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

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ACKNOWLEGEMENTS

We thank all the agencies and individuals who contributed to the preparation of this manual. The first acknowledgement goes to the authors and contributors to the original edition of *Protecting Water Quality in Urban Areas*, which remains the standard of comparison for this type of document in Minnesota.

Many of the sediment- and erosion-control practices in this manual are based on best management practice (BMP) manuals or sediment-control handbooks from the states of Maryland, Virginia and North Carolina. Also, the State of Washington manual, *Storm Water Management Manual for the Puget Sound Basin*, was a primary source for information on a variety of subjects, but especially for chapter 7, Pollution Prevention.

The Metropolitan Washington Council of Governments (MWCG) was a primary source for summary information and design concepts related to treatment practices, as is the Center for Watershed Protection (CWP).

The *Engineering Field Manual* of the U. S. Department of Agriculture's Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, is a primary source for many design details found in this manual.

The Minnesota Department of Transportation (MnDOT) has been a primary source of local experience and information. The MnDOT *Standard Specifications* and *Manual of Practice* are sources that should be referenced for many design details. The Minnesota Department of Natural Resources (MDNR), Board of Water and Soil Resources (BWSR) and the Metropolitan Council of the Twin Cities (Met Council) where also significant sources of practical information.

In many cases, the recommended practices in this manual are based upon experience from organizations or individuals who have used them in Minnesota. These include local consultants, conservation districts, and individuals that have also been major contributors.

The names of the many individual contributors and reviewers who helped in the development of this manual are listed in Appendix II.

The U.S. Environmental Protection Agency (EPA) provided grants under section 319, which were the primary source of support and funding for this effort. The EPA was also the source of much technical data and analysis of information related to urban runoff issues.

PREFACE

This manual contains specific recommendations and criteria to be considered when implementing BMPs; however, it should not be confused with a design document. The manual does not contain complete detailed design information for all practices that are referenced.

The examples, recommendations and criteria highlight some of the major principles and notable points related to the practices based upon the best information available from a variety of sources. These sources should be used with caution since you must demonstrate the appropriateness and applicability of the practice to Minnesota and to your project in particular.

Some of the examples shown in this document represent projects which, under state or federal laws, may require permits or design by a registered design professional. This manual, the source references, and professional integrity should be seen as three legs providing a stable foundation for your project BMPs.

INTRODUCTION

Minnesota's waters — including its lakes, streams and ground water — are among our greatest resources. They provide recreation and livelihood for thousands of Minnesotans. They support our tourism industry, and are enjoyed by many visitors to our state. They are also used for industrial activities. However, these waters are fragile resources that are vulnerable to pollution from a wide variety of human activities. Water quality has become one of the more important environmental issues facing our state today.

In many areas of Minnesota, wetlands, lakes and streams are increasingly vulnerable to human impacts. Game-fish populations have declined because wetlands and shallow lakes have filled with sediment. Many waters have become unsuitable for swimming and fishing because of sediment and other pollutants. Moreover, there is increasing concern about the quality of Minnesota's ground water, which supplies drinking water for 75% of the state's population.

In the past, efforts to improve Minnesota's water have concentrated on controlling pollution from point sources — municipal or industrial facilities discharging to state waters. We have made good progress in controlling pollution in recent years, largely through the construction of new wastewater-treatment facilities for cities and industries. Nevertheless, Minnesota's lakes, streams and ground waters continue to be degraded by pollutants that are carried in runoff. These forms of pollution are called nonpoint-source pollution.

Nonpoint-source pollution has become a serious problem, affecting many of Minnesota's lakes and rivers. Table 1 compares the number of miles of rivers and acres of lakes in Minnesota that are affected by point- and nonpoint-source pollution.

Some people may believe that runoff from urban areas is "clean" or "natural" and that it does not harm water quality. This perception is understandable since many people do not realize that the volume and pollutant loading of runoff has been changed subtly over time. In addition, the amount of pollution from any one spot can be so small that it would be insignificant were it the only source. However, when all these small amounts are combined, they can cause serious water-quality problems. Current development practices have been shown to significantly impact watersheds by increasing runoff and pollutant loading with impervious surfaces covering as little as 10% of the watershed (Schueler, 1994b).

There are two main reasons why urbanization increases pollutant loads. First, the volume and rate of runoff are typically increased as an area is developed, providing a larger capacity to transport pollutants. The second reason is that some materials are typically more easily picked up in runoff as the vegetation is reduced and the impervious surface increases.

The discharge of storm water and snowmelt into wetlands can often have an adverse and sometimes devastating impact. Chapter 1 describes these hydrologic effects and the pollutants commonly associated with urban watersheds. Although many of the effects discussed here relate to surface water quality, it is important to note that ground water quality can also be adversely affected by urbanization.

Table 1 Statewide assessment of use attainability for Minnesota's waters

LAKES		
Statewide (1998): 1,984 lakes assessed representing 2,128,270 acres, of which 1,458,450 acres (69%) fully support swimmable use. **Lake Superior Basin**: 208 lakes assessed (80,059 acres), of which 60,881 acres (76%) fully support swimmable use. **Minnesota River Basin**: 176 lakes assessed (112,066 acres) of which 36,622 acres (33%) fully support swimmable use. **Red River Basin**: 142 lakes assessed (148,401acres) of which 130,632 acres (88%) fully support swimmable use.	Individual basins are assessed on a rotating basis; assessments are under way for remaining basins.	Swimmable use assessment is based on trophic status measurements. Use support categories are based on ecoregion-based P criteria and Carlson's TSI. In-lake phosphorus (P) is primary basis for assessment — chlorophyll-a or Secchi are used in absence of P. Lake assessment database is redone annually by downloading data from STORET.
STREAMS		
Statewide (1998): 62% of stream miles meet aquatic life use; 59% of stream miles meet swimmable (recreation) use. **Lake Superior Basin:** 62% of stream miles meet aquatic life use; 100% of stream miles meet swimmable use. **Minnesota River Basin:** 64% of stream miles meet aquatic life use; 20% of stream miles meet swimmable use. **Red River Basin:** 35% of stream miles meet aquatic life use; 34% of stream miles meet swimmable use.	Individual basins are assessed on a rotating basis; assessments are under way for remaining basins.	These assessments reflect the use of MPCA turbidity data, and more data from other sources, than previous assessments. These percentages are based on a consistent set of stream sites.

This manual is designed to help local government officials, urban planners, developers and citizens become aware of urban nonpoint pollution problems and to provide detailed information about management practices to help prevent and control nonpoint pollution. The first chapter of the manual describes the basic principles of water quality protection, types of nonpoint-source pollutants found in urban areas and their effects on water quality. Chapter 1 also provides a brief explanation of the hydrologic changes that occur with urbanization. Chapter 2 is a discussion of the use of BMPs in policy and practice.

Chapter 3 is designed to help the reader understand some basic aspects of comprehensive planning to control urban nonpoint-source pollutants. It provides a discussion of how careful site planning of new developments can help prevent pollution, and how stormwater-management strategies can be used to trap urban pollutants. Chapter 3 also describes a process for selecting BMPs to correct existing water-quality problems. Many of these principles and practices can also be used to control urban point-source pollution.

Chapters 4, 5, 6 and 7 discuss the BMPs that can be used to control urban nonpoint-source pollution. The BMPs are divided into three areas: stormwater-management practices (Chapter 4), ponds (Chapter 5), sediment- and erosion-control practices (Chapter 6) and housekeeping practices (Chapter 7). The discussion about each BMP contains information about target pollutants, effectiveness and planning considerations.

Chapter 8 discusses hydrologic and water quality models, as well as methods of determining runoff and peak discharge. This chapter also discusses the limitations of models and warnings on how models can be abused and misused.

Design recommendations are provided for the BMPs whenever it is desirable to highlight a specific aspect of the management practice because it is important to water quality, or to explain a standard used to judge the acceptability of a practice for water quality. Not all design details are provided. When this manual is silent on an issue, industry standards should be assumed to apply for the practice. These practices often involve a great deal of site-specific professional judgment. State laws may require that registered professionals design or approve design for some of the BMPs that affect public health or safety.

For some of the examples shown in this manual, state, federal or local laws require permits or that they be conducted by registered design professionals. No implementation of the practices in this manual should be allowed without an appropriate and demonstrated level of professional competence.

Our lakes, streams and ground water can be kept clean by understanding how urban activities can cause pollution, and by selecting appropriate BMPs. Used wisely, these practices can help protect Minnesota's waters for future generations.

CHAPTER 1

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1.00 WATER QUANTITY AND QUALITY

1.10 HOW URBANIZATION AFFECTS WATER QUANTITY

URBANIZATION CHANGES HYDRAULICS

In Minnesota, precipitation varies from event to event and geographically from the northwest to the southeast. We use statistics to help understand the significance of these patterns and variability. Over time, these events can be averaged to develop what is called the "normal annual precipitation pattern" (see Figure 1.10-1).

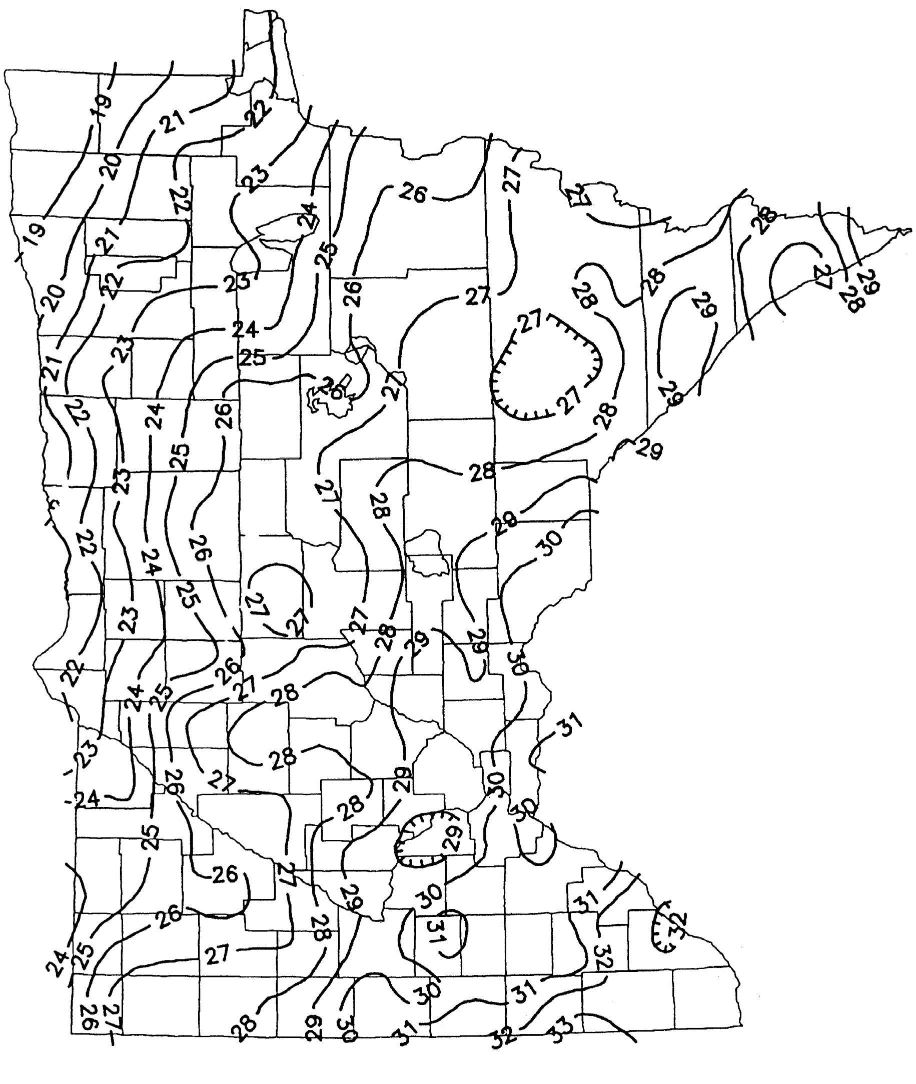


Figure 1.10-1 "Normal" annual precipitation in inches in Minnesota, 1961-90 (prepared by State Climatology Office, Minnesota Department of Natural Resources, Division of Waters)

While rainfall patterns may or may not have been affected by human activity, it is clear that runoff has changed significantly with human development. In the presettlement Midwest, entire watersheds were in vegetative cover (*e.g.*, prairie, oak savanna), with maximum infiltration and minimum runoff. With the massive conversion of the landscape to agricultural and urban uses came substantial changes in runoff of precipitation to wetlands, lakes and streams.

Table 1.10-1 Urban areas: average percent impervious surface by type of land use

Land Use Type	Percent
Commercial and business districts	85
Industrial areas	72
Residential districts by average lot size	
1/8 acre or less (townhouses)	65
1/4 acre	38
1/3 acre	30
1/2 acre	25
2 acres	12
From: USDA, Soil Conservation Service, June 1986	

Removal of perennial vegetation led to a decrease in infiltration and an increase in the volume of runoff. Exposing soils to wind and water erosion increased sediment loads carried by runoff. Impervious surfaces and artificial drainage systems increased the volume of runoff and accelerated the rate at which water was removed from the landscape. Impervious surfaces in urban areas also transported runoff more rapidly and in greater volumes than before development (see Table 1.10-1). Fertilizers, pesticides, automobile exhaust residues, animal waste and other sources greatly increase nutrient loading and contaminants carried by runoff. All of these factors have prominent roles in altering and degrading wetlands, lakes and streams.

QUANTITY OF RUNOFF

When an urban area is developed, natural drainage patterns are modified as runoff is channeled into road gutters, storm sewers and paved channels. The amount of rainfall that can infiltrate into the soil is reduced, which increases the volume of runoff from the watershed (see Figure 1.10-2). Drainage modifications also increase the velocity of runoff, which decreases the time required to convey it to the outlet of the watershed.

Figure 1.10-2 shows the relationship of runoff, infiltration and evaporation for watersheds with varying degrees of impervious cover. Typical impervious cover percentages are shown in Table 1.10-1.

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 1.10-3 shows typical predevelopment and postdevelopment 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.

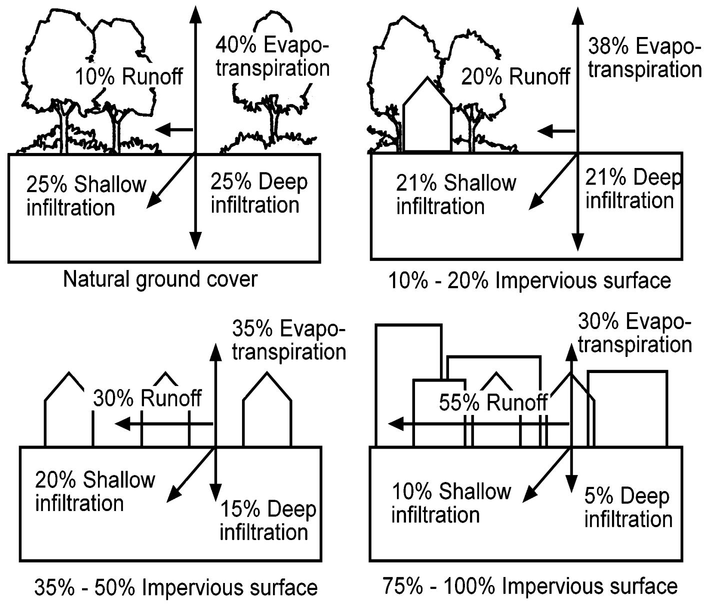


Figure 1.10-2 Changes in runoff due to urbanization

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). After urbanization, increased flows can cause bank-full flow to be exceeded several times each year. 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. These changes in hydrology, combined with increased pollutant loadings, can have a dramatic effect on the ecosystem of urban streams. Studies of streams affected by urbanization have shown that fish populations either disappear or are dominated by “rough” species that can tolerate a lower level of water quality (Klein, 1979).

HYDROLOGIC CHANGES IN WETLANDS AND WATERWAYS

Water is the driving force in wetlands. A naturally fluctuating hydrologic cycle over hundreds or thousands of years has helped shape the plant and animal communities present in wetlands. Many of the organisms, including plants, have become adapted to fluctuating water levels, saturated soils and anaerobic conditions. Wetlands have adapted to natural cycles of wetness and drought. These are important factors in natural wetland hydrology that maintain the functions and values that wetlands provide.

Water that drains from a project area into an off-site drainage basin impacts trees and other vegetation. In such cases, water itself is the damaging agent even if it is clean. The increase in water level, both surface and subsurface, can result in the death of roots. In Minnesota, few tree species can tolerate extended periods of flooding. Roots require oxygen from the air, and saturated soils create an anaerobic condition that will eventually kill the roots. A case in point is a tamarack swamp that receives water from several developments. The water travels very slowly through the swamp, and the increased flow results in the death of many of the tamarack trees.

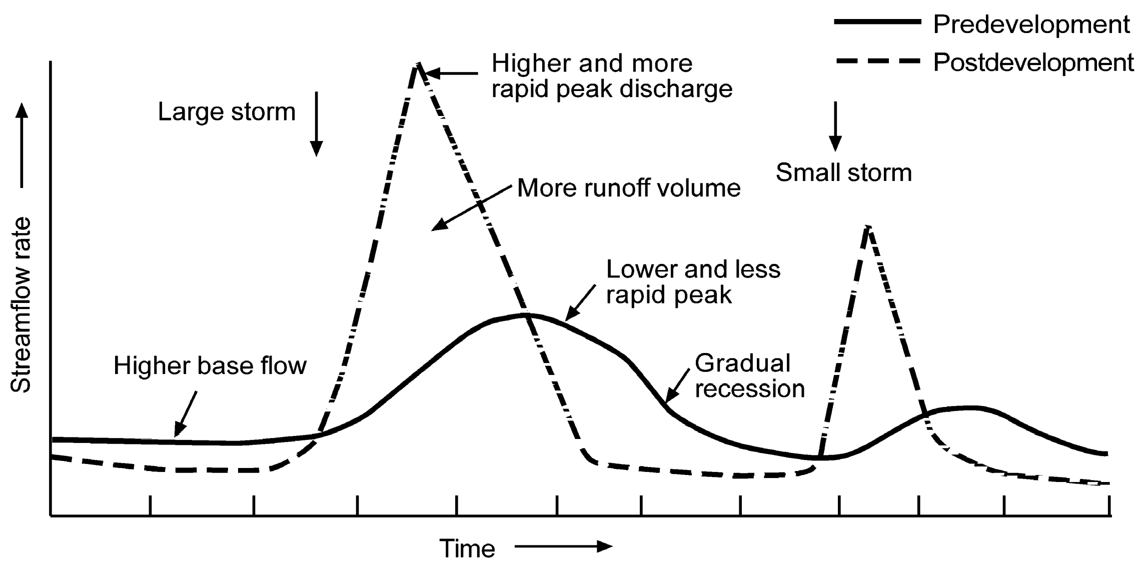


Figure 1.10-3 Changes in stream hydrology as a result of urbanization (Schueler, 1992)

HYDROLOGIC MODELING CONCEPTS

Urban hydrology models often depend on information gained from studies of flood and drainage conditions in rural areas. However, assumptions that are appropriate for large storms may create problems when used for small storms. The runoff values for storms often do not approach conventional runoff predictions until several inches of rain have fallen.

