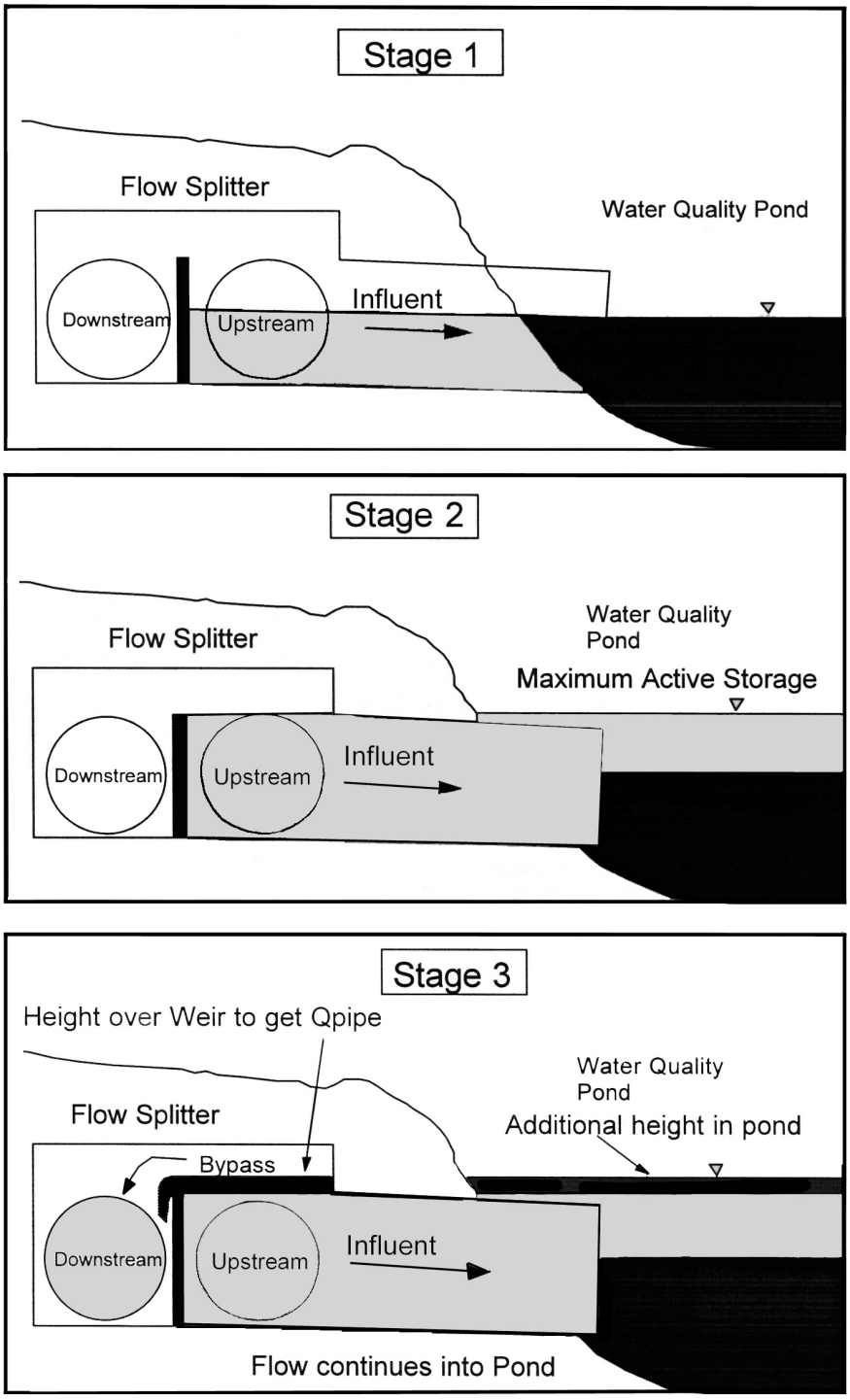


Figure 1: Operation of a Hydraulic Flow Splitter
Source: Ontario Ministry of the Environment. 1999.

Flow Splitters

reaches its design capacity, water backs up in the influent pipe and into the flow splitter itself. When the water level reaches the bypass elevation, stormwater begins to bypass the BMP facility. The bypass is generally created and controlled by a weir in the flow splitter structure.

The StormGate™ system, produced by Stormwater Management, is an example of a proprietary flow splitter that can be installed as a complete manhole unit (Figure 2). This unit can be used in conjunction with any stormwater quality facility. StormGate is mentioned here as simply an example of proprietary flow-splitters; its inclusion in this BMP section is not an endorsement by the sponsors of this document.

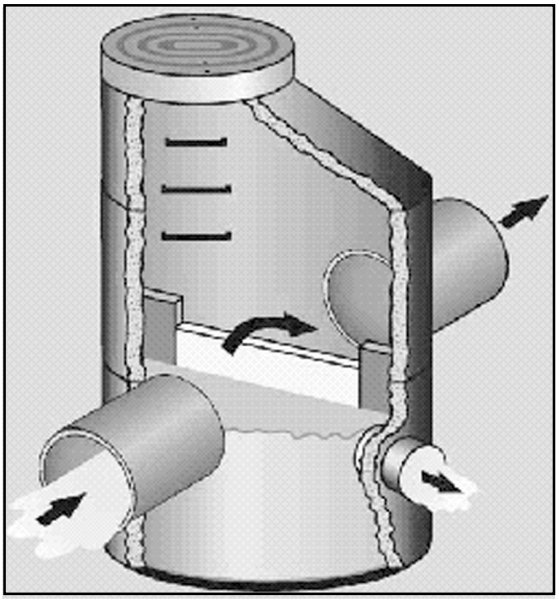


Figure 2: StormGate™ System*
Source: Stormwater Management Inc.

Important features in any flow splitter include:

- Reduction of high-flow turbulence to improve water quality performance
- Field adjustable weir
- Corrosion-free construction, with no galvanized components
- Optional low-flow isolation valve for maintenance or spill isolation
- Typical pipe sizes of 48” diameter or greater

Several typical applications of flow splitters are shown in Figure 3.

Advantages

- Limits the inflow to a BMP facility to the design volume, enhancing their longevity by reducing volumetric rate of treatment, erosion, slope, and vegetation damage.
- Reduces chances for resuspension of sediment in the BMP.
- Reduces dilution effect in the BMP.

Limitations

In some BMP facilities, a flow splitter has the potential to cause flow reversal. Flow reversal is the flow of water out of a BMP facility back through the flow splitter structure. Flow reversal has the potential to occur when the flow over the bypass subsides quickly while the flow out of the pond is governed by a slow extended detention release. In these instances, water levels in the facility above the bypass elevation can force water back into the flow splitter and over the bypass structure during the recession limb of a bypass storm. In order to minimize flow reversal several guidelines can be followed:

- Provide an overflow outlet above the design water level in the BMP facility. It should be recognized, however, that the provision of an overflow outlet will result in more water being conveyed into the pond,

** This mention does not constitute an endorsement of product.*

Flow Splitters

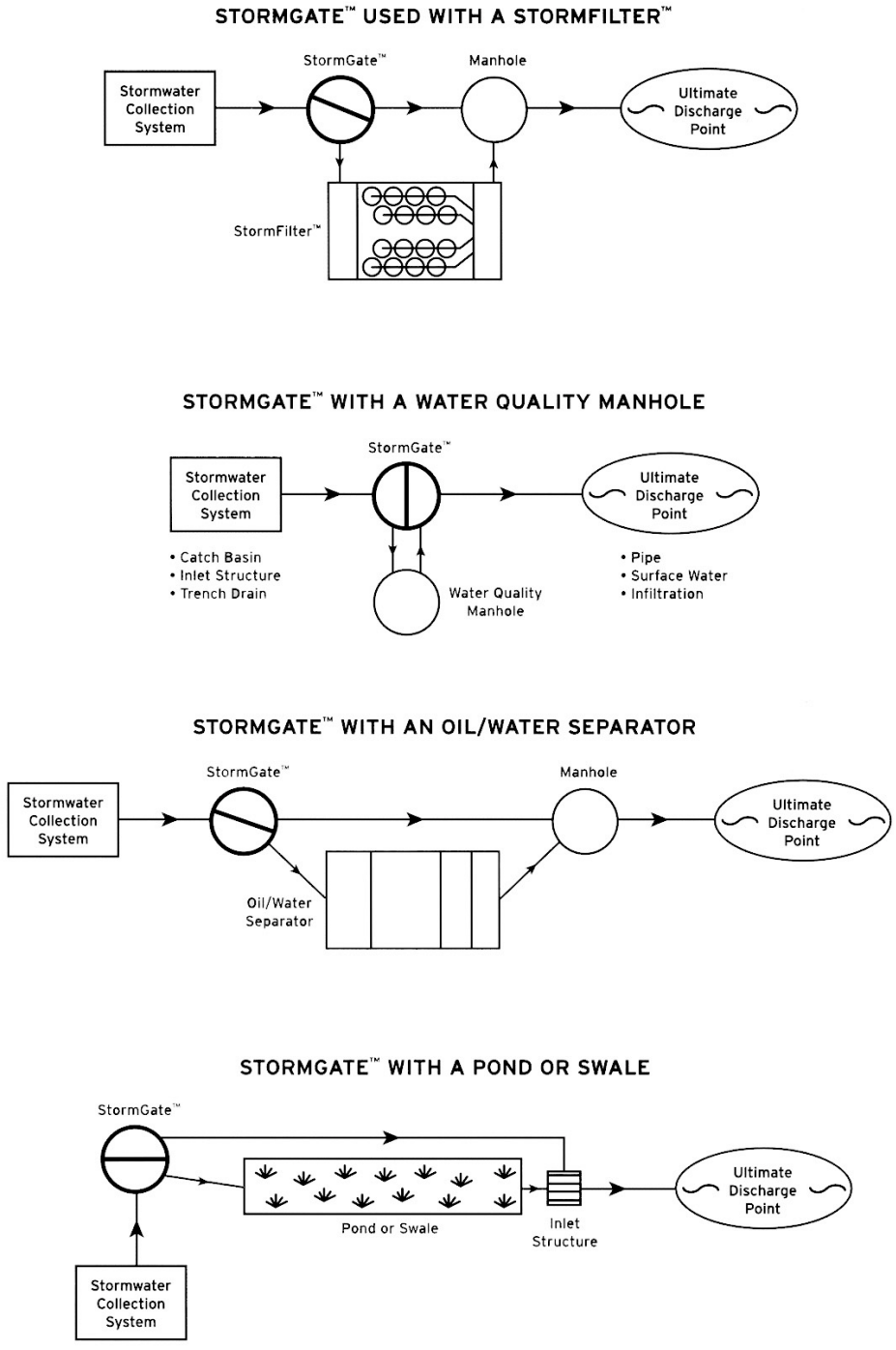


Figure 3: Typical StormGate™ Applications*
Source: Stormwater Management Inc.

Flow Splitters

which defeats the original purpose of the flow splitter. Therefore, the provision of an overflow outlet is not generally recommended as a standard practice to minimize flow reversal.

- Minimize the depth of bypass to achieve the desired bypass rate
- Maximize the elevation difference between the water level in the facility and the flow splitter to minimize the potential for reverse flow.

Requirements

Design

Flow splitters are typically manholes or concrete vaults with concrete baffles or weir walls. Or, the splitter mechanism may be a half tee section with a solid top and an orifice in the bottom of the tee section. Two possible design options for flow splitters are shown in Figure 4 and Figure 5.

The bypass elevation, bypass capacity, and influent pipe capacity dictate how the flow splitter will operate.

Bypass Elevation

To a large degree, the elevation of the bypass baffle or weir dictates the maximum elevation of the water in the BMP facility. Therefore, the bypass elevation must be carefully chosen. One recommended methodology is to set the bypass elevation equal to the design storage elevation in the BMP facility. Using this method, flow will only start to bypass the BMP once the inflow pipe has conveyed the design runoff volume. Although this ensures that the design volume will be captured, it also means that the water level in the BMP may exceed the design level for large infrequent storms that utilize the bypass. The larger events may result in additional height in the BMP pond. See Figure 1, Stage 3.