More infiltration occurs through street pavement than is generally anticipated, and the infiltration rates through disturbed urban soils are highly irregular. Under some conditions, these disturbed areas can have much less infiltration than pavement. For example, turf playing fields and unpaved parking lots can have less infiltration than a paved area, such as a roadway. However, large paved areas, including freeways, have less infiltration because of longer drainage paths and sealing overcoats (Pitt, 1987).

Figure 1.10-4 (Pitt, April 29-30, 1998) shows measured rain and runoff distributions for Milwaukee during 1983. Rains between 0.05 and 5.0 inches were monitored, and two very large events (greater than 3.0 inches) occurred, which greatly bias these curves, compared to typical-rain years. It was found that the median rainfall was about 0.3 inch, and that 66% of all Milwaukee rains were less than 0.5 inch. In addition, 50% of the runoff was associated with rains of less than 0.75 inch for medium-density residential areas.

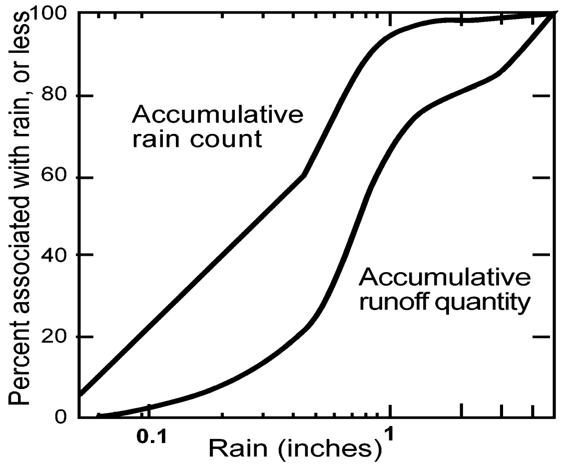


Figure 1.10-4 Milwaukee rain and runoff distributions

In contrast, a 100-year, 24-hour rain of 5.6 inches for Milwaukee could produce about 15% of the average annual runoff volume, but only contribute about 0.15% of the average annual runoff volume when amortized over 100 years. Similarly, typical 25-year drainage design storms (about 4.7 inches in Minneapolis) produce about 12.5% of the annual runoff volume when they occur in a typical year, but only about 0.5% of the average runoff volume over a given 100-year period.

Figure 1.10-5 (Pitt, April 29-30, 1998) shows actual measured Milwaukee pollutant discharges associated with different rain depths for a medium-density residential area. Monitored discharges of suspended solids, chemical oxygen demand, lead, and phosphates (PO_4) closely follow the runoff distribution shown in Figure 1.10-4. These figures substantiate typical statistical analysis results that show that concentrations of most runoff pollutants do not significantly vary for runoff events associated with different rainfall amounts.

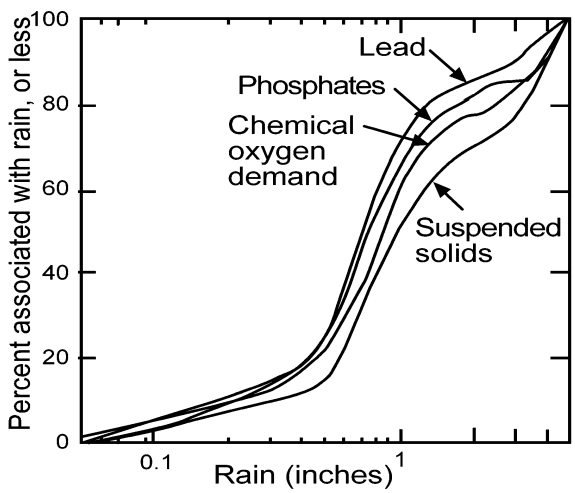


Figure 1.10-5 Milwaukee pollutant discharge distributions

Therefore, being able to accurately predict runoff volume is very important in order to reasonably predict runoff pollutant discharges. The best way to verify how well a model and the included assumptions perform is to compare the results with data independent from those used for calibration. Data can be collected on site or from other sites considered adequately representative of the study site. This verification of model results is often overlooked. Encouraging or requiring verification is the only way to have confidence in the results.

Figures 1.10-4 and 1.10-6 show three distinct rainfall categories:

1. Common rains less than approximately 0.5 inch have relatively low pollutant discharges (less than 25% 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.
2. Rains between 0.5 and 1.5 inches are responsible for about 75% 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.
3. 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 (Figure 1.10-6). 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 (Pitt, April 29-30, 1998). The pollutant loading is more closely associated with total runoff volume than with peak runoff rates.

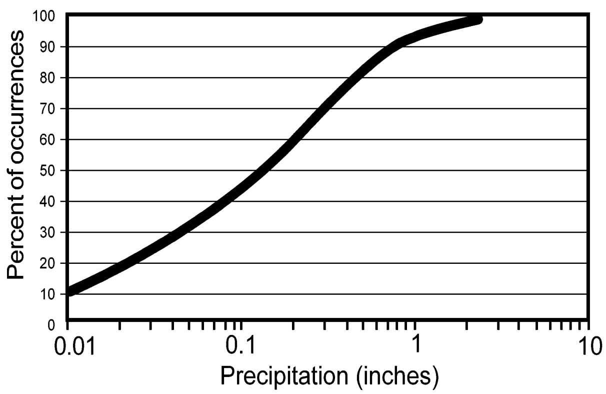


Figure 1.10-6 Daily precipitation — cumulative frequency distribution, Minneapolis-St. Paul (April-October 1891-1998)

SMALL-STORM HYDROLOGY

Urbanization will increase the runoff volume from each storm event, thereby overloading the natural drainage systems. Existing stream characteristics are a reflection of past conditions in the watershed.

The frequency of bank-full events increases with urbanization, causing the stream to enlarge its channel to reach a new equilibrium with the increased flows. Increased flow volumes increase 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 (Schueler, Thomas R., *et al.*, 1998) and erosive flow controls (Washington State Department of Ecology, 1992a). 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.

WATERSHED ANALYSIS

Predicting the magnitude of adverse impacts when natural watersheds are converted to urban development is a complex task. One must assume that any change in the landscape changes the runoff from what had occurred previously due to any given rainfall event. A water body can be affected when urban development surrounds it, but does not actually encroach upon it. If the supply of water is increased or reduced beyond the limits that a water body's sensitivity allows, or if it carries excess pollutants, the important functions and values of that water body may be destroyed.

CONCLUSION

Maintaining the pre-existing 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.

1.20 HOW URBANIZATION AFFECTS WATER QUALITY

The Nationwide Urban Runoff Program (NURP) sampled and studied urban runoff on a large scale throughout the United States. The final report of this study presented the results and a statistical analysis of those data (USEPA, December 1983).

Urban surfaces are subject to the deposit of contaminants, which are then subject to wash-off by rainfall or snow melt. Typical contributors to pollutants in runoff include vehicular traffic, industry, power production, lawn care, pets, eroded sediments and vegetative litter.

The major urban nonpoint-source pollutants include sediment, nutrients, oxygen-demanding substances, toxic chemicals, chloride, bacteria and viruses, and temperature changes. Each of these pollutants is discussed below.

SEDIMENT

Sediment is made up of tiny soil particles that are washed or blown into lakes and streams. Sediment is considered one of the more damaging pollutants in Minnesota, and it is the major pollutant by volume in the state’s surface waters.

The suspended particulates and bed-load solids are inorganic (sediment, sand) and organic debris (vegetative and animal waste) that enter the water through bed and bank erosion as well as by wind and water. De-icing grit, dirt, soil disturbed by construction activities, litter, vegetative debris and lawn clippings are some of the many sources.

Among the problems these pollutants cause in receiving waters are turbidity (cloudiness), destruction of the aquatic habitat (burying, alteration of bottom material), transport of adsorbed contaminants, clogging of drainage systems, and direct impact on aquatic organisms (altered respiration, reduced light penetration).

Sediment fills in road ditches, streams, lakes, rivers and wetlands and can affect aquatic life by smothering fish eggs and larvae. Suspended soil particles cause water to become turbid. Excessive turbidity reduces light penetration in water, impairs sight-feeding fish, clogs fish gills, and increases the cost of treating drinking water. Fine sediment also acts as a vehicle to transport other pollutants, including nutrients, trace metals and hydrocarbons, to nearby surface waters.

Runoff from construction sites is a major source of sediment in urban areas under development. Average sediment-loading rates from construction sites vary from 36.5 to 1,100 tons per acre per year. Rates for construction sites are five to 500 times greater than those from undeveloped land (USEPA, 1977). Another major source of sediment is streambank erosion, which is accelerated by increases in peak rates and volumes of runoff due to urbanization. In fully developed urban areas, sand applied to icy roads can also create a significant sediment load (Oberts, G.L., 1986).

Control of solids can be achieved by avoiding or minimizing impacts from activities such as clearing, grading and filling. BMPs, such as detention ponds, or prevention measures, such as housekeeping and street sweeping, can be used to reduce impacts. The use of reduced impervious surface and enhanced infiltration can be encouraged to reduce total surface water movement.

NUTRIENTS

Phosphorus and Nitrogen

Many naturally occurring materials are essential for life, and are therefore termed “nutrients.” However, an excess of some nutrients can lead to explosive growth of noxious life, such as algae, or can be toxic to some forms of aquatic life (as is the case with ammonia). Most of the complaints received by the Minnesota Pollution Control Agency (MPCA) about lake water quality concern problems that are caused by excessive nutrient levels (Munson, W., 1988).

Of particular concern for receiving waters are nutrients that are increased in urban runoff from such sources as lawn-care products, vegetative and animal debris, or automotive additives. Atmospheric deposition (wind erosion, industrial activity) is a concern in urban areas because it can easily be picked up by runoff from impervious surfaces. Nitrate nitrogen, most commonly from fertilizer overuse, can also adversely impact ground water when concentrated to high-enough levels.

Control of nutrients before discharge can be achieved by such measures as source control (fertilizer application limits), housekeeping (pet control ordinances, street sweeping), detention and enhanced infiltration.

In Minnesota, the effects of nutrients are a major concern for surface water quality. Nutrients — especially phosphorus and nitrogen — can cause algal blooms and excessive aquatic plant growth. Of the two, phosphorus is usually the limiting nutrient that controls the growth of algae in lakes. As phosphorus loadings rise, the potential for algal blooms and accelerated lake eutrophication also increases.

Un-ionized ammonia (NH_3) is highly toxic to aquatic organisms. The ammonium (NH_2) form of nitrogen can also have severe effects on surface water quality. The ammonium is converted to nitrate and nitrite in a process called “nitrification.” This process consumes large amounts of oxygen and can kill fish by lowering dissolved oxygen levels of the water. These conditions can impair many important uses of these waters, including recreation, fish habitat and water supply.

The nitrate form of nitrogen is very soluble, and it is present naturally in water at low levels. When nitrogen fertilizer is applied to lawns or other areas in excess of plant needs, nitrates can leach below the root zone, eventually reaching ground water. Water contaminated with high levels of nitrates presents a health hazard to young infants who consume formula prepared with it. Adults can tolerate higher levels of nitrates in drinking water; however, studies suggest that long-term consumption of drinking water with elevated nitrate levels may cause some forms of cancer (Freshwater Foundation, 1988).

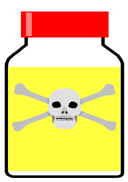
Major sources of nutrients in urban areas are organic matter, such as lawn clippings and leaves, and fertilizers applied improperly or in excessive amounts. In areas with heavy automobile traffic, orthophosphate from auto emissions also contributes phosphorus (Shelly and Gaboury, 1986).

Phosphorus in urban runoff has also been associated with the application of sand and salt to roads (Oberts, 1986).

OXYGEN-DEMANDING SUBSTANCES

While land animals extract oxygen from the air, aquatic life depends on oxygen dissolved in water. When aquatic microorganisms consume organic matter, dissolved oxygen is depleted. Following a rainfall, urban runoff can deposit large quantities of oxygen-demanding substances in lakes or streams. The biochemical oxygen demand (BOD) of typical urban runoff is about as large as that of effluent from an efficiently run secondary wastewater treatment plant (USEPA, December 1983). A "pulse" of high oxygen demand can be created during storm runoff that can totally deplete oxygen supplies in shallow, slow-moving or poorly flushed waters. Oxygen depletion is a common cause of fish kills. In urban areas, pet wastes, street litter and organic matter are common sources of oxygen-demanding substances.

Much of the material washed off urban surfaces exerts a demand for oxygen as it degrades in the water. Organic debris, oxidizable metals and nutrients all require some oxygen in their material degradation. If the levels of these materials are high enough, oxygen otherwise available for aquatic life is depleted, resulting in stress or death for these organisms. Oxygen depletion can cause water-quality problems in any kind of receiving water body. Oxygen-demanding substances can be limited through such BMPs as erosion control, leaf and litter management, and storm water detention.



TOXIC CHEMICALS

Many of the everyday activities in urban areas also contribute substantial amounts of toxic material to receiving waters. Essentially, anything that is applied to the land or emitted from fertilizer or pesticide applications, a smokestack or a vehicle's tailpipe can be deposited on, and washed off, impervious urban surfaces.

Trace metals

The toxic effects that trace metals can have on aquatic life are a major water-quality concern. The most common trace metals found in urban runoff are lead, zinc and copper (USEPA, December 1983). These metals were found in more than 90% of the samples taken as part of the Nationwide Urban Runoff Program (NURP) (USEPA, December 1983). Chromium, cadmium and nickel were also detected frequently in the NURP sampling. These metals originate from galvanizing, chrome plating and other industrial operations in urban areas. Automobile emissions used to be a major source of lead in urban areas. Lead and zinc in urban runoff have also been associated with the application of sand and salt on roads (Richards *et al.*, 1973; Oberts, G. L., June 1986).

As metals corrode, dissolve or settle out of the air, small amounts are carried away by wind or water and concentrate in urban runoff. The toxicity of trace metals in runoff varies with the hardness of the receiving water. As total hardness of the water increases, the threshold concentration levels for adverse biological effect increases. Many of these metals become attached to fine sediment and are carried with it until the sediment settles out. When these metals settle out, they can accumulate over a period of time to levels that are harmful to aquatic life. Studies have shown that trace metals bioaccumulate in plants and aquatic life in areas where they are contained in sediment (Meiorin, December 1986; USFWS, 1988).

Hydrocarbons

As part of the NURP study, residential runoff was sampled to determine the presence of more than 100 organic compounds. NURP's analyses generally indicated that organic compounds are not normally found in residential runoff.

When these chemicals were detected, their concentrations were generally low. The most commonly detected compound was a plasticizer used in plastic products. However, there were two instances in which the concentrations reached toxic levels. In those cases, one compound was a wood preservative and the other was a pesticide (USEPA, 1983). This indicates that these materials can result in significant water quality problems if they are not properly handled and applied.

Hydrocarbons and organic chemicals permeate commercial, industrial and highway runoff, and can be toxic to aquatic life if they are at high enough levels. These materials also move easily, exist for extended periods in a toxic state, and concentrate in sediments, from which they can be re-suspended later. The petroleum (gas and oil) that leaks from cars or comes out tailpipes, or the pesticides applied to urban lawns, can wash into gutters and eventually into a water body.

Petroleum-derived hydrocarbons commonly found in urban runoff initially float on the surface of the water and create the familiar rainbow-colored film, or sheen. Hydrocarbons have a strong affinity for sediment and quickly become adsorbed to it. They are then transported with the sediment and settle out with it. Hydrocarbons are a concern because they are known to be toxic to aquatic organisms at relatively low concentrations (Stenstrom *et. al*, 1984). Common sources of hydrocarbons are spillage at oil-storage and fueling facilities, leakage from crankcases and improper disposal of drained oil (MacKenzie and Hunter, 1979).

CHLORIDE

In Minnesota, a tremendous amount of salt is used each year to melt ice from roads, parking lots and sidewalks. Although the Minnesota Department of Transportation has reduced the amount of sodium chloride applied to highways in the Twin Cities metropolitan area in the last 10 to 15 years by about 50%, much salt is still being applied. Because it is extremely soluble, almost all salt applied ends up in surface or ground water (Pitt *et al.*, 1994a). If the concentration of chloride becomes too high, it can be toxic to many freshwater organisms.

Normal application of de-icing salt to roads is unlikely to create toxic conditions due to elevated chloride levels. However, there have been many documented cases of surface and ground water contamination caused by runoff from inadequately protected stockpiles of salt and sand-salt mixtures.

BACTERIA AND VIRUSES

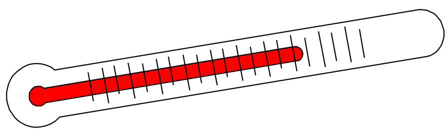
High concentrations of many bacteria and viruses are found in urban runoff.

The NURP study found that total coliform counts exceeded U.S. Environmental Protection Agency (EPA) water-quality criteria at almost every site and almost every time it rained (USEPA, 1983). Apparently, soil can act as a source of bacteria even when it is very unlikely that the high levels are of human origin or that they indicate significant human health risk (Barrett *et al.*, 1996). The coliform bacteria that are detected may not be a health risk in themselves, but are often associated with pathogens that are.

The sources of pathogens can include sanitary sewer leaks, pets, vermin and discarded infected material. The result of contact with these pathogens can be disease.

Pathogens can often be controlled by good urban housekeeping, disconnection of illegal sanitary sewer connections, and pet control.

TEMPERATURE CHANGES



While temperature is usually not considered a critical factor for discharges to most wetlands, temperature differences can significantly impact streams (especially trout streams).

Various types of temperature criteria can affect the success and mortality of organisms in waterways. Temperature changes that occur over a short period can have a shock effect, resulting in their death. There can also be long-term temperature effects, which cause changes in the growth, reproduction or mortality of organisms. These mean and maximum temperature effect levels vary from organism to organism and can be different for even the same organism in a different waterway.

In Minnesota, the water-quality standards reflect daily maximum average temperatures for most waterways, or changes above the ambient which are limited to a few degrees on a monthly average basis (Minn. R. ch. 7050).

The Washington Council of Governments (Galli, December 1990) concluded that several factors affect extreme temperatures. The primary determinants of extreme temperature are watershed imperviousness and riparian canopy. In addition, Galli studied four BMP types: (1) infiltration dry pond, (2) extended-detention artificial wetland, (3) extended-detention dry pond and (4) wet pond. The researcher concluded that all four caused temperature increases, and each monitored BMP violated applicable water-temperature standards at least once.

POLLUTANT DELIVERY

Both the short- and long-term impacts of pollutant delivery must be understood and addressed to meet water-quality goals.

Many people tend to be concerned about pollutants only if they cause fish kills or toxic problems. The short-term effects on water quality may need to be considered. These effects are important when evaluating pollutants, such as toxic trace metals and oxygen-demanding substances, which can kill aquatic life. A more thorough understanding of the characteristics of urban runoff is needed to select BMPs to meet a long-term water-quality goal. For many situations in Minnesota, estimates of annual pollutant loadings or concentrations in runoff can be used to evaluate these characteristics. These estimates provide an indication of long-term effects on water quality, such as nutrient loading to lakes and trace metal buildup in sediments. A different methodology is used to evaluate these effects.

VARIATION DUE TO LAND USE

One component of the NURP study involved an evaluation of the data based upon geographic location. The study did not find any distinct patterns in the data that could be attributed to geographic location. NURP concluded that individual site differences are far more significant than geographic differences for urban pollutant concentrations. This is important to remember when determining how transferable data are from one location to another.

NURP also evaluated the impact of different land uses on urban runoff characteristics. The mean concentrations from the NURP study are included in Table 1.20-1. Because of the variability of the data, the researchers concluded that, except for open/nonurban land use, differences in pollutant concentrations were not statistically significant. In addition, the NURP data showed that urban pollutant concentrations for most sites could not be correlated statistically with either storm runoff volume or storm intensity.

When estimating pollutant concentrations, using water-quality-monitoring data for a local watershed is preferable to using data from remote study areas or using summary data (such as the NURP data) from areas with similar land uses. However, if local data are not available, values from NURP (Table 1.20-1) or Bannerman (Table 1.20-5) can be used for an estimate of pollutant export from similar urban land-use areas.

Table 1.20-1 Mean pollutant concentrations (mg/L)

Pollutant	Land Use			
	Residential	**Mixed**	**Commercial**	**Open/nonurban**
Chemical oxygen demand	83	75	61	51
Total suspended solids	140	101	90	216
Lead	0.18	0.19	0.13	0.054
Zinc	0.18	0.19	0.33	0.23
Total Kjeldahl nitrogen	2.35	1.44	1.40	1.36
Nitrate nitrogen	0.96	0.67	0.63	0.73
Total phosphorus	0.46	0.33	0.24	0.23
Soluble phosphorus	0.16	0.07	0.098	0.06

Some local data are available from a study that was based on a smaller data set than NURP. During this study, the U.S. Geological Survey and the Metropolitan Council collected water quality data from 19 monitoring sites in the Twin Cities area (USGS, 1982). These data show considerable difference in pollutant loadings, which vary according to watershed land-use characteristics. To provide a basis for judgment about local loadings, mean pollutant concentrations from four of these sites are included in Table 1.20-2. These watersheds' characteristics are described in Table 1.20-3.

In Table 1.20-2, the ranges of the data are presented in addition to mean values to show the extreme variability that occurs in urban runoff water-quality monitoring. It is important to keep this variability in mind when using mean values. Mean values should always be used with caution and qualified to avoid the impression that they are absolute values. These data are provided to help a planner decide the range in values that may be appropriate for a given situation.

Table 1.20-2 Flow-weighted mean pollutant concentrations (mg/L) and ranges

Pollutant	Monitoring Site				
	Yates	**Iverson**	**Sandburg**	**Elm**	
Chemical oxygen demand	90 24-879	38 1-597	138 10-850	65 4.5-157	mean range
Total suspended solids	133 2-758	740 17-26,610	337 7-4,388	10 2-374	mean range
Lead	0.23 0.015-1.8	0.02 0.008-0.31	0.19 0.003-1.5	0.005 0.001-0.012	mean range
Zinc	0.198 0.02-2.2	0.235 0.028-0.53	0.185 0.02-0.81	0.012 0.005-0.019	mean range
Total Kjeldahl nitrogen	3.6 0.6-28.6	1.2 1.0-29.2	2.5 0.4-16.0	2.1 1.2-5.4	mean range
Nitrate nitrogen	0.79 0.05-4.5	0.07 0.05-2.45	0.42 0.05-2.4	0.27 0.05-1.35	mean range
Total phosphorus	0.63 0.10-3.85	0.62 0.2-13.1	0.63 0.07-4.3	0.35 0.11-2.23	mean range
Source: U.S. Geological Survey, 1982					

In Table 1.20-3, Elm Creek data show typical values for a watershed with a minimal amount of development. The Iverson and Yates data are included to provide a comparison of residential runoff for a stabilized watershed (Yates), and a watershed under development (Iverson). Note the elevated total suspended solids (TSS) levels in the developing watershed. The Sandburg site provides data from an area with a commercial/industrial land use.

Table 1.20-3 Watershed characteristics for monitoring sites in Table 1.20-2

Name	Monitoring Site			
	Elm Creek	**Iverson**	**Sandberg**	**Yates**
Major Land Use	Relatively open, less than 25% farmed	Residential area under construction	Light industrial	Medium to high density
Drainage Area (square miles)	14.3	0.15	0.12	0.35
Drainage	Low-gradient stream	Curb and gutter with some in-stream wetlands	Curb and gutter	Curb and gutter
Typical Soils	Loamy, well-drained soils	Gently sloping, loamy soils	Moderately loamy soils	Flat, sandy soils

When comparing pollutant levels for present and future land uses, it is extremely important to understand the difference between pollutant loadings and concentrations. Tables 1.20-1, 1.20-2 and 1.20-4 show mean concentrations of pollutants in runoff. In many cases, the differences in concentrations for various land uses may not be significant. However, pollutant loadings are a function of both concentration and runoff volume. As an area develops and the percentage of impervious area increases, the volume of runoff can increase drastically. If the pollutant concentration remains constant while the volume of runoff triples, the annual pollutant loading will also triple.

Table 1.20-4 Median stormwater pollutant concentrations for all site by land use, nationwide Urban Runoff Program

Pollutant	Residential		Mixed Land Use		Commercial		Open/Nonurban	
	Median	COV[1]	Median	COV	Median	COV	Median	COV
BOD_5, mg/L	10.0	0.41	7.8	0.52	9.3	0.31	--	--
COD, mg/L	73	0.55	65	0.58	57	0.39	40	0.78
Total soluble solids, mg/L	101	0.96	67	1.14	69	0.85	70	2.92
TKN, µg/L	1900	0.73	1288	0.50	1179	0.43	965	1.00
$NO_2 – N + NO_3 – N_1$ µg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total phosphorus, µg/L	383	0.69	263	0.75	201	0.67	121	1.66
Soluble phosphorus, µg/L	143	0.46	56	0.75	80	0.71	26	2.11
Total lead, µg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total copper, µg/L	33	0.99	27	1.32	29	0.81	--	--
Total Zinc, µg/L	135	0.84	154	0.78	226	1.07	195	0.66

[1]COV: coefficient of variation = standard deviation / mean
BOD = biological oxygen demand
COD = chemical oxygen demand
TKN = total Kjeldahl nitrogen
Source: U.S. Environmental Protection Agency, 1983

SOURCES OF POLLUTANTS

Bannerman and others have studied the runoff of pollutants, trying to determine their source and the relationship between concentration and loading from various urban land uses. The findings of the studies are presented in Table 1.20-5. The studies (Bannerman *et al.*, 1992) show that one or two source areas in each land use usually contribute most of the pollutants. Data from Minneapolis compare reasonably well with the Bannerman data.

To determine pollutant loading, the study areas must be accurately characterized for both pollutant concentration and the volume of runoff. It is important to understand the pollutants of concern to the system, their sources (especially by land-use type), the source-area concentrations in runoff, and the source-area loading (see Table 1.20-4). This requires a knowledge of the hydrology of the source areas, especially the small-storm hydrology and the differences between small-storm and floodwater routing models.

Table 1.20-5 Means and coefficient of variation for the source area and storm sewer outfall considerations (Bannerman *et al.*, 1992)

	POLLUTANT											
	Total Solids (mg/L)	Susp. Solids (mg/L)	Total Phos. (mg/L)	Diss. Phos. (mg/L)	Diss. Cd (μ/L)	Diss. Cu (μ/L)	Total Cd (μ/L)	Total Cr (μ/L)	Total Cu (μ/L)	Total Pb (μ/L)	Total Zinc (μ/L)	Total Hard. (mg/L)
	Geometric Mean											
S_IndustRoof	78	41	0.11	0.02	0.2	2	0.3	-	6	8	1155	-
S-ArterialST	879	690	0.94	0.20	0.6	14	2.5	23	74	60	575	38
S_FeederST	958	763	1.50	0.53	0.4	18	3.3	15	76	86	480	43
S_ParkingLot	531	312	0.39	0.05	0.3	15	1.0	12	41	38	304	42
S_Outfall	146	0.34	0.14	0.2	10	1.0	6	28	25	265	31	
M_ResiDriveway	173	1.16	0.49	0.5	9	0.5	2	17	17	107	33	
M_FlatRoof	113	15	0.20	0.08	0.5	6	0.3	-	9	9	331	34
M_CollectorST	494	326	1.07	0.31	0.3	24	1.4	12	56	55	339	30
M_ArterialST	374	233	0.47	.010	0.9	18	1.8	16	46	50	508	35
M_ParkingLot	127	58	0.19	0.05	0.4	9	0.6	5	15	22	178	22
M_ResiLawn	600	397	2.67	1.45	-	6	-	-	13	-	59	39
M_ResiRoof	91	27	0.15	0.06	0.2	3	0.1	-	5	8	149	20
M_FeederST	796	662	1.31	0.37	0.5	9	0.8	5	24	33	220	9
M_Outfall	369	262	0.66	0.27	0.3	5	0.4	5	16	32	204	26
	Arithmetic Mean											
S_IndustRoof	83	54	0.13	0.02	0.3	2	0.3	-	7	8	1348	--
S-ArterialST	993	875	1.01	0.25	1.0	17	2.8	26	85	85	629	41
S_FeederST	1134	969	1.57	0.62	0.6	22	3.7	17	97	107	574	47
S_ParkingLot	603	474	0.48	0.07	0.5	18	1.2	16	47	62	361	48
S_Outfall	293	174	0.38	0.16	0.2	12	1.1	7	31	26	295	32
M_ResiDriveway	328	193	1.50	0.87	1.3	11	0.5	2	20	20	113	34
M_FlatRoof	126	19	0.24	0.11	0.8	8	0.4	-	10	10	363	44
M_CollectorST	544	386	1.22	0.36	0.8	30	1.7	13	61	62	357	32
M_ArterialST	389	241	0.53	0.14	2.0	22	2.6	18	50	55	554	37
M_ParkingLot	165	91	0.26	0.07	0.7	14	0.8	7	21	30	249	24
M_ResiLawn	656	457	3.47	2.40	-	7	-		13	-	60	51
M_ResiRoof	105	36	0.19	0.08	0.2	3	0.2	-	5	10	153	22
M_FeederST	1152	1085	1.77	0.55	1.3	11	0.8	7	25	38	245	30
M_Outfall	462	374	0.86	0.34	0.7	7	0.6	5	20	40	254	27
	Coefficient of Variation											
S_IndustRoof	0.40	0.71	0.72	0.54	0.75	0.81	0.47	-	0.44	0.30	0.46	-
S-ArterialST	0.52	0.64	0.38	0.90	1.25	0.68	0.49	0.53	0.47	0.85	0.40	0.39
S_FeederST	0.60	0.66	0.29	0.60	0.62	0.63	0.49	0.57	0.77	0.60	0.56	0.39
S_ParkingLot	0.44	.061	0.50	0.65	1.04	0.70	0.51	0.64	0.44	0.65	0.50	0.63
S_Outfall	0.60	0.50	0.59	0.70	0.79	0.44	0.42	0.50	0.42	0.45	0.39	
M_ResiDriveway	0.43	0.51	0.84	1.08	1.60	.067	0.42	0.46	0.62	0.53	0.37	0.32
M_FlatRoof	0.48	0.68	0.54	0.75	1.19	0.59	0.87	-	0.52	0.42	0.44	0.72
M_CollectorST	0.42	0.58	0.54	0.58	1.95	0.64	0.75	0.43	0.32	0.49	0.33	0.38
M_ArterialST	0.30	0.26	0.53	0.86	1.78	0.62	1.18	1.47	0.43	0.48	0.44	0.43
M_ParkingLot	0.74	0.91	0.95	0.96	1.22	1.07	0.86	0.84	0.86	0.82	0.90	0.57
M_ResiLawn	0.48	0.58	0.68	0.90	-	0.58	-	-	0.21	-	0.24	0.79
M_ResiRoof	0.60	0.68	0.59	0.82	0.73	0.47	0.57	-	0.25	0.58	0.24	0.36
M_FeederST	1.02	1.19	0.90	1.02	1.48	0.53	0.41	0.91	0.38	0.50	0.44	0.29
M_Outfall	0.64	0.75-	0.70	0.67	1.97	0.63	0.81	0.54	0.67	0.66	0.66	0.25

1) Dash indicates insufficient sample size.
M = Monroe study area
S = Syene study area

Delivery Process

Understanding the pollutant delivery process is fundamental to controlling nonpoint source pollution. There are three steps in the delivery process: availability, detachment and transport. Most substances must go through this entire chain before they become pollutants. Breaking this chain at any step will prevent a substance from being delivered to receiving waters. Some pollutants are more readily controlled at a particular step in the delivery process. A basic understanding of this process and the characteristics of the pollutants in question helps to target BMPs so they prevent delivery most effectively.

Availability

A substance must be available before it can become a potential pollutant. The quantity of a substance in the environment and its characteristics determine its degree of availability. The quantity of certain pollutants is a function of the intensity of the land use. For instance, a high density of automobile traffic makes a number of potential pollutants, such as hydrocarbons, more available. Control methods, such as street sweeping, which would reduce the availability of these pollutants, have been studied as part of the NURP. These studies concluded that street sweeping was ineffective in controlling very fine pollutants such as those associated with automobile traffic (USEPA, December 1983). From a water quality BMP standpoint, these materials are best controlled later in the delivery process (Schaefer and Hey, 1983).

The availability of a material such as fertilizer is a function of the quantity and the manner in which it is applied. Applying fertilizer in quantities that exceed plant needs and soil absorption capacity leaves the excess nutrients available for loss to surface or ground water. Reduced use and proper application are the best ways to control nonpoint-source pollution from fertilizers.

Detachment

Detachment is the process in which materials are dislodged from their original location and become mobile. The detachment process can be physical or chemical. Most physical detachment is the result of raindrop impact or overland flow.

Chemical detachment involves dissolving soluble materials or ion-exchange processes. Control of pollutant delivery in the detachment phase is most practical for materials such as sediment when erosion-control practices are used to prevent the detachment of soil particles. Once soil particles are detached, coarser particles can be trapped effectively by sediment-control practices. However, fine soil particles are not readily trapped except by detention practices with very long detention times.

Transport

Transport is the final phase of the delivery process. Transport involves moving a material from its point of detachment to a receiving water. In urban areas, a large part of the runoff is transported to receiving waters over impermeable surfaces, such as streets or in storm sewers. This results in very efficient transport of pollutants to receiving waters once they are detached.

MITIGATION

Detention or infiltration practices can be effective for interrupting transport of many pollutants. But for many urban nonpoint-source pollutants, especially those associated with sediment, preventing transport by retaining vegetative cover or by providing soil stabilizers such as mulch, is the most practical way to control their delivery to receiving waters.

It is important to note that BMPs cannot completely mitigate the impacts caused by urbanization. A combination of practices, including land-use controls, riparian or stream buffer requirements, and employment of temperature-sensitive BMPs will be required to maintain water quality, especially in cold-water streams. The significance of thermal impacts and their mitigation through appropriate BMP implementation needs further research and careful site-specific evaluation for critical areas.

ESTIMATING ANNUAL POLLUTANT LOADINGS

The procedure presented here gives a planner the flexibility needed to develop a site-specific estimate of pollutant loadings for various conditions. The procedure is relatively simple, but one should be aware of its limitations. First, the results are very dependent upon the mean pollutant concentrations used. As mentioned previously, local monitoring is the best source of data for present conditions as long as sufficient data are available. Lacking local monitoring data, estimates can be made from Tables 1.20-1 or 1.20-2 or from an other appropriate reference. For future conditions, an estimate must always be made based upon mean concentrations from other, similar locations.

The procedure in this chapter uses the product of the estimated annual runoff volume and mean concentrations to estimate annual loading. This procedure, expressed in equation 1.20-1, is only intended to provide a rough indication of loadings for an average year.

Mean pollutant concentrations can be converted to annual pollutant loadings with the following simple relationship:

Equation 1.20-1:

$$L = (C)(V),$$

where L = annual pollutant loading,
C = mean pollutant concentration and
V = annual volume of runoff.

The only factors needed to compute the estimated annual loadings are the watershed size, annual rainfall, watershed runoff coefficient, mean pollutant concentration and a conversion factor.

Normally, the watershed area is determined in the very early stages of any planning activity for stormwater-management considerations. Watershed size can be determined from local data, topographic maps or field inspection. In urban areas, storm sewer drainage areas must also be checked.

The average annual precipitation for an area can be determined from local rainfall records. Table 1.10-1 shows average annual rainfall values for Minnesota.

The runoff coefficient (R) is the ratio of average runoff to average rainfall when both are expressed in watershed inches. Studies (USEPA, 1983) of runoff coefficients from NURP data found them to be related to watershed imperviousness. An analysis of those data resulted in the following relationship:

Equation 1.20-2:

$$R = 0.05 + 0.009(I),$$

where R = runoff coefficient (unitless) and I = impervious area in watershed (percent).

Rainfall events that do not produce runoff should not be considered in this equation. To be compatible with the rainfall values in Figure 1.10-1, an adjustment must be made to account for non-runoff events. Schueler (1987) evaluated rainfall events in the Washington, D.C., area and suggested that 10% of the events resulted in no appreciable runoff. To account for the 10% of events that produced no runoff, R should be reduced by 10%, and can be represented by:

Equation 1.20-3:

$$R = 0.9\,[0.05 + 0.009(I)]$$

This equation only applies to surface runoff and does not consider base flow. If the site under consideration is large enough so that base flow is involved, that loading should be considered separately using site-specific data for base flow volume and pollutant concentrations.

The mean pollutant concentration is best determined from local monitoring data. Lacking those data, estimates of mean concentrations from the NURP studies or the U.S. Geologic Survey Twin Cities data can be used. It is important to realize the general nature of these data when they are used in place of site-specific information.

An average annual pollutant loading (L) can be computed with this information using the following formula:

Equation 1.20-4:

$$L = (A)(P)(R)(C)(0.226),$$

where L = annual pollutant loading (pounds),
A = watershed area (acres),
P = annual precipitation (inches),
R = runoff coefficient (unitless),
C = mean pollutant concentration (mg/L) and
0.226 = the conversion factor.

This average annual pollutant loading can be useful for estimating changes in pollutant loadings and long-term impacts of urban pollutants on receiving waters, such as lakes. It is also a useful tool for comparing the pollutant loadings for pre- and postdevelopment land uses in order to have a basis for BMP selection. Table 1.20-4 lists some typical annual loadings that are estimated for various land uses.

The Metropolitan Council has developed another short-cut procedure for estimating pollutant loadings from urban watersheds. This information is presented in *Surface Water Management, Simplified Modeling for Watersheds* (Oberts, December 1983).

Hydrology Methods

Runoff quantities and pollutant runoff are estimated using such factors as land use, rainfall volume and soil type. Several computer models are described in chapter 8. The runoff curve number was developed by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service, or SCS) for storm events with rainfall amounts over 1.5 inches. When the concern is smaller storm events, methods appropriate for events of this size need to be used. For example, Pitt (1998) has developed methods to compute the volumetric runoff coefficients for smaller storm events based on the characteristics of the land use in the drainage area.

Careful analysis of hydrologic conditions, and planning which minimizes the potential impacts of runoff water provide the best long-term solution.

SHORT-TERM EFFECTS ON WATER QUALITY

If a planner wishes to assess the short-term effects of urban runoff on streams or rivers, a different method is more appropriate. An analysis that determines the probability of exceeding certain threshold levels of pollutants will provide a more meaningful representation of in-stream effects. To evaluate water quality in this manner, NURP developed a stochastic procedure for analysis of data. This method relates the median pollutant concentration and the coefficient of variation for the data to arrive at an expected concentration for any frequency of occurrence. This relationship is expressed by Equation 1.20-5.