Bypass Capacity

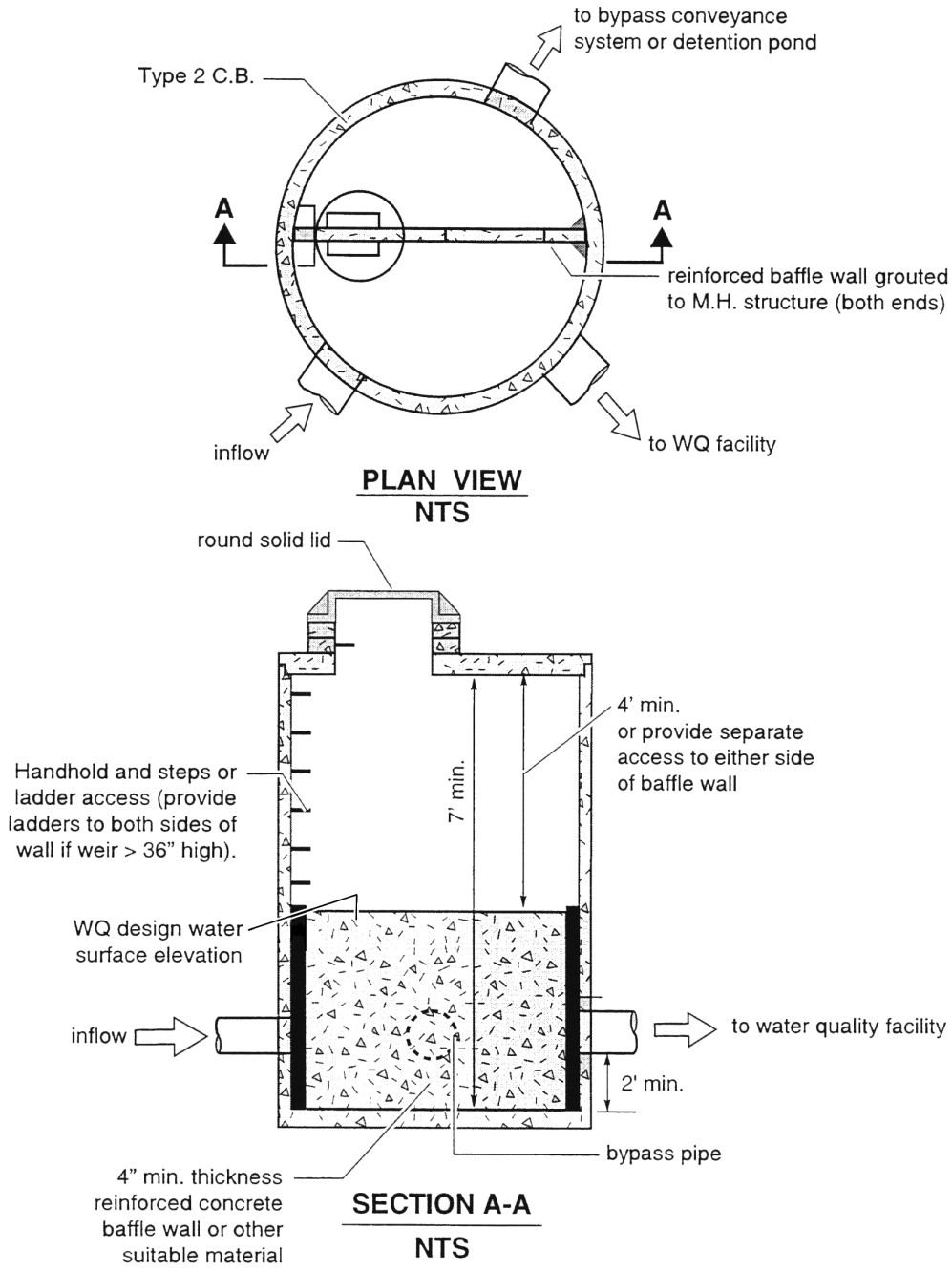
Given that the bypass elevation is set equal to the design storage elevation in the BMP facility, the maximum elevation in the facility depends on the rate of bypass. And, the rate of bypass varies with depth. For example, it would be ideal (from a hydraulic perspective) to have a long bypass weir, such that a small depth increment resulted in a large flow (and very little increase in water elevation in the BMP). However, long weirs result in large flow splitter structures, which are expensive. Therefore, an optimum balance between BMP water level increase and bypass design should be sought, recognizing that the increase in storage depth due to a flow splitter is not prolonged.

Influent Pipe Capacity

The capacity of the influent pipe into the BMP facility determines when a bypass occurs for intense storms, and it adds to the head loss between the bypass and the pond (this determines the hydraulic potential into the pond once the bypass begins to operate). The design of the influent pipe depends on the intensity of the design storm that defines the capacity of the BMP facility. The size of the influent pipe should be chosen in accordance with the design storm event.

* *This mention does not constitute an endorsement of product.*

Flow Splitters

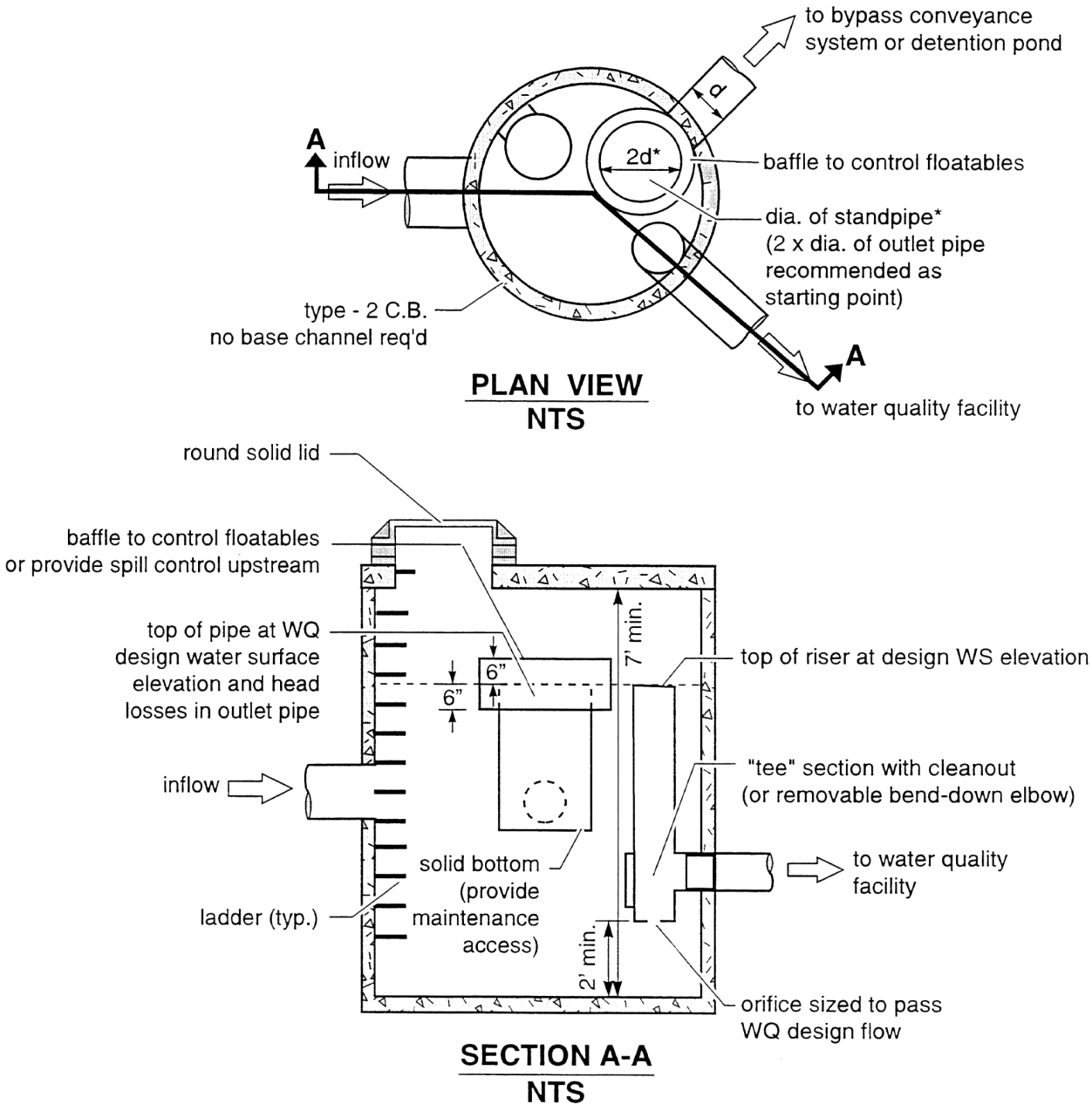


Note: The water quality discharge pipe may require an orifice plate be installed on the outlet to control the height of the design water surface (weir height). The design water surface should be set to provide a minimun headwater/diameter ratio of 2.0 on the outlet pipe.

Figure 4: Flow Splitter, Option A

Source: King County Department of Natural Resources. 1998

Flow Splitters



* **NOTE:** Diameter (d) of standpipe should be large enough to minimize head above WQ design WS and to keep WQ design flows from increasing more than 10% during 100-year flows.

Figure 5: Flow Splitter, Option B

Source: King County Department of Natural Resources. 1998

Flow Splitters

Requirements Design (continued)

Other Considerations

- The operation of the bypass must be assessed for the design event used to size the upstream pipe network. This event will vary from municipality to municipality (2 year, 5 year, 10 year storm). In some cases, the upstream pipe network may even convey the 100 year storm event. In all cases, the splitter operation during the upstream pipe design event must be assessed.
- Special applications, such as roads, may require the use of a modified flow splitter. The baffle wall may be fitted with a notch and adjustable weir plate to proportion runoff volumes other than high flows.
- The baffle wall must be made of reinforced concrete or another suitable material resistant to corrosion, and have a minimum 4-inch thickness. The minimum clearance between the top of the baffle wall and the bottom of the manhole cover must be 4 feet; otherwise, dual access points should be provided.
- All metal parts should be corrosion resistant. Examples of preferred materials include aluminum, stainless steel, and plastic. Zinc and galvanized materials are discouraged because of aquatic toxicity. Painted metal parts should not be used because of poor longevity.

Sources

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Proprietary Flow Control Devices

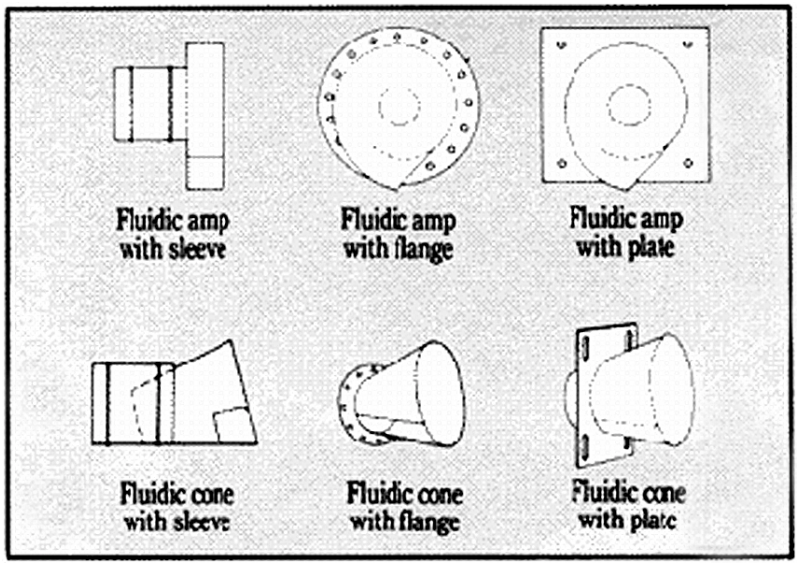


Figure 1: Hydro-Brake™

Description

Hydro-Brakes™ and Reg-U-Flow™

Hydro-Brakes™ and Reg-U-Flow™ (manufactured by Vortechnics, Inc. and H.I.L. Technology, respectively) are stainless steel vortex valves used to reduce the flow rate of water through stormwater structures or combined sewer systems.* (See diagram above.) This outlet design essentially acts as an orifice, restricting the flows leaving a pond or storm sewer. The Hydro-Brake design is shown above in Figure 1. The Reg-U-Flow design is shown in Figure 2.

The design of these devices is simple, consisting of an intake, a volute and an outlet. Flow is directed tangentially into a volute to form a vortex. High peripheral velocities induce an air-filled core with a resulting back pressure that reduces the discharge. According their manufacturers, these designs (as opposed to a regular orifice outlet) minimize clogging, because the velocity of the water caught in this vortex pattern is so high that most debris is pulled through the opening under high force. This can be a useful feature when retrofitting a clog-prone standpipe outlet.

System Features

- Clog resistance
- At the same flow rate, they provide openings up to four times larger than non-vortexing "plug flow" regulators

Purpose

Water Quantity

Flow attenuation	■
Runoff volume reduction	□

Water Quality

Pollution prevention	
Pollutant removal	N/A

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

* *Mention of these products does not constitute an endorsement.*

Proprietary Flow Control Devices

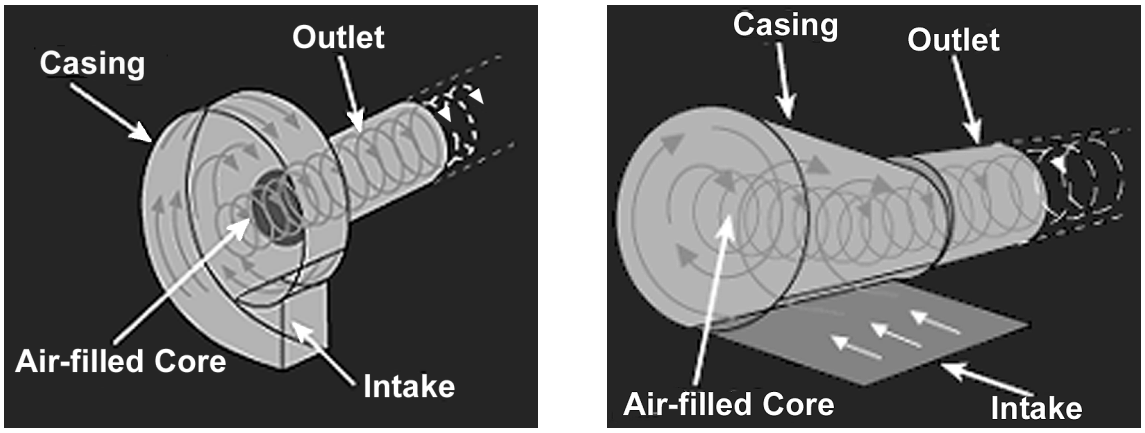


Figure 2: Reg-U-Flow™

Sources

1. H.I.L. Technology, Inc. 94 Hutchins Dr. Portland, ME 04102. www.hil-tech.com
2. Vortechnics, Inc. 41 Evergreen Drive. Portland, ME 04103. www.vortechnics.com

Chapter 4
Regulation of Water Quality

This chapter explains how federal and state water quality rules affect water quality management decisions. References to applicable regulations are also provided.

Municipalities and WMOs are encouraged to adapt this manual by inserting their own requirements following federal and state regulations. This will allow the manual to be a stand-alone document suited to the varying needs of each community.

Federal Regulations

Federal regulations regarding surface water management date back to the 1956 Federal Water Pollution Control Act. In 1972, amendments to this Act were passed by Congress; collectively these amendments became known as the Clean Water Act (CWA), which was to be administered by the U.S. Environmental Protection Agency (EPA). The National Pollutant Discharge Elimination System (NPDES) regulations were originally part of the CWA, then further developed in the CWA amendments of 1987.

Early efforts at water pollution prevention focused on reducing pollutants emanating from industrial facilities and municipal wastewater treatment plants. Over time, however, it became evident that more diffuse ("nonpoint") sources of water pollution were significantly affecting water quality. In 1990, the EPA promulgated rules establishing Phase I of the NPDES stormwater program. Among other pollutant discharges, the Phase I program addresses discharges from large (greater than 5 acres) construction sites. As of 2003, Phase II NPDES permits will be required for construction activities that disturb one to five acres. (See www.epa.gov/owm/sw/phase2/final.htm)

The NPDES permitting system is one of the principal means by which federal laws come to bear on local watershed decision-making. The federal government has given states the responsibility for administering NPDES permit applications. The states also administer such federal water quality programs as the Clean Watershed Partnership grants program established under Section 319 of the CWA.