Equation 1.20-5:

$$x = C_m^{[\,(Z\,\sqrt{\ln(1+(CV)}\,)\,]}$$

where x = expected pollutant concentration for specified chance of occurrence,

Z = standard normal probability,

C_m = median pollutant concentration, and

CV = coefficient of variation.

Equation 1.20-5 can be used to estimate frequency of occurrence from data with a sufficiently large population set. This formula was used to determine expected concentrations of several pollutants based upon NURP median concentrations. Expected values for a 25%, 10% and 1% chance of occurrence were computed. These values are summarized in Table 1.20-6.

Table 1.20-6 Pollutant concentrations (mg/L) in urban runoff for various chances of occurrence

Pollutant	Residential Chance of Occurrence			Mixed Chance of Occurrence			Commercial Chance of Occurrence		
	25%	10%	1%	25%	10%	1%	25%	10%	1%
COD	103	141	241	93	130	223	63	97	199
Lead	0.23	0.34	0.68	0.23	0.42	1.22	0.16	0.23	0.44
Zinc	0.22	0.34	0.47	0.25	0.37	0.77	0.41	0.69	1.7

COD = chemical oxygen demand

Computed from median values in USEPA, 1983, Table 6-12.

To put the trace metal concentrations in perspective, MPCA water-quality standards are reported in Table 1.20-7. This table lists water-quality standards the MPCA has developed for Class 2B, warm-water fishery. Other standards may be applicable (*e.g.*, 2Bd, warm-water fishery used for drinking water). The effect that urban runoff trace metal concentrations will have upon a stream or river depends upon factors such as dilution and total hardness of the water. For information on Minnesota water quality standards, contact the MPCA.

Threshold levels for toxicity usually increase as the total hardness of the water increases. These toxicity data are based on laboratory studies with the trace metals in the ionic form. Trace metal concentrations reported for urban runoff may contain a portion that is not in a toxic form.

The effects of oxygen-demanding substances on a stream or river depend upon several factors. Some of the more important are the oxygen requirements of organisms that inhabit the water body and the ability of the system to reoxygenate itself. In a slow, sluggish or poorly flushed system, oxygen demand from urban runoff can totally deplete the dissolved oxygen supply.

Table 1.20-7 Mississippi River, below St. Anthony Dam and above the Minnesota River

Substance or Characteristic	Units	2B,2C Chronic Standard	2B,2C Maximum Standard	2B,2C Acute Standard	Other Standard
Ammonia, un-ionized as N	µg/L	40			
Bicarbonates (HCO3)	meq/L				5 (4A)
Chloride (3A)	mg/L	230	860	1720	100 (3B)
Chlorine, total residual	µg/L	6	19	38	
Cyanide, free	µg/L	5.2	22	45	
Dissolved oxygen	mg/L				5 (2B,2C)
Fecal coliform	#/100 ml				200 (2B,2C)
Hardness, total as CaCO3 (3A)	mg/L				250 (3B)
Hydrogen sulfide	mg/L				0.02 (5)
Oil (freon extractable)	µg/L	500	5000	10000	
pH	Low				6.5 (2B)
	High				8.5 (4A)
Salinity, total	mg/L				1000 (4B)
Sodium	mg/L				60% cations (4A)
Specific conductance	µmhos/cm				1000 (4A)
Temperature	F				max 86(2B)
Total dissolved salts	mg/L				700 (4A)
Turbidity	NTUs				25 (2B,2C)
METALS AND ELEMENTS					
Aluminum	µg/L	125	1072	2145	
Antimony	µg/L	31	90	180	
Arsenic	µg/L	53	360	720	
Boron	µg/L				500 (4A)
Cadmium*	µg/L	1.64	56.8	113.6	
Chromium, +3*	µg/L	304	2552	5098	
Chromium, +6	µg/L	11	16	32	
Cobalt	µg/L	5	436	872	
Copper*	µg/L	13.2	27.6	55.2	
Lead*	µg/L	5.8	148.5	298	
Mercury**	µg/L	0.0069	2.4	4.9	
Nickel*	µg/L	235	2111	4221	
Selenium	µg/L	5	20	40	
Silver*	µg/L	1	4.5	9.1	
Thallium	µg/L	0.56	64	128	
Zinc*	µg/L	158	174	349	
ORGANICS					
Acenapthene	µg/L	12	41	81	
Acrylonitrile (C)**	µg/L	0.89	1140	2281	
Alachlor (C)**	µg/L	59	800	1600	

Anthracene	µg/L	0.029	0.78	1.6	
Atrazine (C)	µg/L	10	323	645	
Benzene (C)**	µg/L	114	4487	8974	
Bromoform	µg/L	466	2900	5800	
Carbon tetrachloride (C)**	µg/L	5.9	1750	3500	
Chlordane (C)**	µg/L	0.00029	1.2	2.4	
Chlorobenzene	µg/L	10	423	846	
Chloroform (C)	µg/L	224	2235	4471	
Chlorpyrifos	µg/L	0.041	0.083	0.17	
DDT (C)**	µg/L	0.0017	0.55	1.1	
1,2-Dichloroethane (C)**	µg/L	190	45050	90100	
Dieldrin (C)**	µg/L	0.000026	1.25	2.5	
Di-2-ethylhexyl phthalate (C)	µg/L	2.1			
Di-n-Octyl phthalate	µg/L	30	825	1650	
Endosulfan	µg/L	0.031	0.28	0.56	
Endrin	µg/L	0.016	0.09	0.18	
Ethylbenzene (C)	µg/L	68	1859	3717	
Fluoranthene	µg/L	20	199	398	
Heptachlor (C)**	µg/L	0.00039	0.26	0.52	
Heptachlor epoxide (C)**	µg/L	0.00048	0.27	0.53	
Hexachlorobenzene (C)	µg/L	0.00024			
Lindane (C)**	µg/L	0.036	4.4	8.8	
Methylene chloride (C)**	µg/L	1561	9600	19200	
Naphthalene	µg/L	81	409	818	
Parathion	µg/L	0.013	0.07	0.13	
Pentachlorophenol***	µg/L	5.5	24.8	50	
Phenanthrene	µg/L	2.1	29	58	
Phenol	µg/L	123	2214	4428	
Polychlorinated biphenyls (C)**	µg/L	0.000029	1	2	
1,1,2,2-Tetrachloroethane (C)**	µg/L	13	1127	2253	
Tetrachloroethylene (C)**	µg/L	8.9	428	857	
Toluene	µg/L	253	1352	2703	
Toxaphene (C)**	µg/L	0.0013	0.73	1.5	
1,1,1-Trichloroethane	µg/L	263	2628	5256	
1,1,2-Trichloroethylene (C)**	µg/L	120	6988	13976	
2,4,6-Trichlorophenol	µg/L	2	102	203	
Vinyl chloride (C)	µg/L	9.2			
Xylenes, total	µg/L	166	1407	2814	

* Based on a background pH of 8.0.
** Use FAV or 200 x chronic for the end-of-pipe acute standard, whichever is lower.
*** Based on a background hardness of 160 and an effluent hardness of 160.
(C) indicates the chemical is a carcinogen. (3A) indicates the chloride standard is 50 mg/L for 3A waters.
(AL) indicates these values are special action limits.

Example 1.20-1: Estimating pollutant loadings

A planner wishes to compare the predevelopment and postdevelopment pollutant loadings for a proposed commercial development. A detention pond that meets the criteria in this handbook is planned to reduce pollutant loadings as well as to reduce peak discharges from the site. The following procedure is used to evaluate the pollutant loadings:

1. Compile site data:
   Average annual rainfall: 30 inches (from Figure 1.10-1)
   Predevelopment impervious area: 5%
   Postdevelopment impervious area: 80%

2. Compute runoff coefficient (R) using Equation 1.20-3:
   Predevelopment R = 0.0855
   Postdevelopment R = 0.69

   1. Estimate predevelopment mean concentrations and compute annual loadings. In this case, monitoring data were not available, so values from Table 1.20-1 and Table 1.20-2 were used. Equation 1.20-4 was used to compute annual loadings. Values for C were obtained from Table 1.20-2, Elm site.

Pollutant	**Mean Concentration (mg/L)**	**Annual Loading (lb)**
Chemical oxygen demand	65.0	6,029.0
Lead	0.005	0.46
Zinc	0.012	1.1
Total phosphorus	0.35	32.0
TKN	2.1	190.0

3. Estimate postdevelopment mean concentrations and pollutant loading, using the same procedure as above. Values for C were obtained from Table 1.20-2, Sandburg site.

Pollutant	**Mean Concentration (mg/L)**	**Annual Loading (lb)**
Chemical oxygen demand	138.0	103,000
Lead	0.19	140
Zinc	0.185	140
Total phosphorus	0.63	470
TKN	2.5	1,900

4. Estimate postdevelopment loadings after installation of the detention pond.

   Long-term removal efficiencies are based upon the performance data presented in the detention pond section of this handbook.

Pollutant	**Long-term Pollutant Removal (%)**	**Annual Loading with Pond (lb)**
Chemical oxygen demand	95	5,200
Lead	97	4.3
Zinc	80	28
Total Phosphorus	70	140
TKN	40	1,100

Chapter 2

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2.00 BEST MANAGEMENT PRACTICES

2.10 BMP SELECTION

WHAT IS A BMP?

The following definitions are taken from Minn. Stat. §103F.711, Minnesota Clean Water Partnership Act:

> "**Best Management Practices**" are practices, techniques, and measures that prevent or reduce water pollution from nonpoint sources by using the most effective and practicable means of achieving water quality goals. Best management practices include, but are not limited to, official controls, structural and nonstructural controls, and operation and maintenance procedures.
>
> "**Official Controls**" are ordinances and regulations that control the physical development of the whole or part of a local government unit or that implement the general objectives of the government unit.

BMP SYSTEMS

A treatment system consists of a series of best management practices (BMPs). Such systems may include multiple management options, ranging from street sweeping and structures to open space and litter control laws. Although stormwater ponds and wetland-treatment systems are most often the tools for treatment and storage of urban runoff, they are only some of the tools in this process.

PRIORITIES

Address the appropriate BMPs by priority:

1. Avoid adverse impacts.
2. Minimize unavoidable adverse impacts.
3. Mitigate unavoidable adverse impacts.

AVOIDANCE

It is generally the policy of this manual that the first and best BMP is to avoid impacts.

Avoid development-related construction activity in the most sensitive areas. For example, avoid development along the shorelines of lakes or streams, in natural drainageways, or in areas dominated by steep slopes, dense vegetation, porous soils, scientific and natural areas, or other identified resources. Implementing avoidance measures may require zoning and development policies that specifically limit these options.

MINIMIZATION

As development occurs, there is a need to develop policies that reproduce predevelopment hydrologic conditions. This implies looking at reproducing the full spectrum of hydrologic conditions, including peak discharge, runoff volume, infiltration capacity, base flow levels, ground water recharge and maintenance of water quality.

A comprehensive approach to hydrology involves the entire context of site planning. The issues of runoff volume, infiltration recharge, and water quality revolve around the amount of impervious surface required by development and its configuration in terms of its relationship to drainage paths and vegetative cover.

One goal should be to preserve and utilize the natural drainage system. Keep pavement and other impervious surfaces out of low areas, swales and valleys. For example, a site plan should keep roads and parking areas high in the landscape and along ridges wherever possible.

Try to avoid connecting streets, roofing and parking areas with pipes or other structures. Utilize natural topography and vegetated waterways to convey acceptable levels of runoff.

Fit development to the terrain by choosing road patterns that provide access schemes that match the land form. For example, in rolling or dissected terrain (typical in much of Minnesota), use strict street hierarchies with local streets branching from collectors in short loops and cul-de-sacs along ridge lines. This approach results in a road pattern that resembles the branched patterns of ridge lines and drainage ways in the natural landscape. Road patterns like these facilitate the development of plans, which work with the land form and minimize disruption of existing grades and natural drainage. For more information, see chapter 3 and Figure 3.30-1.

These measures are more difficult to achieve than it appears, because they go against long-established policies, which too often increase flows and destroy the waterways we wish to utilize.

MITIGATION

Treatment is mitigation for unavoidable impacts.

Any alteration of the drainage and ecological system can have positive and negative environmental impacts. As Schueler (Schueler *et al.*, 1992) points out: "…systems, which offer reliable pollutant removal and longevity, tend to be associated with the greatest number and strongest degree of secondary environmental impacts. Careful site assessment and design are often required to prevent stream warming, natural wetland destruction, and riparian and habitat modification."

The Metropolitan Washington Council of Governments (MWCG) studied temperature and dissolved oxygen effects from four BMPs: (1) infiltration dry pond, (2) extended-detention artificial wetland, (3) extended-detention dry pond and (4) wet pond (Galli, December 1990).

The MWCG researchers concluded that none of the four BMPs was "thermally neutral." All four BMPs caused a rise in temperature and each violated Maryland standards some of the time. Temperature-standard violations occurred under both base-flow and storm-flow conditions. The infiltration dry pond produced the smallest temperature increases, whereas the wet pond had the highest recorded maximum change in temperature.

The MWCG recommends a long-term, holistic approach to watershed management. Its BMP design recommends increasing the performance of infiltration devices by improving the infiltration design capacity and intentionally oversizing the basins. The design also recommends buffer strips and shading of pilot and riprap outflow channels by landscaping or other means.

The MWCG recommends carefully examining long periods of extended detention control. It recommends a six- to 12-hour detention-period limit be established for sensitive areas, and that shading in the storage pool be required. In addition, the MWCG recommends more research on the case-specific effects of BMPs and their effectiveness at controlling temperature increases; water temperature monitoring for thermally sensitive areas should be greatly increased.

Even if a constructed system of BMPs functions as expected in terms of pollutant removal, other potential impacts could result.

BMP SELECTION OPTIONS

Select and implement BMP options on a system-wide, regional, and waterbody basis, as appropriate to meet the system goals. Also, determine the appropriate measures after considering a variety of factors, including:

- the characteristics of the resource to be protected,
- the feasibility of implementation,
- public demands and
- governmental requirements.

An application for a National Pollutant Discharge Elimination System (NPDES) permit by the City of Minneapolis (Minneapolis, City of, 1991) utilized a tiered or prioritized process for evaluating pollutant management in its stormwater-treatment system (Table 2.10-1). Many of these BMPs can be implemented through education or regulation. Six groups of BMPs listed here are based on the primary implementation method that is likely to be effective. In general, the least-impacting level that will solve the problem should be used.

Note in Table 2.10-1 that structural methods and treatment were in the last tier level. This prioritization is due to the expense and physical alteration necessitated by treating runoff after it is generated. If it is feasible to meet the project objectives, including protection of downstream water-quality characteristics, without structural methods, such as construction of stormwater ponds, this is usually more cost effective and creates less disruption of the community.

SELECTION CONSIDERATIONS

Temperature

Ponds designed to hold large volumes of water to settle solids have a tendency to raise water temperatures. This can lower the concentration of dissolved oxygen in a pond and release phosphorus and toxics that are sensitive to pH and other chemical changes due to low oxygen. Anaerobic conditions or excess production of algae could be other secondary impacts from the construction of ponds.

Table 2.10-1 A list of potential best management practices

Information and Education
- Catch basin stencils
- Erosion control information
- Fertilizer and pesticide application
- Illicit dumping and littering information
- Landscaping information to reduce runoff
- Maintenance of lots (parking and vacant)
- Proper storage of chemicals
- Proper yard waste disposal
- Information on hazardous waste and used motor oils

Ordinances and Regulations
- Erosion-control ordinances
- Comprehensive management plans for developments
- Elimination of illegal connections
- Fertilizer and pesticide licensing
- Illicit dumping and littering enforcement
- Land use controls
- Landscaping requirements to reduce runoff
- Special commercial or industrial requirements
- Pet ordinances

Elimination of Discharges
- Infiltration basins
- Pervious structures
- Diversion or off-line infiltration devices

Source Controls by the City
- Limiting infiltration to storm sewers
- Effective use of deicing chemicals
- Management of hazardous waste and used motor oils
- Management of commercial and residential yard wastes
- Monitoring programs
- Storm sewer outlet and streambank erosion prevention and maintenance
- Spill response and prevention
- Street cleaning
- Storm sewer maintenance

Minor Structural Controls
- In-line sediment traps
- Skimmers and separators

Treatment Measures
- Detention basins
- Stormwater-treatment facilities
- Swirl concentrators
- Alum treatment

Modified from: City of Minneapolis, 1992

Aesthetics

The appearance of stormwater ponds varies tremendously depending upon the desires of the local community, the amount of money available for aesthetic work, such as landscaping, and the intended function of the pond or system of ponds. The trend in the Twin Cities area is to incorporate stormwater ponds into parks and recreational areas. Safety and aesthetic concerns can often be addressed together through appropriate use of vegetation.

There are many good examples of multiple-use facilities that incorporate stormwater detention into the provision of accessible recreation. Recent projects have created permanent areas of open water in wet ponds that are integrated into walking trail systems and other features.

The development of multiple-use facilities depends upon the support of local government and the availability of funds.

Effect on Other Resources

When planning a BMP, consider the effect it will have on other resources. Without proper design and planning, your BMP may simply shift a water-quality problem elsewhere. Improperly designed BMPs can adversely affect stream temperature, peak-flow timing, aesthetics, and ground water. Fish and wildlife can also be adversely affected. Studies have shown that pollutants, such as trace metals, can bioaccumulate in plants and fish that live where sediment from urban storm water is trapped. Many BMPs trap pollutants that need to be disposed of in an environmentally sound manner.

The potential for odor, insects, weeds, turbidity and trash are also important to residents who live near structural BMPs. With regular maintenance, these problems can usually be overcome or be made very temporary.

Physical Site Suitability

BMPs should only be used in areas where the physical site characteristics are suitable. Some of the important physical site characteristics are soil type, watershed area, water table, depth to bedrock, site size and topography. If these conditions are not suitable, a BMP can lose effectiveness, require excessive maintenance or stop working after a short while.

Unfavorable site conditions can often be overcome with special design features. For example, the bottom of a detention pond can be sealed to prevent seepage at a site where a permanent pool is desired. In other cases, a practice will be excluded from consideration when a site presents impractical conditions. An example would be where a high water table or clay soils eliminate an infiltration basin from consideration. The physical site conditions must be examined for each practice.

Maintenance Requirements

Stormwater ponds, as well as wetlands or other areas that receive stormwater flows, require periodic maintenance, such as disposal of trash and sediment. In fact, maintenance is an important part in the operation of any BMP. The initial design of a BMP should take maintenance requirements into account. A feature, such as a forebay in a detention pond, may increase annual maintenance costs slightly, but the interval between costly sediment cleanouts of the whole pond may be extended significantly. Locations for disposal of material should be taken into account during this phase of planning a BMP.

Cost Effectiveness

A continuous tradeoff exists between building ponds and other land and resource commitments. Pond construction and maintenance can be expensive and may reduce the availability of development sites. This is a frequent concern of real-estate interests.

Conversely, stormwater ponds may increase property value as well as aesthetic amenities to the neighborhood. These same ponds may reduce the cost of constructing downstream storm sewers or providing flood-prevention measures.

Economics is an important consideration in the selection of BMPs that will achieve the water-quality goal at the least cost. This should be considered when selecting BMPs and deciding how they will be implemented. To properly compare alternatives, all costs for the design life of a BMP should be included. These include expected maintenance costs as well as the initial costs for land, engineering and construction.

To create a true economic picture of a BMP, benefits other than water quality and flood prevention should also be considered. Some benefits, such as increases in land values for property next to an attractive detention pond, are direct economic benefits. Other benefits, such as incidental recreation or wildlife benefits, may be more difficult to quantify.