CWA Section 404 (www.epa.gov/OWOW/wetlands/regs/sec404.html) addresses local activities that impinge on wetlands. Section 404 permits are granted by the U.S. Army Corps of Engineers.

State Participation

Administration of Federal Programs

The state, through the Minnesota Pollution Control Agency (MPCA), administers the federal NPDES permitting program on behalf of the federal government. The MPCA's NPDES permitting program is detailed at www.pca.state.mn.us/water/stormwater.html.

The MPCA also administers the federal the Clean Watershed Partnership grants program on behalf of the EPA (see www.pca.state.mn.us/water/cwpartner.html). It has an advisory role in the Corps of Engineers' Section 404 wetland permitting process.

Minnesota Water Quality Law

State laws and rules guiding water quality management operate in tandem with federal regulations. Minnesota regulations aim to protect all waters from significant degradation via point- and nonpoint-source pollutants and wetland alterations, to maintain existing water uses aquatic and wetland habitats, and the level of water quality necessary to protect these uses. The intent of the state is to protect and maintain surface waters in a condition

which allows for the maintenance of all existing beneficial uses. The water body's physical, chemical, and biological qualities determine its condition.

The main body of Minnesota state water law is found within the 10 chapters of state statutes 103A to 103G (see www.revisor.leg.state.mn.us/stats/103A.html). These statutes regulate activities that may affect surface water and wetlands in the state.

Some of Minnesota's authority is retained within state agencies. The Minnesota Department of Natural Resources (DNR), for example, carries out the Protected Waters Permit Program controlling activities affecting certain lakes, watercourses and wetlands in Minnesota. Some activities often requiring permits under the program include draining, filling, dredging, channelizing, and placement of culverts.

However, much of the state's regulatory authority is delegated to local entities – counties, cities, and WMOs. Minnesota statutes provide a mandate for the creation of WMOs and give those entities authority to create and enforce rules to regulate, conserve, and control the use of water resources. The Board of Soil and Water Resources (BWSR) plays a key role in overseeing these local efforts on behalf of the state.

The BWSR administers Minnesota's Metropolitan Surface Water Management Act, which calls for the metropolitan cities and WMOs to establish (and conduct periodic revisions of) local Surface Water Management Plans.

Minnesota has also authorized the formation of Soil and Water Conservation Districts (SWCDs, usually based on county lines) that work to encourage sound watershed management. The SWCD's primary function is to offer technical and financial assistance in conservation efforts. SWCDs operate in close association with both federal agencies (for example, the U.S. Department of Agriculture's Natural Resources Conservation Service), and with Minnesota's BWSR.

Paralleling wetland preservation efforts by the federal government, the state legislature passed the Minnesota Wetland Conservation Act (WCA) in 1991. The BWSR administers Minnesota's WCA, evaluating permit applications for activities that affect wetlands. A concise and helpful summary of state and federal wetland regulatory issues can be found at www.greatplains.org/resource/1998/wetregmn/wetregmn.htm#wetland.

Further information regarding BWSR and its management of state water quality programs may be found on the web at www.bwsr.state.mn.us.

The Role of Local Agencies

Where they exist, WMOs govern surface water management through rules established as part of their Surface Water Management Plans. In most cases, cities also have their own water management plans, which must be approved by the local WMO. If necessary, BWSR helps resolve any conflicts between the municipal and WMO plans.

In the Twin Cities metropolitan area, the Metropolitan Council is also charged with overseeing water management and improvement efforts, and has developed its own regional water quality management plan. The Environmental Services (ES) division of the council reviews municipal and WMO water management plans for consistency with the regional plan.

Local municipalities and WMOs also play a role in the administration of the state's WCA and they may have their own ordinances governing activities in and around wetlands.

When planning a development or redevelopment project, it is best to contact a representative of the local

municipality or WMO early in the process. These representatives can provide information on applicable watershed regulations and permits required before construction can proceed. In addition, local administrators may be able to assist in the selection of BMPs that make the most sense for a particular site.

A locator map at the Minnesota Association of Watershed Districts website is helpful in determining if a particular location has an established watershed district: http://www.mnwatershed.org/whereis.htm.

Appendix A
Local Regulations

Information and contacts for local water management regulations are displayed and/or referenced below. If this section of the BMP manual has been left blank, consult your local municipality for regulatory information.

City of Minneapolis

Contacts

Engineering and Design

Jodi Polzin, Engineer III
Public Works, Engineering Services
309 Second Avenue South, Room 300
Minneapolis, MN 55401
612-673-3626

Erosion Control, Stormwater Management, Storm and Sanitary Sewers, Site Plan Review

Paul Chellsen, Engineering Technician III
Public Works, Engineering Services
309 Second Avenue South, Room 300
Minneapolis, MN 55401
612-673-2406
paul.chellsen@ci.minneapolis.mn.us

Erosion Control for Single Family Homes and Demolitions, Environmental Inspections

Roger Van Tassel, Environmental Inspector
Minneapolis Environmental Management
250 South Fourth Street, Room 401
Minneapolis, Minnesota 55415
612-673-5816

Utility Excavations, Sewer and Water Connection Permits

Richard Insellman, Chief of Utility Inspections
Minneapolis Public Works Engineering Services 250 South Fourth Street, Room 222
Minneapolis, Minnesota 55415
612-673-2451

Site Plan Review, Zoning Code

Andy Carlson, Zoning Inspector II
Department of Regulatory Services
250 South Fourth Street, Room 300
Minneapolis, Minnesota 55415
612-673-2498

Storm and Sanitary Sewer As-Builts, Watershed and Flood Plain Designations

Robbin Sorensen, Engineering Technician
Public Works, Engineering Services
309 Second Avenue South, Room 300
Minneapolis, MN 55401
612-673-3630 or 612-673-2405
robbin.sorensen@ci.minneapolis.mn.us

Stormwater BMP Registrations, Permits and Inspections

Tom Frame, Environmental Inspector
Minneapolis Environmental Management
250 South Fourth Street, Room 401
Minneapolis, Minnesota 55415
612-673-5807

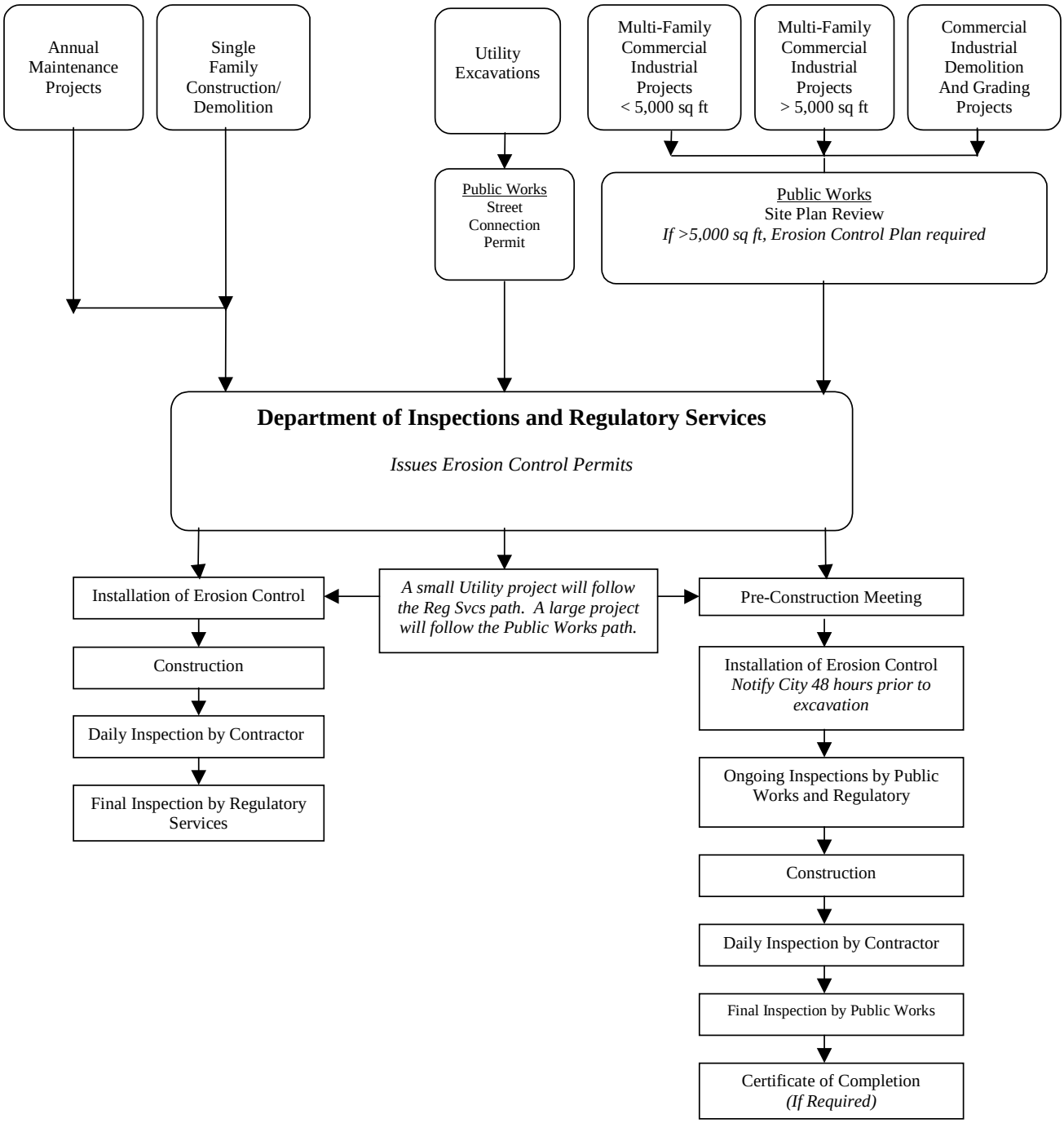
Inspections Division of Regulatory Services Permit Counter

Minneapolis Public Service Center
250 South Fourth Street, Room 300
Minneapolis, Minnesota 55415
612-673-5800

Erosion Control Summary

- ORDINANCE: On May 16, 1996 the Minneapolis City Council amended Title 3 of the Minneapolis Code of Ordinances relating to Air Pollution and Environmental Protection by adding Chapter 52 entitled "Erosion and Sediment Control for Land Disturbance Activities. This Ordinance regulates *everyone* who disturbs topsoil and is designed to insure that soil does not leave the excavation site or enter any storm drain system on either private property or the public right of way.
- REQUIREMENTS: All sites disturbing topsoil are subject to erosion control compliance under the ordinance. Sites disturbing more than five cubic yards or 500 square feet of topsoil including utility excavations and any residential or commercial demolition projects need an erosion control permit prior to commencement of work. Demolition and construction sites greater 5,000 square feet require an approved erosion control plan prior to a permit being issued for the site.
- REVIEW: Erosion control plans are required and for all projects going through the City of Minneapolis' Site Plan review Process. Construction or Demolition Sites over 5,000 square feet not involved in this process are reviewed and approved by Engineering Services.
- ENFORCEMENT: Ongoing site inspections are by done by Public Works and Regulatory Inspectors. Violation of the Ordinance is a Misdemeanor, which holds a maximum penalty of $700 and/or ninety days in jail. Inspectors finding sites in violation of the ordinance may issue a warning notice, citation or a "Stop Work Order" to the permitee. Furthermore failure of the permittee to comply with the ordinance will constitute a violation pursuant to Section 52.300, and will be considered a nuisance pursuant to Laws of Minnesota for 1994, Chapter 587, Article 9, Section 4. The issuing authority may cancel the permit and proceed with the necessary restoration of the site at the expense of the owner.
- For the complete text of the Minneapolis Erosion Control Ordinance, fee schedule and related information see the Minneapolis Public Works Engineering Services website: www.ci.minneapolis.mn.us/citywork/public-works/eng-design

Erosion Control Permitting Process



Stormwater Management Summary

- ORDINANCE: On November 24, 1999 the Minneapolis City Council amended Title 3 of the Minneapolis Code of Ordinances relating to Air Pollution and Environmental Protection by adding Chapter 54 entitled "Stormwater Management". Chapter 54 establishes requirements for land disturbing activities on sites greater than one (1) acre; including phased or connected actions and for existing storm water constructed devices.
- PLAN REVIEW: Stormwater Management plans are required for all construction projects greater than 1 acre in size. These plans are reviewed through the "Public Works Site Plan Review" process.
- REGISTRATION: Stormwater devices will be registered with the City of Minneapolis Department of Regulatory Services, with an annual permit being required for each Stormwater device registered.
- GOALS: The Minneapolis Storm Water Ordinance specifies that stormwater management standards be set according to the receiving water body. These standards include but are not limited to:
  - Reductions of suspended solids for Mississippi River discharges.
  - Controlled rate of runoff for discharges to streams, areas prone to flooding and areas with infrastructure limitations.
  - A reduction in nutrients for storm water discharging to lakes and wetlands.
- STORMWATER "BUY OUT": This option is only reserved for those sites that can demonstrate they do not have sufficient space for stormwater treatment structures. Therefore, with approval of the City Engineer the ordinance allows developers to contribute to the construction of a regional storm water facility in lieu of on-site treatment. The fee for contribution to a regional facility in lieu of onsite treatment is established at $15,000 for January 1 to December 31, 2001. Final Plan approval is conditional on payment received.
- For the complete text of the "*Minneapolis Stormwater Ordinance,*" requirements and related information see the Minneapolis Public Works Engineering Services website http://www.ci.minneapolis.mn.us/citywork/public-works/eng-design

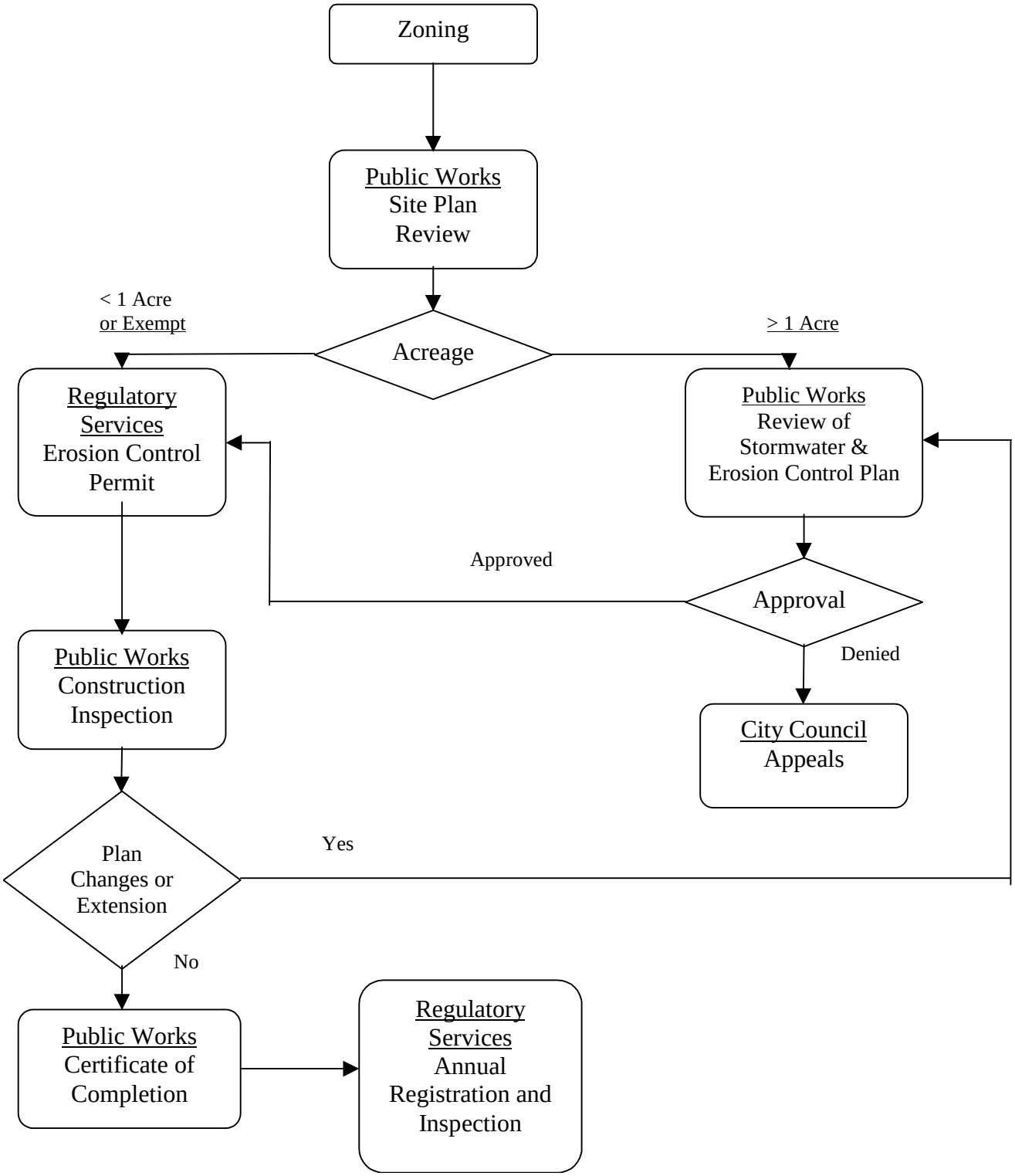
Stormwater Load Reduction Requirements

Receiving Waters	Total Discharge Requirements
All receiving waters	70% removal of total suspended solids
Brownie Lake	10% phosphorus load reduction
Cedar Lake	40% phosphorus load reduction
Lake of the Isles	20% phosphorus load reduction
Lake Calhoun	30% phosphorus load reduction
Lake Harriet	20% phosphorus load reduction
Powderhorn Lake	30% phosphorus load reduction
Lake Hiawatha	42% phosphorus load reduction
Lake Nokomis	25% phosphorus load reduction
Loring Park Pond	0% phosphorus load increase
Webber Pond	0% phosphorus load increase
Wirth Lake*	30% phosphorus load reduction
Spring Lake	30% phosphorus load reduction
Crystal Lake**	30% phosphorus load reduction
Diamond Lake	30% phosphorus load reduction
Grass Lake	30% phosphorus load reduction
Birch Pond	0% phosphorus load increase
Ryan Lake	30% phosphorus load reduction
Other wetlands	30% phosphorus load reduction
Mississippi River	70% removal of total suspended solids
Minneapolis streams	No increase in rate of runoff from site

* Wirth Lake is not within the city limits of Minneapolis.

** Crystal Lake is in Robbinsdale but receives runoff from Minneapolis.

Construction Plan Approval Process



Minnehaha Creek Watershed District

Contact

Jim Hafner
Minnehaha Creek Watershed District
Gray Freshwater Center, Navarre
2500 Shadywood Road, Suite 149
Excelsior, MN 55331
952-471-0590 • Fax: 952-471-0682
Jhafner@minnehahacreek.org

Web Resources

General information regarding the District's rules and permits can be found at the Minnehaha Creek Watershed District website at www.minnehahacreek.org/f-Permits.htm.

The complete text of the rules is available in PDF format at www.minnehahacreek.org/Permit_Rules/rules-5-25-00.PDF. The District's Combined Joint Notification Water Resources Application Form is also available at the District's website: www.minnehahacreek.org/Permits/apply.pdf.

Summary Information

The Minnehaha Creek Watershed District Rules were last amended May 25, 2000. These rules seek to protect the public health and welfare and the natural resources of the District by providing reasonable regulation of the modification or alteration of lands and waters of the District:

- to reduce the severity and frequency of flooding and high water
- to preserve floodplain and wetland storage capacity
- to improve the chemical and physical quality of surface water
- to reduce sedimentation, to preserve hydrologic and navigational capacity of water bodies
- to preserve natural shoreland features
- to minimize public expenditures to avoid or correct such problems in the future

General Rules Policy Statement

Under the Watershed Act, the Minnehaha Creek Watershed District exercises a series of powers to accomplish its statutory purposes. The legislature has recognized the public need to conserve natural resources through land utilization and flood control based upon sound scientific principles.

Land alteration affects the rate, volume, and quality of surface water runoff, which ultimately must be accommodated by the existing surface water systems within the District. The watershed is large, 180 square miles, and its outlet, Minnehaha Creek, has limited capacity to carry flows. Flooding problems already occur in the urbanized areas of the District along Minnehaha Creek, and on Lake Minnetonka shoreland.

Land alteration and utilization also can degrade the quality of runoff entering the streams and water bodies of the District due to nonpoint source pollution. Sedimentation in lakes and streams from ongoing erosion pro-

cesses and construction activities reduces the hydraulic capacity of water bodies and degrades water quality. Water quality problems already exist in many of the lakes and streams throughout the District.

Projects that increase the rate of stormwater runoff can aggravate existing flooding problems and contribute to new ones. Projects that degrade runoff quality can aggravate existing water quality problems and contribute to new ones. Projects which fill floodplain or wetland areas can aggravate existing flooding by reducing flood storage and hydraulic capacity of water bodies, and can degrade water quality by eliminating the filtering capacity of such areas. Dredging projects can also degrade water quality and eliminate the natural appearance of shoreland areas.

City of St. Paul

Contact

Anne Weber, St. Paul Public Works
25 West 4th St., #700
St. Paul, MN 55102
651-266-6245
anne.weber@ci.stpaul.mn.us

Summary Information

Erosion Control

All projects disturbing over 10,000 square feet and going through the city's site plan review process, must follow the Ramsey County Soil and Water Conservation District (SWCD) Soil and Erosion Control Handbook requirements.

Runoff Rate Control

All projects over one-quarter (1/4) acre going through the city's site plan review process, cannot release water in excess of 1.64 cubic feet per second (cfs) per acre of site area.

Rice Creek Watershed District

Contact

Kate Drewry, District Administrator
3585 N. Lexington Ave., #330
Arden Hills, 55126-8056
651-766-4193 • Fax 651-766-4196
kate.drewry@state.mn.us

The contents of the Rice Creek rules follow. The complete text is available on the watershed's web site: www.mnwatershed.org/ricecreekrules.htm

Rules Table of Contents

General Policy Statement

Relationship of Rice Creek Watershed District to Municipalities

Rule A: Definitions

Rule B: Procedural Requirements

1. Application Required
2. Forms
3. Action by Board of Managers
4. Issuance of Permits
5. Permit Term
6. Permit Assignment
7. Permit Fees
8. Performance Surety
9. Other Permits and Approvals.

Rule C: Stormwater Management

1. Policy.
2. Regulation.
3. Design Criteria for Stormwater Management Plans.
4. Required Exhibits.
5. Platting or Easement Documents.
6. Exceptions.

Rule D: Erosion Control Plans

1. Policy.
2. Regulation.
3. Design Criteria for Erosion Control Plans.
4. Required Exhibits.
5. Exceptions.

Rule E: Floodplain Alteration

1. Policy.
2. Regulation.
3. Criteria for Floodplain Alteration.
4. Drainage Easements.
5. Required Exhibits.

Rule F: Wetland Alteration

1. Policy.
2. Regulation.
3. Criteria.
4. Local Government Unit.
5. Required Exhibits.
6. Exceptions.

Rule G: Bridges and Culvert Crossings

1. Policy.
2. Regulation.
3. Criteria.
4. Required Exhibits.
5. Exceptions.

Rule H: Shoreland Development

1. Policy.
2. Regulation.
3. Criteria.
4. Required Exhibits.
5. Exceptions.

Six Cities Watershed Management Organization

The Six Cities Watershed Management Organization (SCWMO) is located in southern Anoka County adjacent to the Mississippi river and covers approximately 21 square miles. The member cities of Blaine, Columbia Heights, Coon Rapids, Fridley, Hilltop, and Spring Lake Park are wholly or partially included within the legal boundary.

The member cities of the SCWMO have each enacted local plans for development plan review and storm water control with guidance from the SCWMO Watershed Management Plan. Please contact the individual City for specific policies and rules associated with development in that community.

Contacts

City of Blaine

Chuck Lenthe, Chair
Public Works Coordinator/City Engineer
9150 Central Avenue NE
Blaine, MN 55434
(763) 785-6188 • FAX: (763) 785-6139
clenthe@ci.blaine.mn.us

City of Fridley

Jon Haukaas, Secretary
Director of Public Works
6431 University Avenue NE
Fridley, MN 55432
(763) 572-3550 • FAX: (763) 571-1287
haukaasj@ci.fridley.mn.us

City of Columbia Heights

Kevin Hansen, Treasurer
Director of Public Works
590 – 40th Avenue NE
Columbia Heights, MN 55421
(763) 706-3705 • FAX: (763) 706-3701
Kevin.Hansen@ci.columbia-heights.mn.us

City of Hilltop

Peter Molinaro – Pioneer Engineering
2422 Enterprise Drive
Mendota Heights, MN 55120
pmolinaro@pioneereng.com
(651) 681-1914 • FAX: (651) 681-9488

City of Coon Rapids

Steve Gatlin, Vice Chair
Public Works
11155 Robinson Drive NW
Coon Rapids, MN 55433-3761
(763) 767-6458
gatlin@ci.coon-rapids.mn.us

City of Spring Lake Park

Joe Rhein – Bonestroo & Assoc
2355 West TH 36
St. Paul, MN 55113
(651) 604-4803 • FAX: (651) 636-1311
jrhein@bonestroo.com

Appendix B
Local Examples of BMPs

Designers, developers, planners and regulators may find it useful to observe operational BMPs described in this manual. To that end, a listing of example BMPs within the Twin Cities metropolitan area is offered here. Location and contacts are included wherever possible, so in addition to visiting the site, users may discuss the installation with someone knowledge of the site.

Examples are provided for only some of the 40 BMPs described in this manual. The omissions are intentional; data was not collected for Housekeeping BMPs (for example, pavement management or landscape maintenance). Nor are examples given for those BMPs that are installed only temporarily, then removed when construction is complete.

Runoff Pollution Prevention

Impervious Surface Reduction

Cul-de-Sacs

Location: 15th Street North, east of Inwood Avenue, Lake Elmo
Contact: Tom Prew, City Engineer, Lake Elmo • 651-292-4400
Notes: Proposed summer 2001–conversion of a round cul-de-sac to a T-shaped turnaround

Location: 15th Street North, east of Inwood Avenue, Eagan
Contact: Planning and Zoning Department, City of Eagan • 651-681-4685

Location: St. Francis Woods, Falcon Way and Duckwood Trail, Eagan
Contact: Planning and Zoning Department, City of Eagan • 651-681-4686

Parking Lot Design

Location: H.B. Fuller Corporation, 3210 Labore Rd., Vadnais Heights (southeasr corner of Labore Road and Wolters Blvd.)
Contact: Dana Larsen Ramsay, H.B. Fuller Corp. • 651-236-4554
Notes: Please make appointment with Dana before entering the campus. Alternate contact: Rob Langer Ramsey Washington Metro Watershed District • 651-704-2089.

Location: Shepherd of the Valley Lutheran Church, Hudson Road South about a mile west of Stagecoach Trail, Afton
Contact: Afton City Hall • 651-436-5090
Notes: Proposed 2001–parking lot with islands and infiltration basins

Turf Pavers, Soil Reinforcement

Location: University of Minnesota St. Paul Campus, Intersection of Hoyt Avenue and Flandrau Street, St. Paul
Contact Pat Byrne, City of St. Paul • 651-266-6171
Notes: Flood remediation, erosion protection (Paramat)

Location: Parking area, Lake Harriet Rose Gardens, Dupont and West 42nd Streets, Minneapolis
Contact: Jeff Lee, Minneapolis Park and Recreation Board • 612-370-4900
Notes: Summer turf parking

Location: Tamarack Swamp Water Quality Ponds, immediately north of Wood Park Boulevard and 2 blocks east of Tower Drive, Woodbury
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Street Design

Location: Stonebridge of Lilydale, northwest quadrant of Trunk Highway 13 and I-35E, Lilydale
Contact: Mike Rancone, Rancone Development Co. • 651-688-9689
Notes: Narrow streets, shared parking and bumpout parking

Location: Birmingham and Ripley Streets south of Frost Avenue, Maplewood
Contact: Chris Cavett, City of Maplewood • 651-770-4550
Notes: Curbless, gutterless streets allow runoff to flow into rainwater gardens located in rights-of-way.

Location: Century and Harvester Avenues, Maplewood
Contact: Chris Cavett, City of Maplewood • 651-770-4551
Notes: Curbless, gutterless streets allow runoff to flow into rainwater gardens located in rights-of-way.