2.20 BMP SYSTEMS

It is very important to adopt an interdisciplinary approach when designing BMP systems. Create a design team as an integral part of this approach. Members of the team should have expertise in stormwater engineering, wetland ecology and other natural-resource-management skills, such as landscaping and construction of BMPs. The design team should work together through a four-stage process that begins with a watershed assessment and ends with site management. The entire sequence may take several years.

Table 2.20-1 outlines the tasks required for each stage of BMP-system planning and construction. These tasks are suggested with the realization that designing a BMP system is too complex and site-specific to be reduced to a "cookbook" guidance. Rather, the tasks are intended to help the design team adopt and modify the process to meet local conditions and plan-review requirements.

Table 2.20-1 Stages of stormwater-treatment system design and construction

1. **Develop the watershed plan for stormwater-treatment systems**
   - Inventory wetlands, lakes, flowages and streams.
   - Consider potential BMP sites.
   - Establish management goals for waters.
   - Determine growth rates and ultimate development.
   - Design a system that accommodates this plan without resource destruction.
   - Establish a funding mechanism to fund studies and implement a plan.
2. **Develop the on-site concept plan for the BMP system.**
   - Locate flow patterns and discharge points from the area.
   - Protect local resources and unique features.
   - Locate potential treatment options.
3. **Refine the BMP system design for each site.**
   - Design the BMP system for maximum pollutant removal.
   - Incorporate standard design features into the system.
   - Develop a plan for the BMP system and its aesthetic and habitat components.
4. **Implement and maintain the system.**
   - Prepare the site and construct the treatment system.
   - Establish and maintain the site and surrounding areas.
   - Inspect, manage, monitor and maintain the treatment system after construction.
   - Re-evaluate and adapt the system as needed.

Stage 1: Watershed Plans

Inventory and analyze the physical and natural features of the watershed to determine which treatment system is realistic. Plan to meet stormwater and water-quality goals. This should be accomplished as soon as possible. Key feasibility factors include:

Inventory. The location and quality of all aquatic systems, including lakes, streams, springs and wetlands, and important upland features, such as mature forests, should be carefully delineated. Potential BMP sites should be identified.

Management Goals. Establish goals and functions for significant water bodies, such as lakes or wetlands. Goals should be based on the characteristics of the water bodies. For example, the influx of phosphorus and total suspended solids (TSS) to lakes may require treatment to prevent eutrophication, while wetland vegetation may need to be protected from drainage and inundation. Streams may require erosion-control measures to protect the banks.

BMPs should generally not be constructed in natural wetlands. The exceptions to this rule should be based on plans that protect the wetland functions and values. Stormwater-wetland conflicts can often be avoided if overlay maps are developed that show all existing wetlands and other pertinent features, such as existing and proposed drainage systems.

Assess Environmental Constraints. BMP systems should not overload the hydraulic or nutrient capacity of natural stream or wetland systems.

Protect Unique Systems. Streams capable of supporting trout may require special protection from suspended solids and increased temperature. Infiltration may be required.

The use of shade strips along a stream will help maintain lower water temperatures. For example, the Minnesota Department of Natural Resources Forestry guidelines for trout streams suggest a 50-foot-wide filter strip along streams where the slope exceeds 10%. The strip not only shades the stream surface, but allows the overland flow to be cooled as it passed under the forest canopy.

Control runoff from industrialized areas or areas with a potentially significant loading of pollutants, such as road salts and deicing compounds.

If the contributing drainage area to a proposed stormwater-control system is larger than 100 acres, flow-control and channel-protection measures should be seriously considered.

Determine Ultimate Development. Zone and restrict uses that are clearly not compatible with the stormwater-management and water-quality goals for the system.

Design a System. The system should meet all management objectives, not just stormwater control.

Establish a Funding Mechanism. Establish and maintain a reliable and effective funding system. Area charges or utility assessments for storm water have been shown to be an effective method to finance new systems, maintain existing systems and fund system improvements. We recommend a “surface water utility” or other permanent mechanism be implemented.

Stage 2: On-site Assessment Plan

The second design stage involves the selection and adaptation of basic BMP designs to a specific area.

Staking the Site. The team should visit the site to locate unique features, flow patterns and discharge points from the area. An attempt should be made to identify and protect local resources and unique features.

Consider Potential Treatment Options. The design team reviews the overall development plan to find opportunities to make the BMP system easier to establish. For example, the possibility of regional ponds or construction of new wetlands might be explored. Similarly, the site plan can be adapted to designate protected areas, such as extending “tree-save” areas to retain forest cover, wetland buffers, or provide buffer-area links to increase contiguous habitat area.

Assess Your Opportunities. The concept design for the BMP system should explicitly consider the method of runoff conveyance to the stormwater-treatment system. Decide whether the treatment system will be on-line or off-line, and how it will manage large- and small-design storms.

Stage 3: Refine the Stormwater-Treatment-System Design

Stage 3 is the design stage, where the design team refines the plans, including the geometry and volume of the stormwater ponds, hydraulics of the conveyance systems and other BMPs, to optimize pollutant-removal performance.

The design team should select the most appropriate BMP-system design, based upon the results of the feasibility analysis conducted in Stage 1. The basic design is adapted to a concept plan, which is submitted to the appropriate agencies for preliminary approval.

Design features intended to accommodate operation and maintenance activities should be incorporated into the final design.

Permanent easements should be obtained to provide access for activities, such as removal of sediment removal and maintenance of pond outlets.

Stage 4: Implementation and Maintenance

A plan outlining operation and maintenance activities for the site should be developed. Site-specific BMPs should be developed, especially for projects proposing to discharge stormwater runoff to waterways or wetlands. Often, these BMPs should include a schedule for removing sediment from retention basins and other maintenance measures.

Projects that require a NPDES permit may require specific BMPs during construction. A stormwater-management plan is generally required under the permit to manage pollutants in runoff from the site during and after construction. Federal, state and local units of government may require other permits also.

Design needs to be continued through the operation-and-maintenance phase. Measures that need to be addressed include:

- establishing and maintaining the site and surrounding areas;
- inspecting, managing, monitoring and maintaining the treatment system; and
- re-evaluating and adapting the system as needed.

CHAPTER 3

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3.00 COMPREHENSIVE STORMWATER POLICIES AND PLANS

3.10 STORMWATER-MANAGEMENT POLICIES

COMPREHENSIVE POLICIES

The stormwater-management process must be a comprehensive program to manage storm water for aesthetics, flood control, pollution control and all other appropriate purposes. It involves public and intergovernmental participation. Local government should analyze the system-wide needs of the community, addressing the appropriate measures for the site, watershed, region or water body.

Water-quality Goals

The National Urban Runoff Program (NURP) (USEPA, December 1983) studied a variety of treatment systems and found that 90% removal of total suspended solids (TSS) is achievable in well-designed ponds. Significant removal of other pollutants, such as phosphorus, can also be expected.

Water Quality Volume

In Minnesota, over 90% of the daily precipitation events are under one inch (See chapter 1, Figure 1.10-6). These rainfall events also account for about 80% of the cumulative runoff and proportionately large amounts of the pollutant loading associated with these rainfalls (Pitt, 1998). The pollutant loading is more closely associated with total runoff volume than with peak runoff rates.

Large-storm events are important; but for protection of water quality and wetland preservation, small-storm hydrology is a critical component of the hydrologic investigation. The 1.25-inch rainfall event has been selected as the design event that should be used to best evaluate water-quality impacts of urban development. The use of this event as a design parameter is explained in chapter 5.

Developing Local Goals

Selection of the optimal mix of best management practices (BMPs), including stormwater ponds, depends on the goals that are established for the system and the nature of the project site and watershed.

Important factors to consider include:

- Environmental Goals
    - Pollutant-removal targets: phosphorus, total suspended solids, metals, etc.
    - Temperature changes
    - Downstream channel erosion protection
    - Wetland creation
    - Wildlife habitat

- Community Acceptance
  - Safety risks
  - Construction costs
  - Maintenance costs
  - Land-consumption costs
- Nature of the Watershed
  - Developed: retrofit options
  - Undeveloped: prediction of future development
- Selection of Proper Treatment System
  - Selection of ponds
  - Selection of associated BMPs

3.20 RESOURCE-PROTECTION POLICIES

COMPREHENSIVE PLANS

Stormwater discharges to water bodies may be a significant portion of the comprehensive stormwater and surface-water runoff-management plan developed by local units of government. Requirements of the Metropolitan Area Surface Water Management Act and other applicable planning requirements should form the basis for comprehensive review of stormwater and water bodies plans. As with all plans, the first step should be a survey of existing information, including a mapping of all the water bodies in the watershed and associated normal flow paths.

RESOURCE INVENTORY

It is recommended that the local unit of government complete the inventories of existing resources. Existing information, such as the Protected Waters Inventory (PWI/MDNR) and the National Wetland Inventory, U.S. Fish and Wildlife Service (NWI/USF&WLS) or the Watershed Heritage Program (Minnesota Department of Natural Resources) can be used as a starting point for these inventories. Any survey information must be field verified. Much of the original aerial photography was made over 10 years ago, so the surveys can be used only as a guide to field activities. Field visits will be necessary to verify NWI information. Wetlands should be identified in the inventory and classified according to their appropriate wetland sensitivity group (Eggers, 1997; Minnesota, State of, June 1997). The size should be estimated and the surface hydrologic connections should be recorded for each water body identified on the inventory.

Classification of Water Bodies

A visit should be made to a water body to determine its type. Figures 3.20-1 through 3.20-4 contain a fairly comprehensive listing of wetland types and their adjacent deep-water habitats, including a description of their sensitivity to hydraulic changes.

Assess Quality and Condition

An assessment of water-body quality and condition is probably best conducted using a methodology that evaluates the condition of the biological community. The functioning of many water-body uses is directly related to the biological integrity, since the biota will reflect the overall health of the system. Therefore, an assessment of the condition of a water body is best based on an evaluation of the relative "biotic impoverishment" (such as provided by Karr, 1993).

Two strategies are used to assess the quality and condition of a water body. The first is a quantitative-research method that is resource intensive. This method may be necessary to assess identified high-priority water bodies and continue to monitor their relative condition.

The second strategy is a rapid/practical assessment that is more qualitative and based on best professional judgment. This is an appropriate method for local government staff to conduct or to contract out for evaluation of each water-body basin or complex within the watershed. The Minnesota Routine Assessment Methodology (Minnesota Interagency Wetland Group, Board of Water and Soil Resources) is an example of a method that can work for this type of assessment.

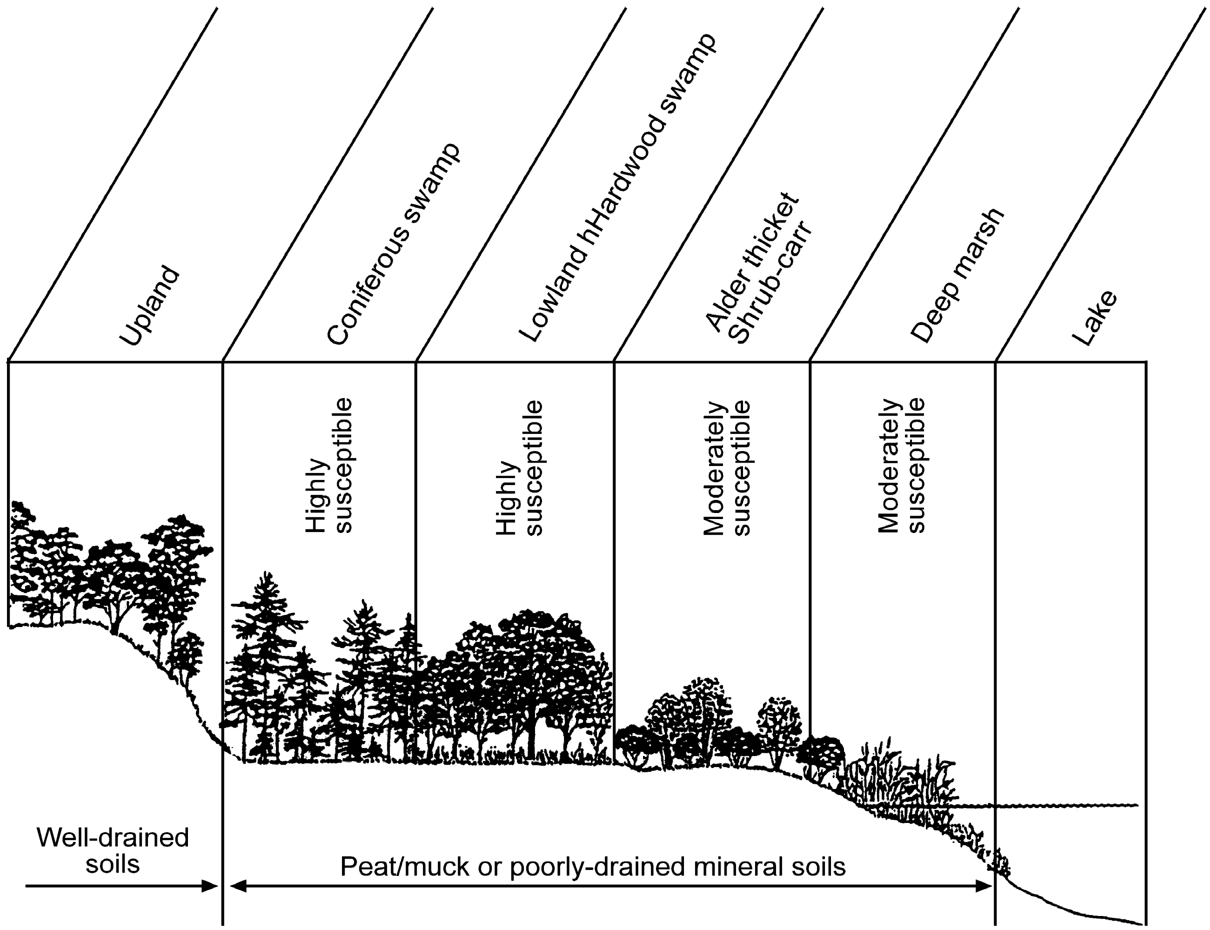


Figure 3.20-1 Susceptibility of wetlands to stormwater input: plant communities in a lake basin

These two assessment methods vary greatly in the precision of the data collected. To reduce assessor bias, both methods should include least-disturbed reference water bodies. Once identified, these least-disturbed water bodies should be used as standards in making judgments about the condition of the assessed water bodies. It is recommended that three reference water bodies be identified for each of the various hydrogeomorphic water body classes found within the watershed -- for example, depressional water bodies, riparian wetlands, lake-fringe wetlands, and peatlands (Brinson, 1993).

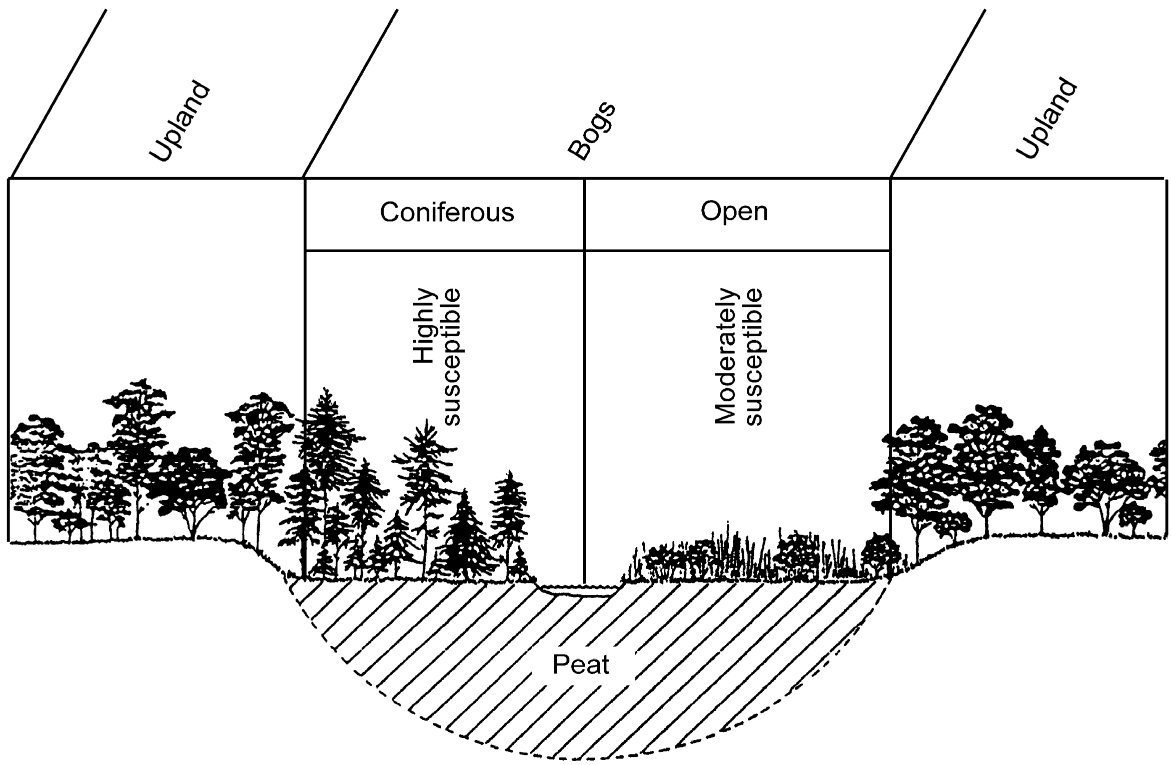


Figure 3.20-2 Susceptibility of wetlands to stormwater input: generalized cross section of a bog

Water-body quality can be assessed as excellent, moderate or highly impacted, depending on the extent to which human activities have affected the water body. Water bodies should be evaluated using the following criteria:

Excellent-quality water bodies. These water bodies remain in a least-impacted condition and, as such, typically possess very diverse vegetative assemblages. Strata are well developed and composed of native species. Non-native species, if present, are infrequent and do not comprise significant relative cover percentiles. Water bodies that support rare, threatened or endangered species are likely to be included as high-quality water bodies.

Moderate-quality water bodies. Areas that have been subjected to varying degrees of human disturbance, but still provide important ecological water body functions and values, are considered to be of moderate quality. An example would be a partially drained wetland complex composed of 60% cover of reed canarygrass and 40% cover of native species, such as sedges. These wetlands often provide important wildlife habitat and water-quality benefits.