Location: 50th Street North west of Highway 5, Lake Elmo
Contact: Tom Prew, City Engineer, Lake Elmo • 651-292-4400
Notes: Construction scheduled for 2001

Location: Fields of St Croix residential development, Highway 5 north of Manning Avenue and the Wash ington County Fairgrounds, Lake Elmo
Contact: Tom Prew, City Engineer, Lake Elmo • 651-292-4400
Notes: Narrow streets and median strips.

Green Rooftops

Location: Phillips Eco-Enterprise Center, 2801 21st Ave. S. (one block north of Lake Street off Highway 55), Minneapolis
Contact: Jonathon Sage-Martinson, The Green Institute • 612-278-7120

Housekeeping

Animal Management

Location: Loring Park, Hennepin Avenue and Vineland Place, Minneapolis
Contact: Jeff Lee, Minneapolis Park and Recreation Board • 612-370-4900
Notes: Buffer strip around pond for goose control.

Stormwater Treatment BMPs

Infiltration Systems

On-Lot Infiltration

Location: Riverwood development, Hastings: (1) south of Intersection of Vista Drive and Vista Court, (2) west of intersection of Village Trail and South Point Drive, (3) east of Intersection of South Point Drive and Vista Trail, (4) east of intersection of South Point Drive and South Point Court. Remainder of infiltration ponds are scattered around the development,
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Location: Kwanzaa Community Fellowship, 2100 Emerson Ave. N., Minneapolis
Contact: Sarah Wash, Environmental Organizer, Hawthorne Area Community Council • 612-529-6033 or Carmen Simonet, Barr Engineering • 952-832-2718.
Notes: Rainwater garden for infiltration function and amenity

Location: Birmingham and Ripley Streets, south of Frost Avenue, Maplewood
Contact: Chris Cavett, City of Maplewood • 651-770-4550
Notes: Lushly planted rainwater gardens in sandy soils

Location: Saint Mary's Greek Orthodox Church, 3450 Irving Avenue South, Minneapolis
Contact: Paul Chellsen, Minneapolis Public Works • 612-673-2406
Notes: Parking lot and building addition required removal of suspended solids and rate control.

Infiltration Basins

Location: Intersection of Lexington Ave. and Nebraska Street, St. Paul
Contact: District 10, Como Park, Environment Committee • 651-644-3889
Notes: Difficulty establishing vegetation because contractor applied excessive mulch. This caused a nitrogen deficiency and lack of plant growth.

Location: Swede Hollow Café, 7th Street East and Bates Avenue, St. Paul
Contact: Upper Swede Hollow Neighborhood Association • 651-771-2659
Notes: Accepts water from a portion of street and roof. Extensive removal and replacement of compacted soil was necessary because the garden was built where a section of street had been removed.

Location: Quarry Ridge Development, northeast of Radio Drive and Afton Road, Woodbury
Contact: Steve Kernik, City of Woodbury • 651-714-3533
Location: County Ditch P85, West of County Road 19, Woodbury
Contact: Matt Moore, South Washington Watershed District • 651-714-3729
Notes: Large infiltration basin for pumped water

Infiltration Trenches

Location: Lexus of Maplewood, 3000 N. Hwy. 61, Maplewood
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Kline Volvo, Highway 61, 1/2 mile north of Beam Avenue, Maplewood
Contact: Rob Langer, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: RWMWD is monitoring this site.

Location: County Ditch P85, Woodbury
Contact: Matt Moore, South Washington Watershed District • 651-714-3729
Notes: Two installed trenches in bottom of larger basin

Filtration

Surface Sand Filters

Location: Denny's Restaurant, east ditch along Century Avenue, 1/4 mile north of I-94, Oakdale
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Underground Filters

Location: Tamarack Ponds, south end of Tamarack Nature Preserve: (1) Wood Park Boulevard and Tower Drive, (2) Wood Park Boulevard and Evergreen, Woodbury
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Bioretention

Location: Southeast corner of Early Lake, Burnsville
Contact: Pulte Homes • 651-452-5200

Location: Kwanzaa Community Fellowship, 2100 Emerson Ave. N., Minneapolis
Contact: Sarah Wash, Environmental Organizer, Hawthorne Area Community Council • 612-529-6033 or Carmen Simonet, Barr Engineering • 952-832-2718.
Notes: Rainwater gardens

Location: Bryant Avenue just north of Highway 55, Minneapolis
Contact: Lois Eberhart, City of Minneapolis • 612-673-3260
Notes: Intended to be a demo site, for Mississippi River protection.

Location: Silver Lake, Lake Boulevard and 19th Avenue, North St. Paul
Contact: Greg Wilson, Lower St. Croix Valley Watershed District • 952-832-2672

Location: Near North Side Redevelopment Project, north of Olson Memorial Highway, from Lyndale Avenue to Fremont, Minneapolis
Contact: Lois Eberhart, Near North Side Redevelopment, City of Minneapolis • 612-673-3260
Notes: First large redevelopment project required to meet city stormwater requirements

Constructed Wetlands

Stormwater Wetlands

Location: Carlton College Arboretum, Highway 19, Northfield
Contact: Mark McKone, Carleton College • 507-646-4393

Location: Target Store pond, Trunk Highway 36 at McKnight Road, North St. Paul
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Kohlman Basin, southeast of Beam Avenue and Highway 61, Maplewood
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Tanners Lake wetland, northwest of 7th Street and Gershwin Avenue North, Oakdale
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: McCarron's wetland treatment system, Roseville
Contact: Duane Schwartz, City of Roseville • 651-490-2311 or Gary Oberts, Metropolitan Council • 651-602-1079
Notes: Detention ponds followed by series of small wetland chambers

Wet Swales

Location: Carver Ravine ponds, West of Intersection of Jordan Dr and Buckingham Road, Woodbury
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

BMPs in Series

Location: Plymouth Boulevard and 34th Avenue, Plymouth
Contact: Ron Quanbeck, City of Plymouth • 763-509-5525
Notes: Multiple cell basin.

Location: North of Tanners Lake: (1) south of intersection of Minnehaha and Century Avenues and (2) north of Intersection of Century Avenue and 7th Street, Oakdale
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: Alum treatment, followed by wetland, sediment basin and weirs.

Location: McCarron's wetland treatment system, Roseville
Contact: Duane Schwartz, City of Roseville • 651-490-2311 or Gary Oberts, Metropolitan Council • 651-602-1079
Notes: Detention ponds followed by series of small wetland chambers

Location: Lake Calhoun, southwest side, near Xerxes and Lake Calhoun Blvd., Minneapolis.
Contact: Mike Panzer, Wenck Associates • 763-479-4200

Retention Systems

Wet Ponds

Location: Gervais Mill Pond - Edgerton Street, 1/4 mile north of Little Canada Road, Little Canada
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: Large site

Location: Tanners Lake Park, east side of lake, Grafton Location:Avenue and 2nd Street North, Oakdale
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: Smaller site

Location: Carver Ravine, south of Lake Road on east side of Jordan Drive, Woodbury
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: Smaller site

Location: Schaper Park Pond, north side of Trunk Hwy 55, East of Trunk Hwy 100, Golden Valley
Contact: Jeff Oliver, City of Golden Valley • 763-593-8034
Notes: Pond removes nutrients so they do not enter Sweeney Lake

Location: Beam Avenue Pond, one block south of Beam Avenue and Hazelwood Road, Maplewood
Contact: Chris Cavett, City of Maplewood • 651-770-4550

Location: McKnight Basin, east of Larry Ho Drive and McKnight Road, Maplewood
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Bredeson Park, Vernon Avenue and Olinger Boulvard, Edina
Contact: Bob Obermeyer, Nine Mile Creek Watershed District & City of Edina • 612-832-2857

Location: Normandale Lake, southwest of Highway 100 and 82nd Street, Bloomington
Contact: Bob Obermeyer, Nine Mile Creek Watershed District • 612-832-2857

Extended Storage Ponds

Location: Hastings Industrial Park, one block southeast of intersection of Spiral Boulevard and Enterprise Avenue, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Location: Summit Point Development, one block east of intersection of 4th Street and General Sieben Drive, north side of 4th Street, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Location: Carver Ravine, south of Lake Road on northwest side of Jordan Drive, Woodbury
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Detention Systems

Dry Ponds

Location: Intersection of Hoyt Avenue and Flandrau Street, St.Paul
Contact: Pat Byrne, City of St. Paul • 651-266-6171

Location: Hazel Street and Bush Avenue, St. Paul
Contact: Karl Johnson • 651-266-6256

Location: 14th Street basin, 14th Street and Tierney Drive, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Location: 20th St. Basin, 20th St and Pleasant Dr., Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Location: Conzemius Park, Park Lane and Bahls Drive, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Location: Northwest ponding basin, northeast of intersection of West View Drive and Pleasant Drive, Hastings
Contact: Tom Montgomery,City of Hastings • 651-437-4127

Location: Pine Tree Ponds subdivision, Cottage Grove
Contact: City of Cottage Grove • 651-458-2825
Notes: Series of dry ponds throughout 1970s development by Orrin Thompson.

Location: Marigold Foods, 4th Street and 21st Avenue North, Minneapolis
Contact: Paul Chellsen, Minneapolis Public Works • 612-673-2406
Notes: Dry pond constructed for treating of runoff from new parking lot.

Oversized Pipes

Location: 14th Street Basin, 2 Blocks South of intersection of General Sieben Drive and Hwy 55, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Oil & Grit Separators

Location: Target Store, I-94 near Lexington Avenue, St. Paul
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Twin Cities Air Force Base, Minneapolis
Contact: Robert Callery, U.S. Air Force • 612-292-4487
Notes: Example provided by Vortechnics, Inc.

Location: Hastings Industrial Park Pond, east side of pond, 1 block south of Spiral Boulevard and Enterprise Avenue, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Dry Swales

Location: Hastings Industrial Park, Spiral Boulevard and Enterprise Avenue, Hastings
Contact: Tom Montgomery, City of Hastings • 651-437-4127

Flow Control Structures

Permeable Weirs

Location: Kohlman Basin, Beam Avenue and Highway 61, Maplewood
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Tanners Lake wetland, 7th Street, 1 block east of Century Avenue, Oakdale
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Location: Lake Gervais wetland, Edgerton Street, 1/4 mile north of Little Canada Road, Little Canada
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089

Flow Splitters

Location: Intersection of Lexington Avenue and Nebraska Street, St. Paul
Contact: Dan Krivit, District 10, Como Park, Environment Committee • 651-489-4990
Notes: Infiltration basin also located here

Location: Near intersection of Century and Minnehaha Avenues, Maplewood
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: Flow splitter for Tanner's Lake alum treatment

Location: Near North Side Redevelopment Project, north of Olson Memorial Highway, from Lyndale Avenue to Fremont, Minneapolis
Contact: Lois Eberhart, Near North Side Redevelopment, City of Minneapolis • 612-673-3260
Notes: First large redevelopment project required to meet city stormwater requirements.

Proprietary Flow Control Devices

Location: Apostolic Bible Institute, I-94 and Hadley Avenue, Oakdale
Contact: Cliff Aichinger, Ramsey-Washington Metro Watershed District • 651-704-2089
Notes: To be constructed in 2001

Location: Lake Nokomis, Minneapolis
Contact: Dave Johnson, HDR Engineering • 763-479-4200
Notes: Large site offers examples of "swirl technology," grit chamber and constructed wetlands

Appendix C Model Stormwater Ordinances

Designers of stormwater management ordinances do not have to start from scratch. Many model ordinances are available to help communities implement effective runoff control. These ordinances can be used as a template for communities to customize to fit their needs.

Local Resources

The Metropolitan Council developed a model stormwater management ordinance, available on the web in both PDF and text formats: www.metrocouncil.org/environment/Watershed/model_sw_ord.pdf and www.metrocouncil.org/environment/Watershed/model_sw_ord.txt

The Minnesota Pollution Control Agency's model ordinance is aimed at controlling pollution in new developments. It is available in two formats (MS Word and PDF) on the MPCA website: www.pca.state.mn.us/water/stormwater-c.html. Look under Program Information on the lower right side of the page.

A stormwater ordinance is included in a publication by Minnesota Planning, *From Policy to Reality: Model Ordinances for Sustainable Development*. In addition, the document contains ordinances pertaining to growth management, neighborhood design, efficient building and other areas. The full publication is available on the web in PDF format: www.mnplan.state.mn.us/SDI/ordinancestoc.html.

National Web Sites

The Center for Watershed Protection (CWP, Ellicott City, Maryland) administers two thorough, easy-to-use websites on stormwater management (www.stormwatercenter.net and www.cwp.org). These sites provide text and tools to help users custom-design stormwater ordinances to suit their local communities. On either site (the information is same on both), click on the Ordinances section for a menu of categories, which include Post-Construction Runoff, Erosion and Sediment Control (ESC) and Operations and Maintenance, among others. Each category includes a model ordinance, examples of ordinances from various municipalities and explanation of the reasoning and goals of the regulations.

Also on the web, the U.S. Environmental Protection Agency Office of Water offers "Model Ordinances to Protect Local Resources," with categories similar to those at the CWP site, mentioned above. See www.epa.gov/owow/nsp/ordinance/index.htm.

Appendix D Source List

Stormwater BMP Manuals

Boise Storm Water Standards: When it Rains it Drains. Public Works Department, Boise, ID. 1999.

Developing Successful Runoff Control Programs for Urbanizing Areas: Stormwater Issues and Management Manual. Northern Virginia Soil and Water Conservation District, Fairfax, VA. July 1994.

Highway Runoff Manual. Washington State Dept. of Transportation – Environmental and Engineering Service Center. Olympia. February, 1995.

King County, Washington Surface Water Design Manual. King County Dept. of Natural Resources. Seattle. September 1998.

Maryland Stormwater Design Manual. Maryland Dept. of the Environment. Baltimore. n.d.

Pennsylvania Handbook of Best Management Practices for Developing Areas. Pennsylvania Association of Conservation Districts, Harrisburg. 1999.

Planning and Design Manual for the Control of Erosion, Sediment, and Stormwater. U.S. Department of Agriculture, Natural Resources Conservation Service and Mississippi Dept. of Environmental Quality. Washington, D.C. April 1994.

Protecting Water Quality in Urban Areas: Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban and Developing Areas of Minnesota. Minnesota Pollution Control Agency, Minneapolis. March, 2000.

Protecting Natural Wetlands: A Guide to Stormwater Best Management Practices. Office of Water, U.S. Environmental Protection Agency. Washington, D.C. 1996.

Stormwater Best Management Practices. North Carolina Department of Environment and Natural Resources – Water Quality. Raleigh. 1999.

Stormwater Management Plan. Washington State Dept. of Transportation. Olympia. March 1997.

Stormwater Management Planning and Design Manual Draft Final Report. Ministry of the Environment, Toronto, Ontario, Canada. November, 1999.

Stormwater Management in Washington State – Volume V: Runoff Treatment BMPs. Washington State Dept. of Ecology. Olympia. October 1999.

Stormwater Management. Massachusetts Dept. of Environmental Protection. Volume Two: Stormwater Technical Handbook. Boston. March, 1997.

Stormwater Quality Best Management Practices. Ministry of the Environment, Ontario, Canada. 1991

Texas Nonpoint Sourcebook. Statewide Storm Water Quality Task Force – American Public Works Association & Texas Natural Resource Conservation Commission. Austin. n.d.

The Wisconsin Stormwater Manual. Wisconsin Department of Natural Resources. Madison. 1994.

Water Related Best Management Practices in the Landscape. Center for Sustainable Design. Mississippi State University. Mississippi State, MS. 1999.

Region-Specific Stormwater BMP References Cold Climate

Best Practices for Street Sweeping. Metropolitan Council. St. Paul February 1994.

"Better Site Design" in *Quarterly Bulletin on Urban Watershed Restoration and Protection Tools.* Vol. 3.2 Center for Watershed Protection. Ellicott City, MD. 1999.

Better Site Design: A Handbook for Changing Rules in Your Community. Center for Watershed Protection. Ellicott City, MD. August 1998.

Costs of Urban Nonpoint Source Water Pollution Control Measures. Technical Report #31. Southeastern Wisconsin Regional Planning Commission. Waukesha. June, 1991.

National Stormwater BMP Database – Master BMP Bibliography Used to Develop the Database. US Environmental Protection Agency and American Society of Civil Engineers. Washington, D.C. April 1998.

Nutrient Loading and Conventional and Innovative Site Development. Center for Watershed Protection. Ellicott City, MD. 1998.

Quantity and Quality of Runoff from Selected Guttered and Unguttered Roadways in Northeastern Ramsey County, Minnesota. USGS Water Resources Investigations Report 96-4284. St. Paul 1997.

Riparian Buffer Strategies. Environmental Land Planning Document Series (ELP). Metropolitan Washington Council of Governments. Washington, D.C. 1995.

Site Planning for Urban Stream Protection. Environmental Land Planning (ELP) Series. Metropolitan Washington Council of Governments. Washington, D.C. 1995.

Stormwater BMP Design Supplement for Cold Climates. Center for Watershed Protection. Ellicott City, MD. 1997.

Storm-Water and Wetlands: Planning and Evaluation Guidelines for Addressing Potential Impacts of Urban Storm-Water and Snow-Melt Runoff on Wetlands. Storm Water Advisory Group, Minnesota Pollution Control Agency, St. Paul. 1997.

Urban Landscape as a Source of Phosphorus in Surface Waters. Metropolitan Council Environmental Services Division. St. Paul. September, 1998.

Watershed Protection Techniques. Quarterly Bulletin on Urban Watershed Restoration and Protection Tools. Volumes 1 (1994) - present. Center for Watershed Protection, Ellicott City, MD.

BMP Performance and Performance Enhancement

Development of Performance Measures: Task 3.1 – Technical Memorandums: Determining Urban Stormwater BMP Removal Efficiencies. U.S. Environmental Protection Agency and the American Society of Civil Engineers. Washington, D.C. July, 1999.

Low Impact Development (LID): A Literature Review. Low-Impact Development Center. Office of Water. U.S. Environmental Protection Agency. 2000.

Maintaining Your Stormwater Management Structure. Lou Geiser, Department of Public Works, Bureau of Environmental Service, Howard County. Columbia, MD 1999.

Preliminary Data Summary of Urban Storm Water Best Management Practices (EPA-821-R-99-012). U.S. Environmental Protection Agency. Washington, D.C. August, 1999.

Stormwater BMP Design Specifications, Construction, Operations and Maintenance

Best Management Practices for Erosion and Sediment Control. U.S. Department of Transportation–Eastern Federal Lands Highway Division. Sterling, VA. June, 1995.

Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices (#91702). Metropolitan Washington Council of Governments. Washington, D.C. 1987.

Design of Stormwater Filtering Systems. Center for Watershed Protection. Ellicott City, MD. December 1996.

Design of Stormwater Wetland Systems (#92710). Metropolitan Washington Council of Governments. Washington, D.C. 1992.

Storm Water Technology Fact Sheets (EPA-832-F-99-001 through EPA-843-F-99-050). U.S. Environmental Protection Agency, Washington, D.C. September 1999.

Minnesota Construction Site Erosion and Sediment Control Planning Handbook. Board of Water and Soil Resources and Association of Metropolitan Soil and Water Conservation Districts. St. Paul. 1989.

Rainwater and Land Development. Dan Mecklenburg, Ohio Department of Natural Resources, Division of Soil and Water Conservation. Columbus. 1996.

Ramsey County Erosion and Sediment Control Handbook. Ramsey Soil and Water Conservation District. St. Paul. 1989.

Wisconsin Construction Site Best Management Practice Handbook. Wisconsin Department of Natural Resources. Madison. 1994.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Boise Storm Water Standards
Sub Title:	When it Rains it Drains
Authors:	Boise Public Works Department
Publication Date:	1999
Source:	Boise Public Works Department
Document Type:	General Stormwater and BMP Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Moderate
Nature of Information:	Conceptual / Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Somewhat Applicable
Description:	Design standards manual for the city of Boise, ID. This is not a design manual rather, a manual which provides guidelines to meet the treatment requirements for the city of Boise, ID. The manual provides guidelines for the applicability, sizing, construction, pretreatment, and design of individual stormwater treatment BMPs. The information is similar to that found in other stormwater BMP manuals.
Notes:	This is a draft manual and is incomplete. Document provides familiar information for the most common BMPs.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Developing Successful Runoff Control Programs for Urbanizing Areas
Sub Title:	Stormwater Issues and Management Manual
Authors:	Northern Virginia Soil and Water Conservation District, Fairfax, VA
Publication Date:	July, 1994
Source:	Northern Virginia Soil and Water Conservation District, Fairfax, VA
Document Type:	General Stormwater and BMP Manual
Publication #:	EPA 841-K-94-003
Link:	http://www.bts.gov/smart/cat/RUNOFF.html
Format:	Web - Based
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Cursory
Nature of Information:	Conceptual
Level of Detail:	Low
Applicability to Small Sites:	Not Applicable
Applicability to Cold Climate:	Not Applicable
Description:	Policy manual for implementing urban stormwater BMP practices. Brief descriptions of specific BMPs are given to familiarize the reader with available technologies. No information as to design, construction, or maintenance is provided. Limited performance information is provided however, it is quite limited in nature. Case studies of stormwater management programs and BMP implementation are given for Alexandria, VA, Massachusetts, Austin, TX, Orlando, FL, Fairfax, VA, Eugene, OR and Portland, OR.
Notes:	Not applicable.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Highway Runoff Manual
Sub Title:	
Authors:	Washington State Dept of Transportation
Publication Date:	February, 1995
Source:	Environmental and Engineering Service Center
Document Type:	General Stormwater and BMP Manual
Publication #:	M 31 - 16
Link:	http://www.wsdot.wa.gov/hq/library/Ref/pubs.htm#wsdot
Format:	Digital - pdf
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Cursory
Nature of Information:	Conceptual / Design
Level of Detail:	Low
Applicability to Small Sites:	Somewhat Applicable
Applicability to Cold Climate:	Somewhat Applicable
Description:	The manual provides background information on stormwater hydrology and water quality issues with an emphasis on transportation related issues. Significant portions of the manual are devoted to runoff issues, hydrology, minimum treatment recommendations, stormwater BMPs, erosion and sediment control BMPs, maintenance requirements and operational guidelines.
Notes:	General guidance – no figures or illustrations – limited computations.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	King County, Washington Surface Water Design Manual
Sub Title:	
Authors:	King County Department of Natural Resources
Publication Date:	September, 1998
Source:	King County Department of Natural Resources
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Somewhat Applicable
Description:	This is a comprehensive stormwater BMP design manual. It provides information necessary to stormwater management systems and BMPs. This includes hydrologic analyses of storm events and BMP performance, design of stormwater conveyance systems, flow control and treatment BMP design and a number of appendices which address maintenance requirements, small site considerations and erosion and sediment control standards. This is one of the most complete design manuals in this bibliography.
Notes:	Very useful document. Figures are excellent and available in digital format. Design criteria are clear and complete. Construction, maintenance, environmental, and sequencing issues are addressed.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Maryland Stormwater Design Manual
Sub Title:	
Authors:	Maryland Department of the Environment
Publication Date:	1998
Source:	Maryland Department of the Environment
Document Type:	Digital - pdf
Publication #:	
Link:	http://www.mde.state.md.us/environment/wma/stormwatermanual/
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	The manual provides guidance to protect the waters of the State from adverse impacts of urban runoff, provides guidance on the most effective structural and non-structural BMPs for development sites, and to improve the quality of BMPs that are constructed in the State, specifically with regard to performance, longevity, safety, ease of maintenance, community acceptance and environmental benefit.
Notes:	Specific design criteria and computations included. Figure quality varies by BMP. Comprehensive performance criteria included.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Pennsylvania Handbook of Best Management Practices for Developing Areas
Sub Title:	
Authors:	Pennsylvania Association of Conservation Districts
Publication Date:	1999
Source:	Pennsylvania Association of Conservation Districts
Document Type:	General Stormwater and BMP Manual
Publication #:	
Link:	http://www.pacd.org/products/bmp/bmp_handbook.htm
Format:	Web - Based
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Sediment Control
Depth of Information:	Cursory
Nature of Information:	Conceptual
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Limited Applicability
Description:	An online BMP Handbook. Provides conceptual descriptions of BMPs as well as BMP design criteria. Also addresses maintenance and retrofitting. Scope and depth are quite limited.
Notes:	Very general. Not useful as a BMP Design Manual.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Planning and Design Manual for the Control of Erosion, Sediment, and Stormwater
Sub Title:	
Authors:	USDA NRCS and Mississippi Dept. of Environmental Quality
Publication Date:	April, 1994
Source:	USDA NRCS and Mississippi Dept. of Environmental Quality
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	http://grapevine.abe.msstate.edu/csd/p-dm/
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Moderate
Nature of Information:	Conceptual / General Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	Typical NRCS manual design based upon older SCS design computational methodologies. Covers a wide array of BMPs, many not applicable to urban or developing areas. Includes numerous design figures, sizing nomographs, and photographs of implemented BMPs. Quality and depth of information is inconsistent throughout the manual.
Notes:	Very large array of BMPs presented. The quality of design computations and drawings varies with each BMP. Design drawings, specification worksheets and design guidelines are included for each BMP. Good source of simple figures which illustrate the design of each BMP. Good source for general outlet devices and specifications.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Protecting Water Quality in Urban Areas
Sub Title:	Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban and Developing Areas of Minnesota
Authors:	Minnesota Pollution Control Agency
Publication Date:	March, 2000
Source:	Minnesota Pollution Control Agency
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A comprehensive BMP reference. Content is largely borrowed from familiar sources. Provides a good deal of information on pollution prevention, erosion control, and sediment control. Some generalized information regarding the use of proprietary devices is included.
Notes:	Content on BMPs is borrowed from other sources. Figures are familiar and of good quality. No design computations.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Protecting Natural Wetlands
Sub Title:	A Guide to Stormwater Best Management Practices
Authors:	EPA
Publication Date:	October , 1996
Source:	Office of Water, EPA
Document Type:	Stormwater BMP Design Manual
Publication #:	EPA-843-B-96-001
Link:	http://www.epa.gov
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A comprehensive BMP manual three sections, including the following; Factors to consider when selecting BMPs, Case studies of BMPs in practice in each EPA region, and 22 BMPs in fact sheet layout with simple benefits, limitations and minimal requirements sections.
Notes:	Very informative – well-organized fact sheet format. Figure quality varies by BMP.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Stormwater Best Management Practices
Sub Title:	
Authors:	North Carolina Department of Environment and Natural Resources – Water Quality
Publication Date:	April, 1999
Source:	North Carolina Department of Environment and Natural Resources – Water Quality
Document Type:	General Stormwater and BMP Manual
Publication #:	EPA 841-K-94-003
Link:	http://www.bts.gov/smart/cat/RUNOFF.html
Format:	Web - Based
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A concise stormwater BMP reference. This document is very comprehensive with a chapter devoted to each of the most commonly used stormwater treatment BMPs in North Carolina. An excellent reference.
Notes:	Very concise, nice document. Contains examples of designs and computations for the application of each BMP. Provides advantages and disadvantages for each BMP. Excellent figures.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Stormwater Management Plan
Sub Title:	
Authors:	Washington State Department of Transportation
Publication Date:	March, 1997
Source:	Washington State Department of Transportation
Document Type:	Stormwater Management Manual
Publication #:	40 CFR 122.26(d)2.iv
Link:	
Format:	Digital - pdf
Types of BMPs:	Prevention: None Stormwater: Filtration / Biofiltration / Hydraulic & Proprietary Devices Sediment Control: None
Depth of Information:	Cursory
Nature of Information:	Conceptual
Level of Detail:	Varies
Applicability to Small Sites:	Somewhat Applicable
Applicability to Cold Climate:	Somewhat Applicable
Description:	This is a stormwater management manual. Specific information regarding individual BMPs is not provided. The manual is designed to facilitate the decision making process when planning for stormwater management initiatives. The manual provides a good deal of information on the types, nature, and characteristics of pollutants that exist in stormwater runoff. All of the common stormwater pollutants are covered as well as petroleum based pollutants, heavy metals, numerous chemical species, and other pollutants normally associated with intensive industrial and transportation based land uses.
Notes:	Not useful for typical BMPs. Does provide information for experimental BMPs that target pollutants containing organic, petroleum, and heavy metal constituents. A good source for information on stormwater pollution and proprietary devices. Maintenance guidelines are provided for numerous stormwater BMPs including ponds, infiltration and filters.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Stormwater Management Planning and Design Manual
Sub Title:	Draft Final Report
Authors:	
Publication Date:	November, 1999
Source:	Ministry of the Environment, Ontario, Canada
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	http://www.ene.gov.on.ca/envision/env%5Freg/er/documents/stormwatermanual/index.htm
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Very Applicable
Description:	A very well researched planning and design manual. Provides a breadth of information for all types of BMPs ranging from lot level housekeeping practices to regional stormwater treatment facilities. Also included are design examples, operations and maintenance costs, capital costs, and appendices addressing processes fundamental to the appropriate design and implementation of BMPs. Cold climate considerations are addressed.
Notes:	Very useful for the MCES BMP manual. Figures are simple and not of good quality. Manual addresses the specific mechanisms that affect the performance of BMPs.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Stormwater Management in Washington State
Sub Title:	Volume V – Runoff Treatment BMPs
Authors:	Washington State Dept of Ecology
Publication Date:	August, 2000
Source:	Washington State Dept of Ecology
Document Type:	Stormwater BMP Design Manual
Publication #:	99 - 15
Link:	http://www.ecy.wa.gov/pubs.shtm
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High – varies by BMP
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Somewhat Applicable
Description:	Very comprehensive BMP design manual for stormwater management in the Puget Sound Basin. Provides guidance for BMP selection and design including specific design elements, expected removal efficiencies, and special emphasis on small sites. Covers a wide array of BMPs including roof tops and pervious pavements.
Notes:	Very informative – good source for hydraulic structures, good figures & illustrations. Specific info on enhanced treatment and pre-treatment.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Stormwater Management
Sub Title:	Volume Two: Stormwater Technical Manual
Authors:	Massachusetts Department of Environmental Protection
Publication Date:	March, 1997
Source:	Massachusetts Department of Environmental Protection
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	http://www.magnet.state.ma.us/dep/brp/ww/wwpubs.htm#storm
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A concise technical manual that presents BMP guidance in the selection and design of BMPs for stormwater management. No cost information or specific sizing computations are provided. However, a generalized BMP sizing process is provided which allows the user to determine the required volume of a BMP. Excellent coverage of issues associated with BMPs including expected performance, construction issues, sequencing, and target pollutants.
Notes:	Good source for BMP selection and issues/concerns associated with various BMPs. Quality of figures is fair to good. Good source for design, construction, and maintenance criteria.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Stormwater Quality Best Management Practices
Sub Title:	
Authors:	Ministry of the Environment
Publication Date:	1991
Source:	Ministry of the Environment, Ontario, Canada
Document Type:	General Stormwater and BMP Manual
Publication #:	PIBS 1599
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Erosion Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Limited Applicability
Description:	A BMP design manual for Ontario, Canada. Features a literature review, expected BMP performance, capitol costs, operations and maintenance costs, BMP selection criteria and sizing computations. Figures and diagrams are included in appendices. Issues of concern are also addressed for BMPs. Manual focuses on ponds but does provide information for infiltration basins and wetlands.
Notes:	Good source for BMP issues and costs, maintenance, and removal efficiencies.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Texas Nonpoint Sourcebook
Sub Title:	
Authors:	Statewide Storm Water Quality Task Force
Publication Date:	unknown
Source:	Texas Department of Environmental Resources
Document Type:	Stormwater BMP Handbook
Publication #:	
Link:	http://www.txnpsbook.org/default.htm
Format:	Web - Based
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Moderate
Nature of Information:	Conceptual
Level of Detail:	Low
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Not Applicable
Description:	An online guide to stormwater BMPs. The guide includes background information on the impacts of urbanization on hydrology, programs for managing runoff, and section on stormwater runoff BMPs. BMPs are differentiated based on their roles in pollution prevention, runoff prevention, and stormwater treatment. Target pollutants are identified for each BMP as well as qualitative ratings of general BMP performance and operational considerations. Construction considerations are not addressed.
Notes:	Not useful for MCES BMP Manual. Information is too general. Design computations are not included. Some figures are available on-line.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	The Wisconsin Stormwater Manual
Sub Title:	
Authors:	Jeffery Prey
Publication Date:	1994
Source:	Wisconsin Department of Natural Resources
Document Type:	Stormwater Manual
Publication #:	WR-349-94
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	Covers a broad range of subjects including pollution prevention measures, alternatives for administration and financing, state and federal stormwater regulations, guidelines for stormwater planning, and model stormwater plans.
Notes:	A general manual based on BMP reviews and basic concepts.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Manuals