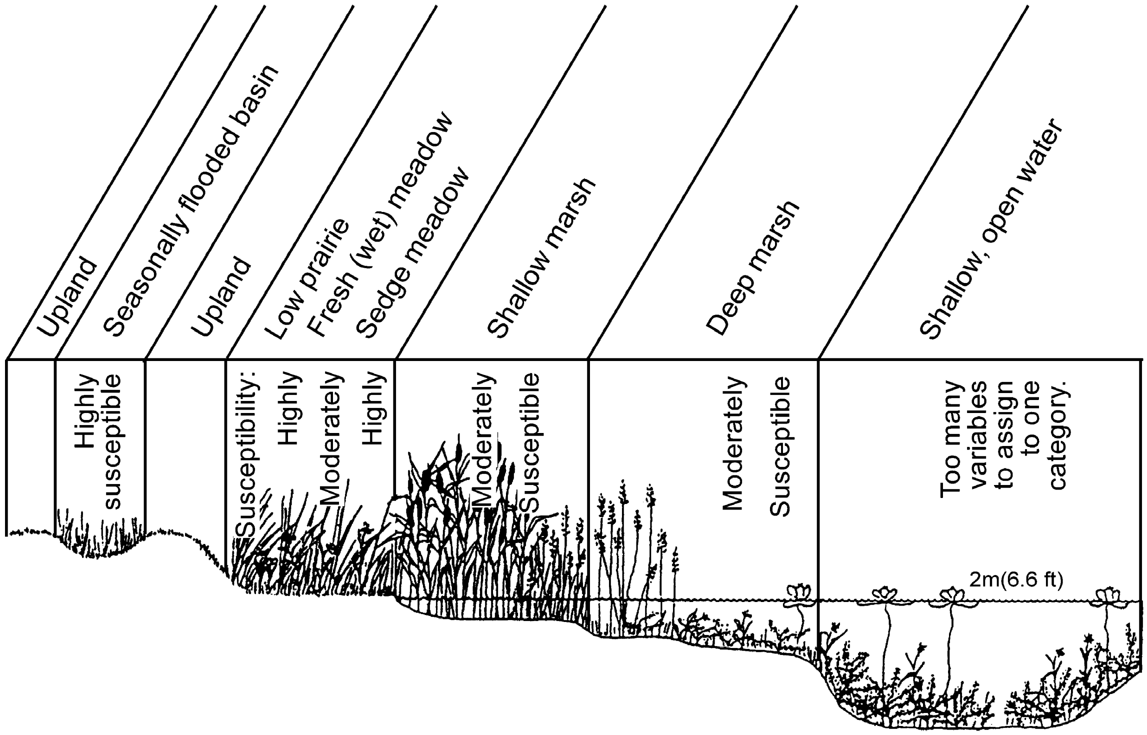


Figure 3.20-3 Susceptibility of wetlands to stormwater input: meadow-marsh-open-water complex

Highly impacted water bodies. Areas that have been so severely degraded that they have little vegetation, or the vegetation is dominated by non-native species or by monotypic stands of species, such as cattails, are considered highly impacted. Hydrologic and/or biological processes have been greatly altered and inputs of urban storm water will have minimal impacts. Examples of highly impacted water bodies are abandoned gravel pits, nutrient-loaded water bodies, stormwater-detention basins, and dredged areas within water bodies that result in extreme hydrologic modifications.

Significant Resources

Water bodies that have been designated by local, state or federal action as providing unique qualities, such as recreational, scientific, educational or aesthetic uses, would be considered significant resources. Other significant water bodies would include those that have been restored for specific purposes, such as water-quality improvement or wildlife, industrial or agricultural uses. Water bodies known to be important to local recreation activities, such as hunting, fishing or bird watching, and water bodies occurring within parks, shoreland areas and conservation corridors would also be considered to be significant resources. Forested areas may also be considered significant resources and should be designated for protection from destruction by removal, inundation and flooding.

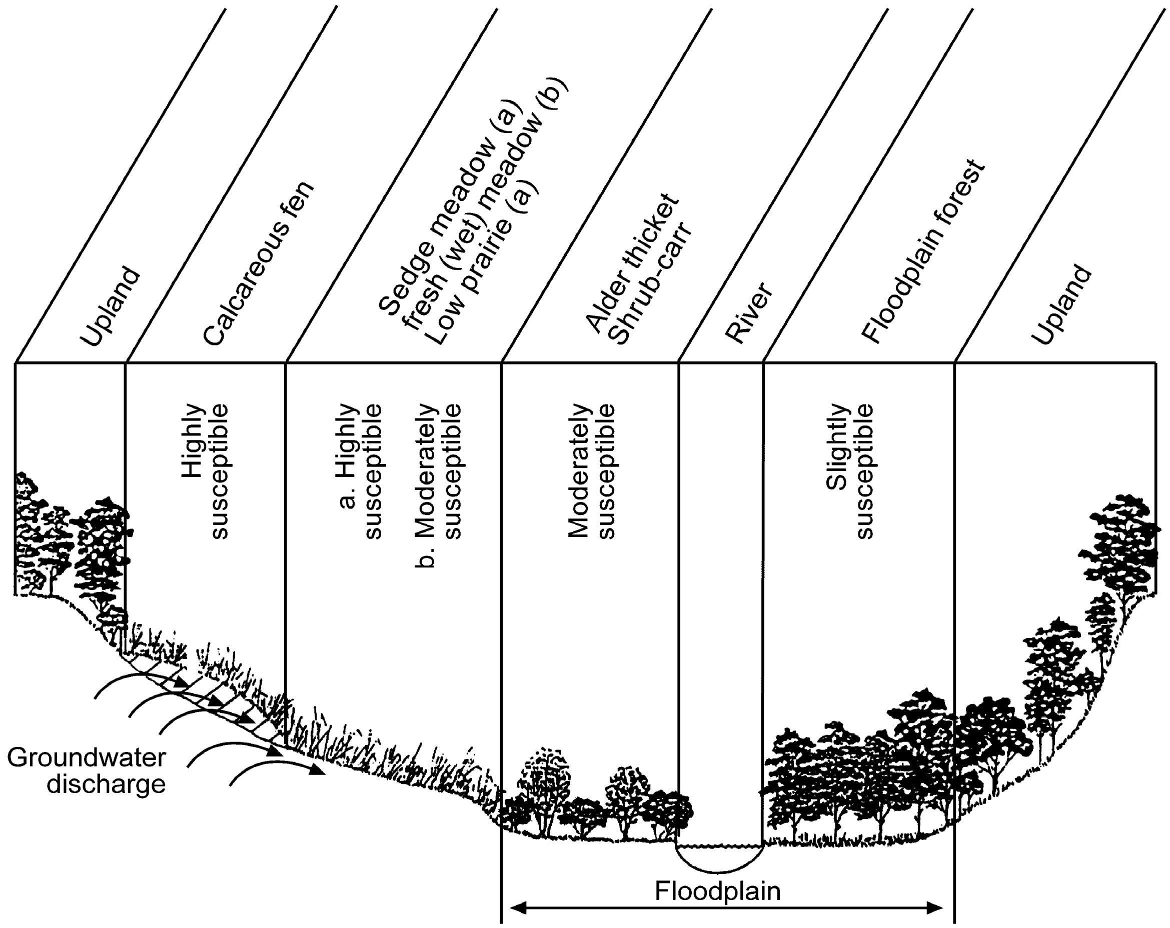
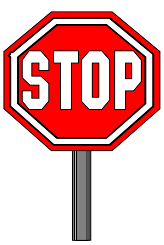


Figure 3.20-4 Susceptibility of wetlands to stormwater input: plant communities in a river valley



Resource-significant "red flags" warn of recognized special uses or unique features such that a water body's integrity should be preserved. Examples of such red flags include if the water body:

- is on the Minnesota Department of Natural Resources protected waters inventory (MS 1036.245).
- has a direct hydrologic association with a designated trout stream.
- borders the Mississippi or Minnesota rivers or Lake Superior.
- borders a state or federal wild and scenic river.
- has been restored or created for mitigation purposes.
- is within an environmentally sensitive area or environmental corridor identified in a local water-management plan, special area-management plan, special water-body inventory or an advanced identification study.
- is recognized as an Outstanding Resource Value Water (Minn. R. ch. 7050).

- is within a local, state or federal park, forest, trail or recreation area.
- is within a state or federal fish and wildlife management refuge or area.
- is part of an archeological or historic site designated by the State Historic Preservation Office.
- is part of a sole-source aquifer-recharge area.
- provides endangered species habitat.
- has biological communities or specie listed in the Natural Heritage inventory database.
- is recognized as an important local recreation resource.

The red flags listed above indicate that there are concerns that are local, regional or statewide that must be addressed in the evaluation.

Water bodies that involve red flags are of special concern beyond the local boundaries.

Excellent-quality water bodies of all types are very rare and becoming more rare as time and development goes on. Therefore, they are given red flags.

Highly sensitive water bodies, even of moderate quality, are red-flagged because of the care that must be taken to preserve them. Also, providing off-site compensation does not easily mitigate these types of water bodies. They often cannot be reproduced through artificial means.

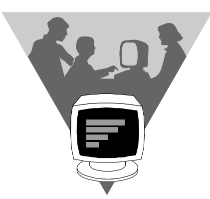
Most moderately and slightly sensitive water bodies should be protected; but importantly, they can more easily be mitigated, preferably through restoration but also through creation.

Maintaining public uses and values is a very important component of maintaining the entire function of a watershed. Piecemeal destruction of minor water bodies or changes in the hydraulic regime can significantly damage the entire system through changes in erosion, nutrients or other pollutant loading on the system.

Stormwater System Inventory

Certain water bodies, because of their position in the watershed, morphology, surface-flow connections or other physical attributes, are especially well suited to be part of a stormwater-management system. Identification of such basins does not necessarily mean they will be targeted only for receipt of storm water, though they should be highlighted in the inventory when this function is believed to be most important.

DECISION TOOLS



Information layers on water-body trends, sensitivity and condition, as well as resource significance and management needs, can be incorporated into a geographic information system (GIS) to provide easy updating and viewing. Viewing these information items as overlays will help the decision-making process.

After the data have been compiled, a process for making decisions should be developed. This should be coordinated with respective local, state and federal permitting and regulatory agencies to ensure that ecologically and socially acceptable decisions are the result. Public participation should be an integral part of the process, and it should be included early and throughout the planning.

Once local water-body-management decisions are made, the local unit of government should make a commitment to initiate a water-body-monitoring and -maintenance effort. Local citizens or schools may be recruited to carry the monitoring effort. If the local government is unable to commit to sponsoring a citizen monitoring effort, then at a minimum it should support monitoring of water bodies afforded long-term preservation. As much as possible, these monitoring efforts should include a review of individual and landscape water body functions.

Water bodies that are less sensitive to stormwater discharge, or are impaired, present opportunities for improving water-body integrity. These water bodies may be good candidates for applying guidelines for control of “storm bounce” and pollutant loading, or to modify the water body basin for improved storm treatment. In a planning context, this is not an easy decision to make, and there are no prescriptive means of further defining how these water bodies should be viewed. However, where possible, the following should be considered in making these decisions:

- relative rarity of habitat types remaining in the water bodies in comparison with historical ratios of water body types. Even if they are impaired, a diversity of water body types is preferred.
- the amount of fragmentation and isolation of a water body that would result.
- the possibility of avoiding, through zoning or other means, development or other pressures that would influence the integrity of the water body basin.
- the ability to minimize the impact of stormwater flows on the water body through consideration of alternatives.
- the relative position of the water body within the watershed in relation to other surface waters.
- greater recognition of seasonal features of water body importance, such as ephemeral wetlands, which have important forage value to migrating aquatic birds. Often these are the first waters to open up in the spring and this triggers complex cycles of certain freshwater crustaceans, such as various species of fairy shrimp.

MITIGATION OF FUNCTIONS AND VALUES

If a significant resource must be used, mitigation should be considered, especially in cases where a wetland is targeted for expanded hydrologic utilization that will not comply with the guidelines presented in this manual. If utilization will change the character of the water body and these conversions will result in changes in the uses that a water body can provide, compensation must be provided. Ideally, this compensation must replace the affected water body’s uses and function. At a minimum, compensation is intended to maintain the no-net-loss water bodies policy enacted at the local, state and federal levels of government. One of the prime questions in replacement is whether water body values can be replaced on site in the watershed or at remote locations. We highly recommend replacement within the watershed if possible. Mitigation for all lost functions and values should be provided, even if less strict regulatory and management options are allowed.

3.30 COMMUNITY PLANNING POLICIES

IMPERVIOUSNESS

While population density is important for many planning and zoning regulations, imperviousness and the way impervious surfaces drain should be considered the primary environmental planning tool, not density of units.

Impervious surface area is the portion of the land where water cannot infiltrate to the subsurface. Instead, water is conducted by gravity on the surface as overland flow. Impervious systems generally consist of roads, parking lots, sidewalks, rooftops and other impermeable surfaces of the urban landscape. While imperviousness is fairly easy to define, it may be hard to identify in practice. While asphalt and concrete are generally considered impervious, they have been found to allow significant infiltration under some conditions. Gravel surfaces can be pervious, but if they contain a high percentage of fines, they may become impervious. Lawns are considered pervious, but disturbed urban soils may allow only minimal infiltration (Pitt, 1994).

Criteria

Imperviousness is still a very useful indicator by which to measure the impacts of land development on aquatic systems. Research conducted in many geographic areas and employing many different methods of analysis has led to surprisingly similar conclusions regarding the nature of impervious surfaces and stream degradation: Stream degradation occurs at levels of imperviousness from approximately 10 to 20% of the watershed. (Schueler, Fall 1994)

One classification for urban stream quality indicates that streams, particularly in watersheds where no BMP strategies are in place, can be stressed from 1 to 10% of impervious cover, impacted by 11 to 25% impervious cover, and degraded by 26 to 100% impervious cover (Schueler, 1994b).

Imperviousness is a good indicator of the impacts of land development on a watershed. It is composed of two primary components, the buildings and the transport system. “Buildings” include homes, shopping centers and industries. The “transport system” consists of roads, driveways, parking lots, and walkways that people use to get from one place to another. The transport component often exceeds the rooftop component in terms of total impact and total impervious area created.

The impacts of impervious surfaces are many. Bacteria in urban runoff or failing septic systems influence the closing of swimming areas in local streams and lakes. Other pollutants from the atmosphere directly deposit and accumulate on impervious surfaces. This allows the quick washoff and rapid delivery of pollutants to aquatic systems. Impervious surfaces also absorb heat, strongly influencing water temperature. Macroinvertebrate diversity drops sharply with impacts caused by increased impervious surface, as do the abundance and diversity of fish.

In addition, impervious surface increases the volume and peak flow of stormwater runoff, contributing to greater annual water-level fluctuations, resulting in stream bank and bed erosion and inundation of wetlands. When the annual water-level fluctuation in wetlands exceeds about 8 inches, the richness of both wetland plant and amphibian communities can drop sharply.

Traditional zoning methods

Municipalities have addressed the problem of impervious surface by setting the maximum density for an area based on building units. The transport component is generally not addressed. However, transport-related imperviousness often exerts a greater hydrological impact than building-related imperviousness. Runoff from rooftops can be spread over pervious areas, such as yards and grassed waterways, whereas roads and parking lots are usually directly connected to the storm-drain system.

Not only are roads generally connected to the drainage system, they also have the secondary effect of producing development with a multiplying effect on the impacts to the watershed system. Because impervious surfaces place greatly increased total flow and loadings on waterways and on aquatic systems, it is very difficult to mitigate the impacts of the impervious surfaces by BMPs. BMPs that provide stable channels, reduce pollutant loading and reduce impacts to benthic biota raise the allowable imperviousness from 35 to 60%.

Therefore, even when effective practices are widely applied, the threshold of imperviousness is eventually crossed, which results in a degraded condition.

Many policies and BMPs can be adopted to reduce the impact of impervious surfaces on the watershed. These include running the roof and roadway runoff over vegetated areas and into soils instead of storm sewers. Use of ponds and other treatment measures can also help reduce pollutant loadings and peak flows from impervious areas to some extent. However, imperviousness increases the total runoff loading of pollutants and may bring new flows, which had not been a contributing part of the watershed, into the watershed.

The relationship between imperviousness and runoff is becoming better understood, but the impact of the changes in runoff to aquatic systems is neither fully understood nor appreciated. The impact of increased runoff from the development of new impervious surfaces must be understood in terms of peak flow and total flows to fully understand the impacts on stream bank erosion, pollutant loadings and inundation effects on the biotic community.

The effectiveness of BMPs to increase the threshold of effect from impervious surfaces should be studied more carefully. The threshold beyond which predevelopment water quality cannot be maintained is not well understood and should be carefully analyzed for each situation. In addition, politically and legally acceptable regulatory programs that reflect our understanding of how impervious surface can affect the aquatic community must be developed. New methods and new ways of looking at these issues must be tried.

RESIDENTIAL DEVELOPMENT

In the past, the concept of low-density development has been used as a planning tool to protect resources. It would seem logical to limit the development to no more than 10% of the impervious cover. Of course, this could not be sustained over a large number of watersheds or a large geographic area due to the long-term physical and social infrastructure costs of this development pattern.

Many planners have proposed that the best way to minimize the impact of impervious area on a watershed is to concentrate it in highly developed clusters. It would be virtually impossible to maintain predevelopment stream quality in the watershed affected by these clusters. Many people find it troubling that it may be necessary to degrade one water body or reach in order to protect another. However, given the low level at which impervious surface can impact a water body, there is no doubt that the present systems of zoning development are already having significant impacts.

On the other hand, cluster development may offer many advantages to the municipality, developer and prospective homeowner.

“Cluster development” is defined as the grouping of all residential structures of a development on a portion of the available land, reserving a significant amount of the site as protected open space. Many communities in Minnesota and across the United States are updating their comprehensive plans and establishing ordinances to guide the development and construction of cluster developments. New ordinances are requiring design standards, and identifying open space and density standards. These key changes have prompted some communities to opt for more descriptive terminology, such as “open-space development” or “conservation subdivision design,” instead of the more traditional “cluster development.” While this use of different terminology has created some confusion, each still maintains the three basic goals of cluster development: (1) preserving open space, (2) protecting critical ecological habitat and (3) preserving agricultural land.

The useable open space created by a cluster development can serve to meet a number of community goals, such as the protection of critical ecological resources, protection of wooded areas or the preservation of farmland. Obviously, these goals overlap and have the potential to conflict with one another. For example, the protection of wildlife habitat may be incompatible with the preservation of agricultural land. However, the key benefit is the quality of life preserved by the availability of open space made possible through the clustering of units. The ultimate use of the open space is left for the landowner and community to decide.

Gross Density and Lot Size

Current zoning practices establish gross population densities based on minimum lot sizes, setbacks and widths that need to be met by developers as they design subdivisions. This leads to a development that maximizes the number of lots based on the total acreage of the parcel. For instance, if the code requires a minimum lot size of 0.5 acre and the developer has a six-acre parcel, barring major site limitations, the site will be developed with 12 residential units (see Figure 3.30-1). The gross density of this parcel is then 12 units per six acres.

Cluster development can achieve the protection of open space by establishing a gross density requirement for the parcel independent of lot size. This density requirement, rather than minimum lot size, determines the number of allowed units. For example, a parcel of six acres that has a gross density requirement of one unit per 0.5 acre will allow a maximum of 12 units to be developed on the site. If the lot size requirement is less than 0.25 acre or variable sizes, some clustering of units will be possible. The developer is still limited to 12 total units, but has the flexibility to place these units in a manner that is more responsive to the physical characteristics of the site, such as the preservation of 2 to 3 acres of commonly owned land (see Figure 3.30-1).