Title:	Water Related Best Management Practices in the Landscape.
Sub Title:	Water Runoff Management
Authors:	Center for Sustainable Design, Mississippi State University
Publication Date:	1999
Source:	Center for Sustainable Design, Mississippi State University
Document Type:	BMP Fact Sheets
Publication #:	
Link:	http://grapevine.abe.msstate.edu/csd/
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance
	Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices
	Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	cursory
Nature of Information:	Conceptual / Design
Level of Detail:	Low to Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	The compendium was created to provide a concise and easily used source of information about the best management practices (BMP's) available for storm water management, erosion control, and protection of natural systems put at risk by the absence of such BMP's. The compendium is not intended as a complete manual for the implementation of each BMP. Such a document could not be contained within a single volume. Rather, it is intended as an entry into the wealth of information on this subject. The document was created specifically for the NRCS urban conservationists, but it is hoped that it will be a useful resource for city planners, developers, homeowners, students, and anyone else who has a vested interest in this area.
Notes:	Detail varies by BMP. Specific drawings, but not clear.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Best Practices for Street Sweeping
Sub Title:	
Authors:	Metropolitan Council
Publication Date:	1994
Source:	Metropolitan Council
Document Type:	BMP Manual
Publication #:	71-94-020A
Link:	http://www.txnpsbook.org/client2.htm
Format:	Web-based - HTML
Types of BMPs:	Prevention: Housekeeping / Operations and Maintenance Stormwater: None Sediment Control: Sediment Control
Depth of Information:	Cursory
Nature of Information:	General
Level of Detail:	Low
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Specific
Description:	A summary of findings from a small demonstration project that identifies a total of 66 “best practices” in street sweeping by public works departments in the Twin Cities metropolitan area.
Notes:	General information. Useful for developing and maintaining a sweeping program.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Better Site Design
Sub Title:	Watershed Protection Techniques
Authors:	Center for Watershed Protection
Publication Date:	1999
Source:	Quarterly Bulletin on Urban Watershed Restoration and Protection Tools, Vol 3.2
Document Type:	Journal Article
Publication #:	Vol. 3, No. 2
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Low Impact Development Stormwater: Infiltration / Filtration Sediment Control: Soil Erosion Control
Depth of Information:	General
Nature of Information:	Conceptual / Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A special issue with articles focusing on model land development principles that can reduce impervious cover, conserve natural areas and improve stormwater treatment, quantifying economic and environmental benefits associated with better site design, benefits of open space design in new residential subdivisions, better parking lot design, and local site planning roundtables.
Notes:	Good general information on impervious surface reduction. There is limited filtration system information. Good background information on urban soils, compaction, and nutrient effects on natural wetlands.

Urban Small Sites BMP Manual
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Region Specific Stormwater BMP – Cold Climate

Title:	Better Site Design
Sub Title:	A Handbook for Changing Development Rules in Your Community
Authors:	Center for Watershed Protection
Publication Date:	1998
Source:	Center for Watershed Protection
Document Type:	General BMP Low Impact Development Manual
Publication #:	
Link:	http://www.cwp.org/
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Soil Erosion / Sediment Control
Depth of Information:	General
Nature of Information:	Cursory/ Conceptual
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	This document is the culmination of the Site Planning Roundtable, a consensus process initiated to create more environmentally sensitive, economically viable, and locally appropriate development. The primary audience for this manual is the local planner, engineer, developer, and official involved in the designing and building of new communities.
Notes:	Emphasis on impervious surface reduction. Provides model principles for BMPs including current practice, recommended practice, perceptions and realities, economic benefits and case studies. Good low impact development and impervious surface reduction information.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Costs of Urban Nonpoint Source Water Pollution Control Measures
Sub Title:	Technical Report Number 31
Authors:	Southeastern Wisconsin Regional Planning Commission
Publication Date:	June, 1991
Source:	Southeastern Wisconsin Regional Planning Commission
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	General
Nature of Information:	Conceptual / Design
Level of Detail:	High – varies by BMP
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	The primary purpose of this report is to provide assistance in estimating the capital and annual operation and maintenance costs of urban nonpoint source water pollution control measures including: wet detention basins, infiltration trenches, infiltration basins, grassed swales, vegetated filter strips, porous pavement, catch basin cleaning, and street sweeping. Cost data are also presented for nine temporary construction erosion control measures: filter fabric fences, straw bales carriers, diversion swales, inlet protection devices, temporary seeding, mulching, sodding, sediment traps, and sedimentation basins.
Notes:	Limited description of BMPs. Detail limited to bullet point guidelines. Includes street sweeping effectiveness and cost comparisons of operations and maintenance for BMP's. Includes a chapter on construction erosion control measures which may be useful for the BMP manual.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	National Stormwater Best Management Practices (BMP) Database
Sub Title:	A new tool for evaluating stormwater BMP effectiveness
Authors:	American Society of Civil Engineers
Publication Date:	1999
Source:	ASCE
Document Type:	Hard Copy and CD
Publication #:	
Link:	
Format:	BMP Manual Database
Types of BMPs:	Prevention: Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	General
Nature of Information:	Data
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	The database was developed as a scientifically based approach and management tool for the information needed to evaluate the effectiveness of urban stormawater BMP's nationwide. The purpose of the database is to promote technical design improvements for BMP's and to better match their selection and design to the local stormwater problems being addressed.
Notes:	Specific site information for Minnesota is included. A good resource when comparing and selecting BMPs.

Urban Small Sites BMP Manual
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Region Specific Stormwater BMP – Cold Climate

Title:	Nutrient Loading and Conventional and Innovative Site Development
Sub Title:	
Authors:	Center for Watershed Protection
Publication Date:	1998
Source:	The Center for Watershed Protection
Document Type:	General BMP Low Impact Development Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Low Impact Development / Operations and Maintenance Stormwater: None Sediment Control: None
Depth of Information:	General
Nature of Information:	Cursory/ Conceptual
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	This study documents the comparative nutrient export and economic benefits of conventional and innovative site planning techniques.
Notes:	Provides comparisons between “typical” development and “innovative design” for medium and low density residential, retail shopping, and commercial office park development. Includes SUNOM – Simplified Urban Nutrient Output Model, draft consensus of model development principles.

Urban Small Sites BMP Manual
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Region Specific Stormwater BMP – Cold Climate

Title:	Quantity and Quality of Runoff from Selected Guttered and Unguttered Roadways in Northeastern Ramsey County, Minnesota
Sub Title:	
Authors:	Gregory B. Mitton and Gregory A. Payne
Publication Date:	1997
Source:	USGS
Document Type:	BMP Performance Report
Publication #:	96-4284
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: None Stormwater: Filtration / Infiltration Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Conceptual
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Specific
Description:	This report describes the quantity and quality of runoff from selected municipal roadway sections in northeastern Ramsey Rounty. The data were collected from five roadways that were guttered or unguttered, and include rainfall- and snowmelt-runoff events monitored during 1993-1995.
Notes:	A good resource for rainfall and runoff trends in the Minneapolis region.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Riparian Buffer Strategies
Sub Title:	
Authors:	Metropolitan Washington Council of Governments
Publication Date:	1995
Source:	Metropolitan Washington Council of Government
Document Type:	BMP Manual
Publication #:	95703
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Operations and Maintenance Stormwater: Filtration / Infiltration Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Specific
Description:	This document is organized into four chapters. The first chapter presents an overview of current buffer programs, particularly those designed to achieve water quality objectives. This is followed by a chapter on the pollutant removal mechanisms of urban riparian buffers. The third chapter describes design criteria for water quality buffers and the final chapter presents guidelines for implementing buffer programs.
Notes:	Comprehensive descriptions of buffer purpose, maintenance, and performance.

Urban Small Sites BMP Manual
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Region Specific Stormwater BMP – Cold Climate

Title:	Site Planning for Urban Stream Protection
Sub Title:	
Authors:	The Center for Watershed Protection
Publication Date:	December, 1995
Source:	The Center for Watershed Protection
Document Type:	Stormwater BMP Design Manual
Publication #:	95708
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Low Impact Design Stormwater: Detention / Retention / Infiltration / Constructed Wetlands Sediment Control: Soil Erosion / Sediment Control
Depth of Information:	Cursory
Nature of Information:	Conceptual / Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	This manual is organized into seven topic areas including stream protection strategy, impervious surface reduction, watershed-based zoning, stream protection clusters, architecture of stream buffers, headwater streets, and green parking lots.
Notes:	Good resource for specific BMP details regarding stream corridors. Good information on parking lots and cul-de-sac designs near streams and creeks.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Stormwater BMP Design Supplement for Cold Climates
Sub Title:	
Authors:	Center for Watershed Protection
Publication Date:	1997
Source:	Center for Watershed Protection
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	http://www.cwp.org/
Format:	Hardcopy
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Erosion / Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Specific
Description:	Specifically addresses issues that arise when BMPs are constructed in cold climates. Focuses on runoff treatment BMPs. Includes examples of BMP design and sizing computations that address cold climate issues.
Notes:	This manual provides information essential to the planing and design of BMPs in Minnesota. Very informative – good source for treatment BMPs. Excellent source for figures which illustrate BMP and outlet design. Provides info on cold sensitive plants as well as construction guidelines to minimize the impact of freezing temperatures on stormwater BMPs.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Storm-Water and Wetlands
Sub Title:	Planning and Evaluation Guidelines for Addressing Potential Impacts of Urban Storm-Water and Snow-Melt Runoff on Wetlands
Authors:	State of Minnesota Storm-Water Advisory Group
Publication Date:	June, 1997
Source:	Minnesota Pollution Control Agency
Document Type:	Stormwater BMP Design Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Low Impact Development Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High for wetland impacts
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Specific to Minnesota
Description:	The purpose of this document is to provide guidance to local governmental units (LGUs) on what they must do if they wish to protect wetlands from storm-water and snow-melt discharges to wetlands. The implementation of urban storm-water management plans that minimize adverse impacts to wetlands and other waters can be achieved through the use of a comprehensive management approach. All elements of a storm-water plan must consider a watershed or other large-scale areas as opposed to piecemeal, project-by-project approaches.
Notes:	Excellent system for rating quality of wetlands and susceptibility to stormwater input.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Urban Landscapes as a Source of Phosphorus in Surface Waters
Sub Title:	
Authors:	Jenni Swenson
Publication Date:	September, 1998
Source:	Metropolitan Council
Document Type:	Stormwater BMP Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Seddiment Control: Soil Erosion / Sediment Control
Depth of Information:	General
Nature of Information:	Conceptual
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Specific / Applicable
Description:	Through efficient land use practices, including cleaning gutters, the proper application and timing of fertilizer, and refraining from sweeping or raking organic debris into streets, homeowners can prevent contributing to the phosphorus load.
Notes:	Very good information source for phosphorus loading and removal effectiveness of BMPs.