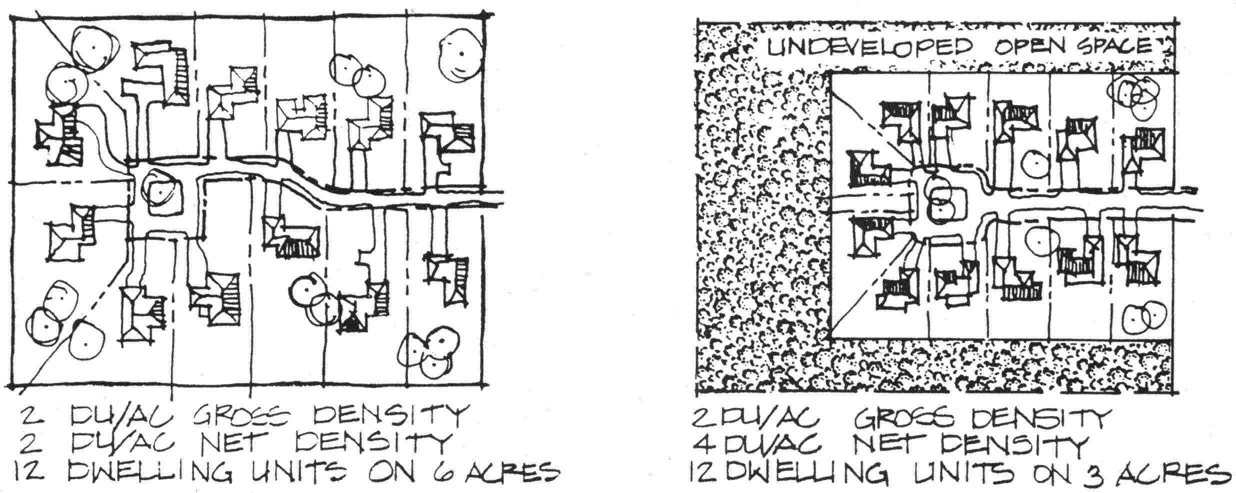


Figure 3.30-1 Cluster development using the PUD approach can result in narrower lot frontages, shorter street and utility rows plus the preservation of significant blocks of undeveloped open space.

Options for Use of Open Space

The open space created by cluster developments can be used in three ways:

1. exclusive use by residents (*e.g.,* private trails, passive recreational areas);
2. preservation of land use, such as agricultural land or wooded areas; and
3. protection of wildlife habitat.

Traditionally, open space has been reserved for recreational use by residents. The local government can encourage other options (preservation of agricultural land, wooded land and critical wildlife habitat) through comprehensive land-use planning and subdivision ordinances. Initially, the municipality needs to identify the areas that are important to the community and develop goals for them These goals can be realized through the establishment of physical design standards, density requirements and the employment of transfer of development rights or other incentive programs.

Ensuring Full Potential of Development

The intent of cluster ordinances is to develop less total land area while allowing the same number of housing units that would be allowed under traditional subdivision ordinances. Since cluster development allows the same number of housing units, it does not penalize landowners or developers financially. In fact, many governmental units allow additional units to be added to encourage this option.

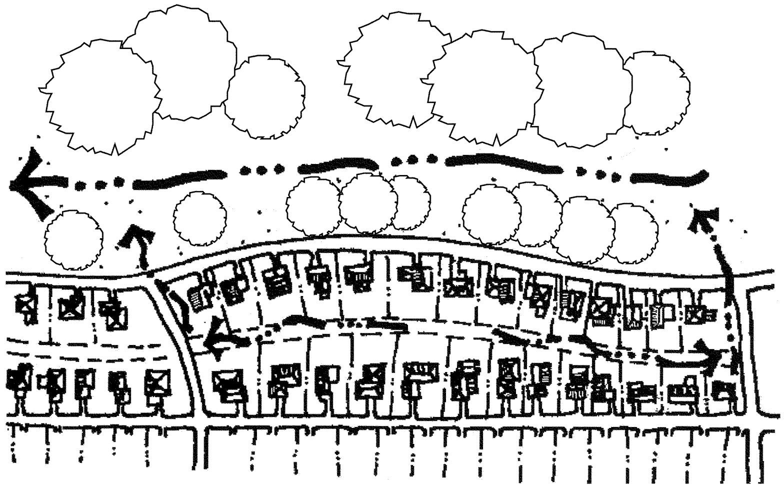


Figure 3.30-2 Example of a development that preserves a natural drainage area

Stormwater Management

Cluster developments can help create undeveloped open space for the neighborhood. The design of stormwater-management systems within cluster developments should maximize overland flow and combine the use of plants and landforms or use grass swales along drainage easements to convey water to natural drainage areas. This will help to infiltrate, slow, hold and treat runoff from new development (see Figure 3.30-2).

The use of rural technologies for stormwater management can avoid the expensive curb, gutter and storm sewer approach. Instead, the development can have a stormwater-management system that is more in keeping with the environmental constraints of the land.

Management of Common Resources

Cluster strategies leave the majority of the new development as open, shared space. Inherent in this design is the mutual ownership and management of the property. Management responsibilities within a cluster development include controlling, directing and handling all resources held in common by the homeowners. This includes, but is not limited to, open space, wastewater-treatment systems and stormwater-management facilities.

Many cluster-development ordinances mandate the establishment of a homeowners association to manage the common open space. The homeowners association is set up by the developer, who may remain a member of the association until all or a specified number of units are sold. The association is then responsible for all management and capital improvements.

In developments with many common resources, the developer may want to explore an alternative homeowners association to manage the resources.

Wastewater Management

Clustering can help limit impacts of development in areas with important natural resources or buffer zones for waters or wildlife. Minimum lot size for cluster development need not be limited by requirements for siting sewage-treatment systems. Options are available to treat sewage off site by collecting the sewage from a cluster of homes, with treatment by community treatment systems (*e.g.*,

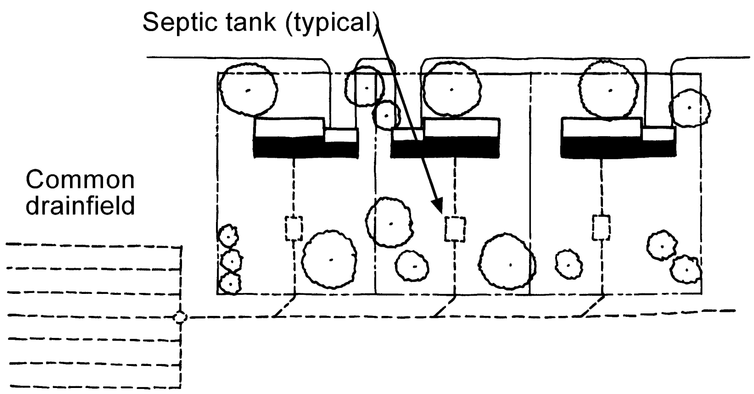


Figure 3.30-3 Typical on-site septic layout for a cluster

drainfields, package plants). These options can reduce infrastructure investment and allow placement of the systems in a way that will minimize adverse environmental impact. Figure 3.30-3 illustrates the use of a community septic drainfield as an alternative to individual systems.

Alternative systems may have additional technical and administrative requirements. Some of the issues that may need to be addressed include:

- location determinations based on site and ground-water conditions,
- design applications to maximize sewage treatment, and
- potential permit requirements.

The Minnesota Pollution Control Agency (MPCA) should be contacted for information about treatment systems related to cluster development.

Mixed Use and Nonresidential Development

Just as creating a storm-water-friendly residential clustered development requires a new way to set standards for a parcel, a similar planning process can be followed when establishing standards, such as minimum parking requirements, floor-area ratios, setbacks and allowable building types for other land-use zones. Typically, these standards are based upon a single type of use on a single parcel, regardless of what the context might be and under the assumption that peak demand for parking must always be accommodated on site. This methodology and set of assumptions are being rethought for a number of reasons, beyond stormwater management. For example, parking space requirements could be reduced for businesses and multifamily homes along a transit line or adjacent to other uses that allow a shared parking arrangement. Structured parking and two-story commercial and/or residential buildings are arrangements that reduce overall impervious surface and provide room to preserve a natural amenity or design a more attractive stormwater pond. All of these strategies are more effective within a mixed-use area where complementary activities are likely to occur. A parking space for a lunch-seeking office worker will not need to be available at a restaurant parking lot if the person works next door or downstairs. The same concept applies to determining the parking requirements for a supermarket located next to an apartment building. For more information on these ideas, see literature on livable communities, sustainable development, transit-oriented development, neotraditional planning and new urbanism.

MODEL DEVELOPMENT PRINCIPLES

In many ways, the suburban landscape is a mix of three habitats. The first habitat is devoted to the automobile, and includes roads, driveways and parking lots. The second is the habitat where we live and work, including our yards and homes. The third habitat includes the open spaces and natural areas that are relatively undeveloped. The size, appearance, location and design of all three areas are determined in large part by local subdivision codes and zoning ordinances.

The model development principles generally fall into one of three areas: (1) residential streets and parking lots, (2) lot development, and (3) conservation of natural areas. Each principle represents a simplified design objective in site planning. More detail on each principle can be found in the Site Planning Summary Sheets in chapter 4.

RESIDENTIAL STREETS AND PARKING LOTS

These principles focus on those codes, ordinances and standards that determine the size, shape and construction of parking lots, roadways and driveways in the suburban landscape.

1. Design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency, maintenance and service vehicle access. These widths should be based on traffic volume.
2. Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.
3. Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate traffic, the sidewalk and vegetated open channels. Utilities and storm drains should be within the pavement section of the right-of-way wherever feasible.
4. Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Consider alternative turnarounds.
5. Where density, topography, soils and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.
6. The required parking ratio governing a particular land use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance taking into account local and national experience to see whether lower ratios are warranted and feasible.
7. Parking codes should be revised to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.

8. Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes and using pervious materials in spillover parking areas.
9. Provide meaningful incentives to encourage structured and shared parking to make it more economically viable.
10. Wherever possible, provide stormwater treatment for parking lot runoff using bioretention areas, filter strips or other practices that can be integrated into required landscaping areas and traffic islands.

LOT DEVELOPMENT

Principles 11 through 16 focus on the regulations that determine lot size, lot shape, housing density and the overall design and appearance of our neighborhoods.

11. Advocate open space development that incorporates smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space and promote watershed protection.
12. Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.
13. Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways to link pedestrian areas.
14. Reduce overall lot imperviousness by promoting alternative driveway surfaces and driveways that are shared by two or more homes.
15. Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.
16. Direct rooftop runoff to pervious areas, such as yards, open channels or vegetated areas, and avoid routing rooftop runoff to the roadway and the stormwater-conveyance system.

CONSERVATION OF NATURAL AREAS

The remaining principles address codes and ordinances that promote (or impede) protection of existing natural areas and incorporation of open spaces into new development.

17. Create a variable-width, naturally vegetated buffer system along all perennial streams that also encompasses critical environmental features, such as the 100-year floodplain, steep slopes and freshwater wetlands.
18. The riparian stream buffer should be preserved or restored with native vegetation that can be maintained throughout the delineation, plan-review, construction and occupancy stages of development.

19. Clearing and grading of forests and native vegetation should be limited to the minimum amount needed to build lots, allow access and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.
20. Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas and promoting the use of native plants. Wherever practical, manage community open space, street rights-of-way, parking lot islands and other landscaped areas to promote natural vegetation.
21. Incentives and flexibility in the form of density compensation, buffer averaging, property tax reduction, storm water credits, and by-right open space development should be encouraged to
22. New stormwater outfalls should not discharge unmanaged storm water into jurisdictional wetlands, sole-source aquifers or sensitive areas.

ADAPTING THE PRINCIPLES FOR YOUR COMMUNITY

The following guidance is offered to township, city and county officials as they adapt the model development principles to achieve better development.

- It should be clearly recognized that the principles must be adapted to reflect the unique characteristics of each community. Further, not all principles will apply to every development or community. In some cases, the principles may not always fully complement each other.
- The principles are offered as a benchmark to guide better land development. Communities should consider the principles as they assess current zoning, parking, street and subdivision codes.
- The principles will not only protect natural and aquatic resources, but can also enhance the quality of life in the community.
- The principles should be used as part of a flexible, locally adapted strategy for better site planning.
- The principles should be considered together with the larger economic and environmental goals put forth in comprehensive growth-management, resource-protection or watershed-management plans.
- Where possible, infill and redevelopment should be encouraged to reduce new impervious cover in the landscape.
- These principles primarily apply to residential and commercial forms of development, but can be adapted, with some modifications, to other types of development.

Taken from *Better Site Design: A Handbook for Changing Development Rules in Your Community,* Center for Watershed Protection (Brown *et al.,* August 1998).

3.40 SITE PLANS

In the past, the focus of stormwater management was on reducing the frequency and severity of flooding, chiefly by leveling peak discharges from new development to predevelopment levels. Concern for volume focused only on providing adequate storage to hold a cap on peak discharge (*e.g.,* detention ponds). Waterways were specifically designed to increase hydraulic efficiency through higher velocities and smooth conveyances (*e.g.,* storm sewers, paved gutters and waterways) and to be self-cleaning. This approach implicitly accepted radical change from predevelopment hydrological conditions as a reasonable and unavoidable consequence of land development.

As concern for water quality increases, developers are finding themselves in a conflicting regulatory environment. First, they face zoning codes and development standards that specifically require significant capital investment in site improvements that reduce infiltration, degrade water quality, increase runoff volumes and boost peak discharges. Then, in the same regulations, they are also required to make further capital expenditures (for the BMPs shown in this handbook) to infiltrate runoff, improve water quality, reduce runoff volumes and level peak discharges. The loser is the consumer or home buyer.

Today, it is clear that development practices and standards that require more than the minimum amounts of impervious surfaces and the use of technologies that increase the hydraulic efficiency of the landscape, create more costly problems than they solve.

The BMPs presented in this manual provide good mechanisms for alleviating problems that cannot be avoided in the site-planning process. However, care must be exercised to avoid simply layering them on top of existing requirements and standard practices. A thorough review of land-development regulations and standards should also be made to remove archaic requirements that ultimately work against the goals of maintaining predevelopment hydrologic conditions and improving water quality. The best approach is to avoid creating a problem in the first place. One important way to avoid problems is to re-think standard approaches in terms of the broad context.

GOALS

In new development, good site planning can reduce excess runoff and the potential for erosion and sedimentation problems. The origins of many accepted site-planning standards and practices can be traced to post-World War II stormwater-management practices. These practices were derived in a context where storm water was regarded as the “wastewater” of the community, to be disposed of as quickly as possible with little regard for downstream consequences and local long-term hydrologic and water-quality impacts.

Although modern stormwater management thinking and sedimentation and erosion-control philosophies have abandoned the idea of runoff as “wastewater,” it remains a generally unacknowledged assumption for many accepted site-planning practices and current standards. As a result, local zoning and subdivision regulations often unwittingly set into motion site-planning strategies that aggravate, and often maximize, many of the problems. This means we must re-think the basic assumptions underlying site planning and development standards. A good starting point for doing this is to identify goals that would help direct the choice of practices and strategies for site development toward those which would reduce the root causes of adverse impact on hydrology and water quality. The following goals provide such direction:

- Restrict development in critical areas: shoreline, natural drainageways, steep slopes and erodible soils.
- Reproduce hydrologic conditions: preserve vegetation, provide infiltration, fit development to the terrain, and preserve and utilize natural drainageways.

RESTRICT DEVELOPMENT IN CRITICAL AREAS

The best way to avoid adverse impacts of development on runoff and water quality is to develop comprehensive site plans that avoid any construction activity in the most sensitive areas. Given the open -space requirements found in most zoning codes, this is a real option which is still too often overlooked. Avoid siting improvements along the shoreline of lakes or streams, in natural drainageways or in areas dominated by steep slopes, dense vegetation or erodible soils.

Shoreline. Construction activity is the most difficult to mitigate with respect to water quality. Vegetated shoreline is a critical part of nature's system for cleansing runoff water of pollutants. Also, once the vegetation is disturbed, shoreline erosion is dramatically increased. Runoff from construction close to the receiving waters is hard to control, making measures to reduce pollutant delivery much more difficult and expensive.

Natural Drainageways. Construction in natural drainageways destroys the natural vegetation that protects the soil from erosion and, with it, the filtering capacity of the vegetation. This type of vegetation is among the most difficult to reestablish. Natural drainageways contribute large amounts of runoff directly to receiving lakes or streams, and once disturbed, they become high-energy, high-volume conduits for moving massive amounts of pollutants to receiving waters. Site plans that disturb these areas result in much larger volumes of water to manage and treat (and much greater costs for BMPs) than would be required by using other areas of the site for the same purpose.

Steep Slopes. Generally, the steeper the slope, the greater the erosion hazard. This is because the effects of gravity and reduced friction between soil particles on steep slopes means it takes less energy for water to dislodge and transport soil particles. Development often results in making flat areas for such things as roads, buildings and lawns. Creating flat areas on steep slopes exposes more soil surface area to erosion during construction than the same action on flat slopes (Figure 3.40-1). Good site planning avoids placing houses and roads on steep slopes.

Erodible Soils. When denuded of vegetation, areas with easily eroded soils yield greater volumes of transported soil than those with erosion-resistant soils. Proactive planning can avoid disturbing erodible soils in the land development process, so that erosion and sedimentation problems will be avoided.

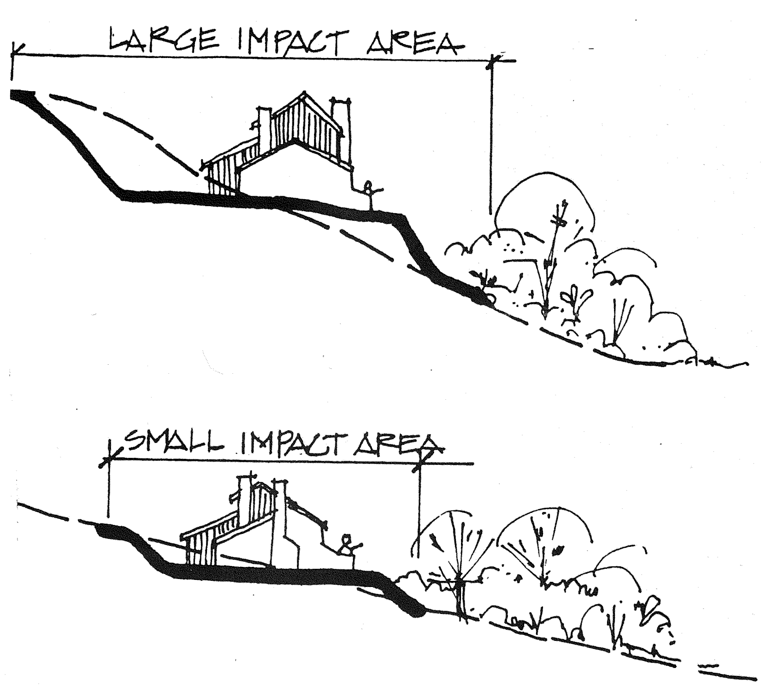


Figure 3.40-1 Making flat areas for home sites on steep slopes disturbs more land area than making flat areas on gentle slopes.

Sensitive areas can be set aside as natural open-space areas to meet open-space-area requirements. Sensitive areas can be used as buffer spaces between land uses on the site or to buffer land uses on adjacent sites as shown in section 3.30. Preserving mature woodlots not only prevents erosion, but can be used to provide visual screening and to establish entry character or boundary definition for the site. Preserved woodlots can be used to preserve views from home sites, and to provide privacy separation between home sites, such as along back property lines. Where preservation needs exceed the open-space requirement for development under straight zoning, cluster development under the planned unit development (PUD) provisions of the zoning code can usually be used to avoid sensitive areas while preserving the gross density allocated to the parcel.

REPRODUCE HYDROLOGIC CONDITIONS

Reproducing hydrologic conditions is a goal that can only be addressed comprehensively at the level of site planning (Schueler, 1987). It means looking at reproducing the full spectrum of hydrological conditions: peak discharge, runoff volume, infiltration capacity, base-flow levels, ground water recharge, and maintenance of water quality.