Urban Small Sites BMP Manual
Annotated Bibliography

Region Specific Stormwater BMP – Cold Climate

Title:	Watershed Protection Techniques
Sub Title:	Vol. 1 No. 2 – Summer 1994
Authors:	Center for Watershed Protection
Publication Date:	1994
Source:	Quarterly Bulletin on Urban Watershed Restoration and Protection Tools, Vol 3.2
Document Type:	Journal Article
Publication #:	Vol. 1 No. 2 – Summer 1994
Link:	
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Cursory
Nature of Information:	Conceptual / Design
Level of Detail:	High – varies by BMP
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable/Specific
Description:	Technical information on stormwater ponds, pond/wetland systems. Snowmelt runoff dynamics.
Notes:	Topics covered include: performance of stormwater ponds, pond/wetland systems, golf course BMP's, wetland creations tips.

Urban Small Sites BMP Manual
Annotated Bibliography

BMP Performance and Performance Enhancement

Title:	Development of Performance Standards: Task 3.1 – Technical Memorandum
Sub Title:	Determining Urban Stormwater Best management Practice (BMP) Removal Efficiencies
Authors:	U.S. EPA and ASCE
Publication Date:	1999
Source:	Office of Water, U.S. EPA
Document Type:	Stormwater Manual
Publication #:	
Link:	
Format:	Digital - pdf
Types of BMPs:	Prevention: Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Calculations
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	Technical review of efficiency calculation methods, methods to be used for analysis of stormwater best management practices.
Notes:	Relevant technical calculation information. Includes comparisons of different methods used for rainfall and storm analysis.

Urban Small Sites BMP Manual
Annotated Bibliography

BMP Performance and Performance Enhancement

Title:	Low Impact Development (LID)
Sub Title:	A Literature Review
Authors:	Low-Impact Development Center
Publication Date:	October, 2000
Source:	Office of Water, EPA
Document Type:	BMP Performance Review
Publication #:	EPA-841-B-00-005
Link:	http://www.epa.gov/owow/nps/lid.pdf
Format:	Digital - pdf
Types of BMPs:	Prevention: Low Impact Development / Operations and Maintenance Stormwater: Filtration / Infiltration Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A literature review to determine the availability and reliability of data to assess the effectiveness of low impact development (LID) practices for controlling stormwater runoff volume and reducing pollutant loadings to receiving waters.
Notes:	Brief general reviews of bioretention systems including grass buffer strips, sand beds, ponding areas, organic layers, planting soils, grass roofs, and vegetation. Describes the performance, operation and maintenance of six case studies in the U.S.

Urban Small Sites BMP Manual
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BMP Performance and Performance Enhancement

Title:	Maintaining Your Stormwater Management Structure
Sub Title:	
Authors:	Geiser, Lou
Publication Date:	1999
Source:	Howard County, Maryland
Document Type:	Journal Article
Publication #:	
Link:	
Format:	Digital - pdf
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration Sediment Control: None
Depth of Information:	Moderate
Nature of Information:	Conceptual
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	This is a brief manual which prescribes maintenance practices to maximize the longevity and performance of common stormwater BMPs. Treatment methods for retention and detention ponds, infiltration devices, grit chambers and underground structures are presented. The information in this manual is qualitative in nature.
Notes:	The maintenance information provided in this publication is a compendium of information from other sources. Information is general in nature. Not likely to be useful for the BMP manual.

Urban Small Sites BMP Manual
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BMP Performance and Performance Enhancement

Title:	Preliminary Data Summary of Urban Storm Water Best Management Practices
Sub Title:	
Authors:	Environmental Protection Agency
Publication Date:	1999
Source:	Office of Water, EPA
Document Type:	Hardcopy
Publication #:	EPA-821-R-RR-99-012
Link:	http://www.epa.gov/OST/stormwater/
Format:	BMP Manual
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	General
Nature of Information:	Calculations, costs, and statistics
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	This report summarizes existing information and data regarding the effectiveness of BMP's to control and reduce pollutants in urban stormwater. The report provides a synopsis of what is currently known about the expected costs and environmental benefits of BMP's, and identifies information gaps as well.
Notes:	Relevant technical operational and maintenance information. Includes comparison of different methods used and respective costs.

Urban Small Sites BMP Manual
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Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Best Management Practices for Erosion and Sediment Control
Sub Title:	
Authors:	U.S. Department of Transportation – Eastern Federal Lands Highway Division
Publication Date:	June, 1995
Source:	U.S. Department of Transportation – Eastern Federal Lands Highway Division
Document Type:	Other
Publication #:	FHWA – FLP – 94 - 005
Link:	http://www.fhwa.dot.gov/environment/h2o.htm
Format:	Digital - pdf
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention Basins, Site Development, Hydraulic Structures Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	This reference is a federal highway standards manual that serves to provide consistent guidance in the prevention of soil erosion and control of sediment. The manual emphasizes practices that can be employed during construction activities, thereby facilitating sound construction practices and the reduction of sediment loading to stormwater.
Notes:	Emphasis is on erosion and sediment control. Very good source for methods of protecting and stabilizing soil, reducing sediment loads, and protecting downstream resources. Features design diagrams, construction recommendations, sequencing guidelines and maintenance requirements. Includes standard rating curves and sizing monographs for design outlets.

Urban Small Sites BMP Manual
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Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Controlling Urban Runoff
Sub Title:	A practical Manual for Planning and Designing Urban BMPs
Authors:	Thomas R. Schueler
Publication Date:	July, 1987
Source:	Metropolitan Washington Council of Governments
Document Type:	Stormwater BMP Design Manual
Publication #:	87703
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High – varies by BMP
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Somewhat Applicable
Description:	The manual summarizes local and national research on BMP performance, design and costs, as well as the practical experience grained in urban BMP implementation at the local level. Specific attention includes extended detention ponds, wet ponds, infiltration trenches, infiltration basins, porous pavement, water quality inlets, vegetative systems, stormwater benefits, performance, costs, maintenance.
Notes:	Detail varies by BMP. Generally an excellent resource for the BMP manual. Not all BMPs have figures. Figures that are included are good quality.

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Design of Stormwater Filtering Systems
Sub Title:	
Authors:	Richard A. Claytor and Thomas R. Schueler
Publication Date:	December , 1999
Source:	The Center for Watershed Protection
Document Type:	Stormwater Design Manual
Publication #:	
Link:	http://www.cwp.org/
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Design
Level of Detail:	High
Applicability to Small Sites:	Applicable / Specific
Applicability to Cold Climate:	Applicable
Description:	The manual presents detailed engineering guidance on eleven different filtering systems. The term stormwater filter refers to a diverse spectrum of stormwater treatment methods utilizing various media, such as sand, peat, grass, soil or compost to filter out pollutants entrained in urban stormwater. These filters are typically designed solely for pollutant removal, and serve small development sties. The three broad groups include: sand filters (surface, underground, perimeter, organic, and pocket designs), bioretention, and vegetated channels (grass channels, dry swales and wet swales, filter strips, and gravel wetlands).
Notes:	Very detailed figures and design criteria descriptions. Includes calculations and small site specifics. Excellent manual for Stormwater sections of BMP manual.

Urban Small Sites BMP Manual
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Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Design of Stormwater Wetland Systems
Sub Title:	Guidelines for Creating Diverse and Effective Stormwater Wetland Systems in the Mid-Atlantic Region
Authors:	Thomas R. Schueler
Publication Date:	1992
Source:	Metropolitan Washington Council of Governments
Document Type:	General BMP Manual
Publication #:	92710
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: None Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: None
Depth of Information:	Comprehensive
Nature of Information:	Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable / Somewhat Specific
Description:	This manual presents an integrated and comprehensive approach toward the design of stormwater wetlands for the mid-Atlantic region. The manual summarizes what is currently known, drawn from an extensive review of local and national research, as well as the practical experience and insights of local stormwater experts.
Notes:	The standard for constructed wetland and stormwater wetland systems. Excellent figures.

Urban Small Sites BMP Manual
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Stormwater BMP Design Specs, Construction, O & M Costs

Title:	EPA Storm Water Technology Fact Sheets
Sub Title:	Vegetated Swales, Sand Filters, Bioretention, Flow Diversion, Minimizing Effect from Highway Deicing, Hydrodynamic Separators, Infiltration Drainfields, Infiltration Trench, Storm Water Wetlands, , Water Quality Inlets, Modular Treatment Systems, Wet Detention Ponds
Authors:	U.S. EPA
Publication Date:	1999
Source:	Office of Water, U.S. EPA
Document Type:	BMP Fact Sheet
Publication #:	EPA 832-F-99-006, EPA 832-F-99-007, EPA 832-F-99-012, EPA 832-F-99-014, EPA 832-F-99-016, EPA 832-F-99-017, EPA 832-F-99-018, EPA 832-F-99-019, EPA 832-F-99-025, EPA- 832-F-99-029, EPA 832-F-99-044, EPA 832-F-99-048
Link:	http://www.epa.gov/owm/mtbfact.htm
Format:	PDF
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A series of BMP fact sheets including figures, drawings, calculation tables on applicability, design criteria, performance and operation and maintenance.
Notes:	Good information and drawings. Good advantages and disadvantages sections. Excellent format for BMP manual.

Urban Small Sites BMP Manual
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Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Minnesota Construction Site Erosion and Sediment Control Planning Handbook
Sub Title:	
Authors:	Minnesota Board of Water and Soil Resources and the Association of Metropolitan Soil and Water Conservation Districts.
Publication Date:	1989
Source:	Minnesota Board of Water and Soil Resources and the Association of Metropolitan Soil and Water Conservation Districts.
Document Type:	Erosion and Sediment Control BMP Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Low Impact Development / Operation and Maintenance Stormwater: Detention / Retention Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable / Specific
Description:	The handbook begins with a chapter listing the General Criteria (GC) for E & S control. Chapter two is a description of how to prepare an erosion and sediment control plan. Chapter three relates to information the plan reviewer needs to ensure adequate protection.
Notes:	Includes a detailed section on selecting the correct BMP for the specific location, a section on example BMP practices in use in Minnesota, and small section detailing silt fences, sediment basins, slope draining, lot benching, subsurface drainage, lined channels and many others. Material may be dated.

Urban Small Sites BMP Manual
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Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Rainwater and Land Development
Sub Title:	Ohio's standards for Stormwater Management
Authors:	Dan Mecklenburg
Publication Date:	1996
Source:	Ohio Department of Natural Resources, Division of Soil and Water Conservation
Document Type:	Stormwater Management BMP Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Housekeeping / Low Impact Development / Operations and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	High – varies by BMP
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable / Specific
Description:	Streams, inclusive of their riparian areas, are vital environmental features and extremely sensitive to urbanization. The intent for this book is to allow land development to occur with less of an impact on water resources, principally streams. The manual has three parts, starting with a general framework for integrating water resource protection into site planning. The second part is three chapters on post-construction pollution prevention: post-construction stormwater quality treatment, permanent runoff control and stream channel construction and restoration. The last four chapters includes present standards and specifications for sediment control, temporary runoff control, soil stabilization and construction pollutants other than sediment.
Notes:	Excellent figures and photographs. Specific design computations with an emphasis on erosion and sediment control. Includes an excellent video training course titles, "Keeping Soil on Construction Sites: Best Management Practices."

Urban Small Sites BMP Manual
Annotated Bibliography

Stormwater BMP Design Specs, Construction, O & M Costs

Title:	Ramsey County Erosion and Sediment Control Handbook
Sub Title:	
Authors:	Ramsey Soil and Water Conservation District
Publication Date:	1989
Source:	Ramsey Soil and Water Conservation District
Document Type:	Erosion and Sediment Control BMP Manual
Publication #:	
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Low Impact Development / Operation and Maintenance Stormwater: Detention / Retention / Infiltration / Filtration Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Design
Level of Detail:	High
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable / Specific
Description:	This handbook contains the operational elements of the Ramsey County Coordinated Erosion and Sediment Control Pilot Program. It provides information to prepare an erosion and sediment control plan, to have it approved, and to put it into practice. People responsible for the design, use, installation, and inspection of erosion and sediment control should be guided by the information contained in this handbook and by their professional judgement.
Notes:	Includes erosion and sedimentation processes and practices to utilize in erosion and sediment control. Most examples are general and the figures are low quality.

Urban Small Sites BMP Manual
Annotated Bibliography

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Title:	Wisconsin Construction Site
Sub Title:	Best Management Practice Handbook
Authors:	Wisconsin Department of Natural Resources
Publication Date:	1994
Source:	Wisconsin Department of Natural Resources
Document Type:	Stormwater BMP Design Manual
Publication #:	WR-222-93
Link:	
Format:	Hardcopy
Types of BMPs:	Prevention: Operations and Maintenance Stormwater: Detention / Filtration Sediment Control: Construction / Soil Erosion / Sediment Control
Depth of Information:	Comprehensive
Nature of Information:	Conceptual / Design
Level of Detail:	Medium
Applicability to Small Sites:	Applicable
Applicability to Cold Climate:	Applicable
Description:	A general manual to supplement the Model Ordinance in Wisconsin based on the following principles: diversion of clean water around disturbed areas, minimized duration of disturbance and area size, implementation of temporary measure pollutants, utilization of runoff channels, and BMP maintenance.
Notes:	Includes computations and general guidelines for erosion and sediment control. Figures and few and low quality.