In the past, peak discharge was considered to be the only problem. As such, it was narrowly defined and easily solved by providing detention facilities.

A comprehensive approach is more difficult, and involves the whole context of site planning, especially in terms of standards and philosophical approach. Runoff volume, infiltration recharge and water quality are greatly affected by the amount of impervious surface. Also important is the configuration of the drainage paths, amount of infiltration and vegetative cover.

In other words, policies are needed that decrease impervious surface and that decrease pipes, sewers and ditching while providing infiltration and protecting natural systems.

Preserve vegetation. Healthy vegetative cover is an important factor in preventing erosion. Disturbance of areas with a well-established vegetative cover causes the greatest increase in erosion risk. Wooded areas with understory cover are the most runoff-absorbent types of cover in the landscape (U.S. Department of Agriculture, Soil Conservation Service, 1986). Destruction of such vegetation adds significant expense to the construction budget for clearing, and destroys trees which are an inherently valuable attribute of the site.

Destruction of a given area with dense vegetative cover produces a greater impact than destruction of the same area of sparse vegetative cover. Destruction of a large area of a given vegetative cover produces greater effects than destruction of a small area of the same vegetative cover. A good site plan preserves large areas of existing dense vegetation.

Provide infiltration. Infiltration into the soil is a natural, cheap, and often the best way to provide stormwater storage volume on a site. Infiltration reduces both the volume of runoff and the peak discharge from a given rainfall event, as well as providing treatment of water by filtration through the soil strata and recharge of ground water. The placement of impervious roofs and pavements in an area removes absorptive capacity. Site planning that locates impervious surfaces in porous soil areas creates the greatest possible change in infiltration between predevelopment and post-development conditions. Placement of the same surfaces in tight-soil areas produces the least change. By devising a site plan that avoids, as much as possible, the placement of impervious surfaces in highly porous soil areas, soil absorption of runoff in a development can be maximized. Such a strategy will pay dividends to the developer in terms of reduced volumes and peak discharges of runoff, which will require the use of BMPs for on-site treatment. It will also significantly reduce the land area that must be committed to detention facilities required for peak-discharge leveling.

Fit development to the terrain. Choose road patterns to provide access schemes that match landform. For example, in rolling or dissected terrain (typical in much of Minnesota), use strict street hierarchies with local streets branching from collectors in short loops and cul-de-sacs along ridge lines. This approach results in a road pattern that resembles the branched patterns of ridge lines and drainageways in the natural landscape, facilitating the development of plans which work with the landform and minimize disruption of existing grades and natural drainage.

Where the topography is characteristically flat, the use of fluid grids may be more appropriate. In this type of scheme, natural drainageways are preserved by interrupting and bending the grid around them. Artificial grassed waterways may then be constructed (at very gentle slopes to maximize pollutant removal), at the back of lots or along the street right-of-ways, to channel runoff to natural drainageways without abrupt changes of direction.

Preserve and utilize natural drainage. Keep pavement and other impervious surfaces out of low areas, swales and valleys. This means preparing site plans in which roads and parking are high in the landscape and along ridges wherever possible, as shown schematically in Figure 3.40-2.

Some development standards and approaches encourage the exact opposite pattern. An example of this is the seemingly desirable requirement for the use of curbing on streets and parking areas in low- and medium-density subdivisions. Curbs are widely held to be the signature of quality development;

they provide a neat, "improved" appearance and also help delineate roadway edges. Because curb-and-gutter streets trap runoff in the roadbed, storm inlets and sewers are logical solutions to providing good drainage for the roadbed. As a result of such thinking, several municipalities require the use of storm sewers and curb-and-gutter streets.

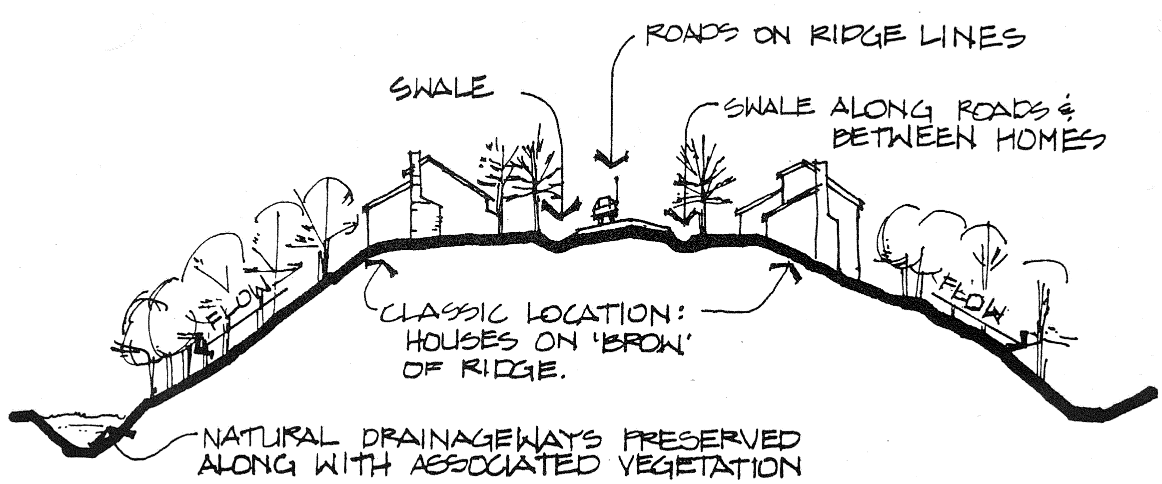


Figure 3.40-2 Place roads along ridge lines. Keep construction areas away from low areas and valley flow lines.

Unfortunately, this solution can create significant stormwater-management problems when looked at in the broader context of devising an environmentally sound land-development scheme. The problem scenario goes something like this. Because storm sewers operate on gravity-flow principles, their efficiency is maximized if they are located in the lowest areas of the site. Since storm sewerage is the preferred technology for providing drainage for the curb-and-gutter streets, it is logical to locate the streets where the storm sewers are best located — in the valleys and low areas, which are the natural drainageways of any site. In this way, natural drainageways can be targeted for destruction; the natural vegetative cover in the most hydrologically critical areas of the landscape is replaced by impervious pavement. Natural filtration and infiltration capacity is lost in the most strategic locations.

Further, in most locations, storm sewers are designed only for short-duration, high-frequency storms (one-hour duration with two-, five-, or 10-year return periods) with flood flows (24-hour duration, 100-year return) handled by street and gutter flows. after the storm sewer capacity is exceeded.

Traditional sewer design often means that the floodways in the landscape are converted from slow-moving, permeable, absorptive, vegetated waterways to fast-moving, impervious, self-cleaning, paved waterways. Hydraulic efficiency is increased, as are peak discharges and flood volumes. Since the natural waterways are paved and specifically designed to be quickly drained by storm sewers, channel storage time is minimized and base flows are sharply reduced together with ground water recharge. The net effect of a seemingly beneficial decision to use curbs can — when thought through in the full, integrated context of site planning decision-making — initiate a snowball effect which amplifies the extremes in the hydrologic cycle, increasing flood flows and reducing base flows.

This scenario also has important effects on water quality. Trace metals from automobile emissions and hydrocarbons from automobile crankcase oil and fuel spillages are directly deposited on the now-paved surfaces of the site's waterways. For the most frequent rainfalls, the first flush of stormwater runoff washes these deposits into the storm sewer system, which is designed to keep in suspension the particles to which the pollutants adhere. The particles, with their attached pollutants, are delivered by the runoff water to receiving waters, where changes in velocity permit the particles to settle out. Nutrient-rich runoff from surrounding lawns is also quickly moved through the paved system with no opportunity to come in contact with plant roots and soil surfaces. The result is efficient delivery of these materials to lakes and streams.

If natural vegetated drainageways are strictly preserved in the site-planning process, flood volumes, peak discharges and base flows will be held closer to their predevelopment levels. Trace metals, hydrocarbons and other pollutants will have a much greater opportunity to become bound to the underlying soil. The infiltration, which would occur along the entire drainageway, would not only contribute to the reduction of runoff volumes, but would also allow nutrients to be taken up by the vegetation lining the drainageway.

A MODERN CLASSIC EXAMPLE

The modern classic example of a comprehensive approach to development incorporating all of these goals is Woodlands New Community located north of Houston, Texas, planned and designed by Wallace, McHarg, Roberts and Todd, Landscape Architects and Planners, Philadelphia, Pennsylvania. This is a 20,000-acre development. This new town was sited on heavily wooded, flat land with extensive areas of poorly drained soils. By working closely with a multidisciplinary team of specialists, including ecologists, hydrologists, engineers and market specialists, a comprehensive plan was developed that preserved the natural drainage system, avoided critical areas, worked with existing topography and maintained predevelopment hydrological conditions.

In the original planning, engineers compared the cost of the natural drainage system to that of a conventional approach and found that the natural drainage option saved over $14 million (Juneja and Veltman, 1980). Further, the conventional approach to stormwater management would have destroyed thousands of trees, lowered water tables, increased runoff volume 180%, degraded downstream water quality and caused a 15-million-gallons-per-day drawdown from the underlying aquifers. The plan avoided or sharply reduced the impact of all of these problems.

The general plan used the existing natural drainage system to provide the major storm subsystem of the stormwater-management plan (WMRT, 1973 and 1974a, b, c). This was accomplished by locating major roads and dense development on ridge lines and higher elevations, while preserving the floodplains in parks and open space and low-density housing on intermediate areas. The minor stormwater-management system focused on maintaining the absorptive capacity of the soil. This was accomplished by careful design of roads, parks and golf courses to maximize infiltration, and the establishment of home-site development strategies that limited impermeable surfaces and included extensive overland drainage systems. Building construction and site grading were also tightly controlled and supervised to preserve the existing soil structure and minimize the area disrupted during construction. The final development increased the volume of runoff generated by only 55% (Juneja and Veltman, 1980).

The ultimate measure of the Woodlands approach occurred in April of 1979. At that time, a record storm hit the Houston area, dropping nine inches of rainfall within five hours. No houses within the Woodlands sustained any flooding (Juneja and Veltman, 1980). Neighboring areas were awash and hard hit with flood damage.

Source: Sykes, August 1989, pp. 3.1-7 through 3.1-8

SITE-PLANNING PROCEDURES[1]

The following procedure for site planning will help designers avoid hydrologic and nonpoint-source water-pollution impacts in housing development:

1. Inventory and map the site.
2. Plan the subdivision.
3. Adapt clusters to the site.
4. Adapt lots to the site.

1. Inventory and map the site.

Working over a topographic map of the site as a base, carefully locate and map all of the critical areas that may exist on the site as described in the previous section on restricting development in critical areas.

The list of goals developed above can be used as a checklist. Map the boundary of each area by carefully determining the limit that should not be crossed by construction activity without causing significant impact. For example, when plotting a natural drainageway, map its flow line, but also be sure to include that area of the adjoining side slopes which, if disturbed, would cause a loss of integrity in its hydrologic function (*i.e.*, side slopes to the top of bank).

The accurate graphic representation of mapped areas is crucial to properly use the map as an aid in site planning. The goal of this map is to provide a clear visual representation of the major patterns of critical areas to avoid, and noncritical areas where it is acceptable to build. To do this, the map must be drawn in a way that facilitates visual pattern recognition. The most difficult figures to recognize and integrate are those that are only outlined. Figures that are both outlined and fully shaded in with a color or pattern are much easier to identify and integrate into concepts for site-planning strategies.

Here are some suggestions for determining the mapping units used, by type of critical area.

- *Shoreline.* Map the water edge and the adjoining areas of riparian vegetation along the water edge.
- *Natural drainageways.* Map flow lines of drainage paths and adjacent areas to top of bank.
- *Steep slopes.* Map slope categories which correspond to the different lot/housing-type combinations to aid matching units to the land and thus avoid excessive lot grading. As a guide, use the slope categories identified below to establish the "boundaries" for the mapping units used. For example, for slopes of 0 to 4%, use flat lots with streets parallel to the contours and rambler housing units. For slopes of 4 to 8%, use sloped lots, with streets parallel to the contours and split-entry or walkout housing units. For streets that run perpendicular to the contours, use side-to-side, split-level housing. For slopes of 8 to 11%, use sloped lots with split-level housing units. For streets that run perpendicular to the contours, use side-to-side, split-level housing units. Slopes steeper than 11% cannot be easily used for residential lots.
- *Dense vegetation.* Map wooded areas with dense undergrowth and forest litter. These areas can be tentatively identified from aerial photographs, but must be field checked to verify actual

[1] This procedure is based upon the Woodlands New Community and the work of Rahenkamp and Associates, Landscape Architects, Philadelphia (Sykes, October 1989).

boundaries and character. Boundaries for these areas should be 10 to 15 ft outside the tree canopy edge to allow for protection of the trees and their feeder roots.

- *Porous soils and erodible soils.* These can be located using the county soil surveys done by the USDA's Natural Resources Conservation Service. The boundaries should be mapped and verified with field checks. Outdated aerial photos should be used only as general guides for site planning.
- In addition to the mapping units suggested, add information that shows the extent of additional flooding, especially into forested areas. If possible, project the increase in the subsurface water levels along the outflow path. This will be useful in determining the areas that could suffer tree mortality from flooding.

2. Plan the subdivision.

Begin planning the subdivision by working on an overlay of the inventory map. Try to arrange clusters of houses so that drainageways and preserved areas fall along the back lot lines between clusters as much as possible. This will provide buffer spaces between clusters. Position clusters so the roads follow ridges or join high points as much as possible. Set and check trial grades for both roads and lot clusters to ensure that prototype slope assumptions are met and to determine the area disturbed by earthwork operations. Adjust layout and slopes as needed to minimize disturbed areas without compromising existing drainage patterns.

3. Adapt clusters to the site.

By working out the objectives and problems of lot-street relationships in a systematic and generalized way in advance, one can more readily see opportunities to capitalize on the physical characteristics of the site to minimize impact and maximize amenities. Systematic lot layout avoids many of the pitfalls encountered by siting the roads before the lots, especially the error of siting the roads through the best home sites. Many municipalities now have planned unit development (PUD) provisions in their zoning codes. The PUD process was developed to provide the flexibility in zoning and subdivision standards needed to accomplish many of the following objectives in the context of a comprehensively designed subdivision:

- Reduce front setbacks to lessen the per-unit amount of paved area via shortened driveways and entry walks. A setback of 20 ft is more than adequate to allow a car to be parked in the driveway without encroaching into the public right-of-way, and it reduces driveway and walk pavement by 30% or more compared to a setback of 30 feet. Setbacks may be needed to separate the home from the noise of the street. But by carefully limiting the number of lots on a local access street, traffic volume (and with it traffic noise) can be held to a minimum. At low traffic levels, it is difficult to justify large setbacks from a health, safety and welfare standpoint.
- Reduce to one, or eliminate, on-street parking lanes on local access roads with less than 200 ADT (average daily traffic) on cul-de-sac streets and 400 ADT on two-way loops. This will reduce impermeable road surface area per unit by 25 to 30%. Even the complete elimination of on-street parking would still provide four parking spaces per unit (two in the garage and two in

the driveway), which is more than is required for rental townhouses in many areas. Single-family, detached housing lots with 75-foot minimum frontages on streets with parking on both sides have parking space for six and one-half cars per house (two in the garage, two in the drive, and two and one-half on the street), which is more than double that typically required for rental townhouses. Because of the low ADT, moving vans and occasional overflows can be parked on the street without seriously obstructing routine and emergency access.

- Limit sidewalks to one side or eliminate them altogether on local access roads with less than 200 ADT on cul-de-sac streets and less than 400 ADT on two-way loops. This reduces impermeable cover per unit by 4 to 8%.
- Use shallow, grassed roadside swales instead of curb-and-gutter/storm sewer technology to handle runoff and provide snow storage. This is very feasible up to net densities of six to eight units per acre. Above that, it is difficult to commit land to swales. The use of roadside swales is especially easy to achieve if roads are placed high or along the ridges, where the drainage area that contributes runoff to the swales is minimized.
- By using the techniques described above, right-of-ways need not be increased by the use of roadside swales. In post-World War II housing developments, the use of such roadside swales was standard. It often resulted in a net decrease in runoff and soil loss levels compared to those generated by the predevelopment agricultural conditions (Jones, 1971).
- Choice of vegetation for the swales is critical to minimizing maintenance. If swales are designed for mowed turf, routine maintenance becomes a part of the abutting homeowners' responsibilities. Repair and removal of sediment then becomes the major maintenance concern, and this should be scheduled on a cycle as with storm sewer repair and cleanout. Such maintenance can be provided by the public works department as a new technology needed to achieve community water-quality goals.
- Properly designed transitions between pavement edge and turfgrass areas are key to the success of roadside swales. Refer to MnDOT standard rural road cross-section templates for proper edge treatments that avoid pavement unraveling and virtually eliminate the problem of snow plow damage. Where off-street parking is a concern, consider using turf reinforcement systems such as pavers, and turf reinforcement mat systems along the pavement edge. All of these systems are capable of protecting turfgrass from even the damage caused by fire truck wheel loads, while still preserving the infiltration capacity of the turf.

4. Adapt lots to the site.

Design the building-to-lot relationships to match site conditions and meet hydrologic objectives. The building-lot relationship is a facet of site planning that is too often not adapted to the site, but is accepted as a given from the zoning code. There are many opportunities to exercise flexibility within the context of zoning. Planned unit-development, cluster development, and the use of restrictive covenants, separately or in combination, provide flexibility to create unit-lot prototypes which help reduce — rather than increase — runoff peaks, volumes and velocities.

- Design the unit-lot relationship in the context of the overall site topography. The slope map will aid in directing this task. Try to use unit floor plans that match the slopes. Do some schematic cross sections through various street-lot combinations to arrive at prototypes that match the site.
- Look at the total pavement and roof area for the unit-lot combination. This requires trying some of the house and site arrangements on paper. Very often, zoning requirements imply large amounts of paving or do not restrict all of the impervious surfaces on home sites. Consider using

deed restrictions to limit total impervious surface area below that permitted by zoning. A maximum of 2,200 square feet (ft^2) of impermeable surface (roofs, walks, drives, patio, etc.) on a 1/4-acre lot can reduce the amount of impervious surfaces by as much as 25% compared to typical development. This would still allow a maximum building footprint (house plus garage) of 1,400 to 1,600 ft^2 per unit usable living space. Totals from 1,800 to 3,300 ft^2 can be achieved by using split-entry, two-story or walkout floor plans.

- Use the PUD provisions for cluster development. This can enable the use of narrower lot frontages so that the area of road pavement required to serve a given lot area can be reduced. With careful site planning, this can significantly reduce the per-unit amount of impervious surface generated by development. Clustering will also yield further savings by reducing the cost of street and utility extension needed to serve a given number of lots.

- One of the areas of greatest potential for reducing impervious surfaces is commercial development.

  Conventional Design. Figure 3.40-3 represents a typical “strip” commercial development. Very little natural open space is maintained in this design due to the amount of space consumed by parking. In addition, this type of site design necessitates automobile use. Given the open nature of the site design, one would most likely drive to get from the bank to the grocery store.

  Strategy for Innovative Design. Figure 3.40-4 incorporates features that preserve open space and reduce impervious cover. Specifically, the parking ratio is reduced compared to the conventional site design, and compact and pervious overflow parking spaces are used. In addition, the design encourages pedestrian use by arranging the buildings in a U shape, to reduce walking distances.

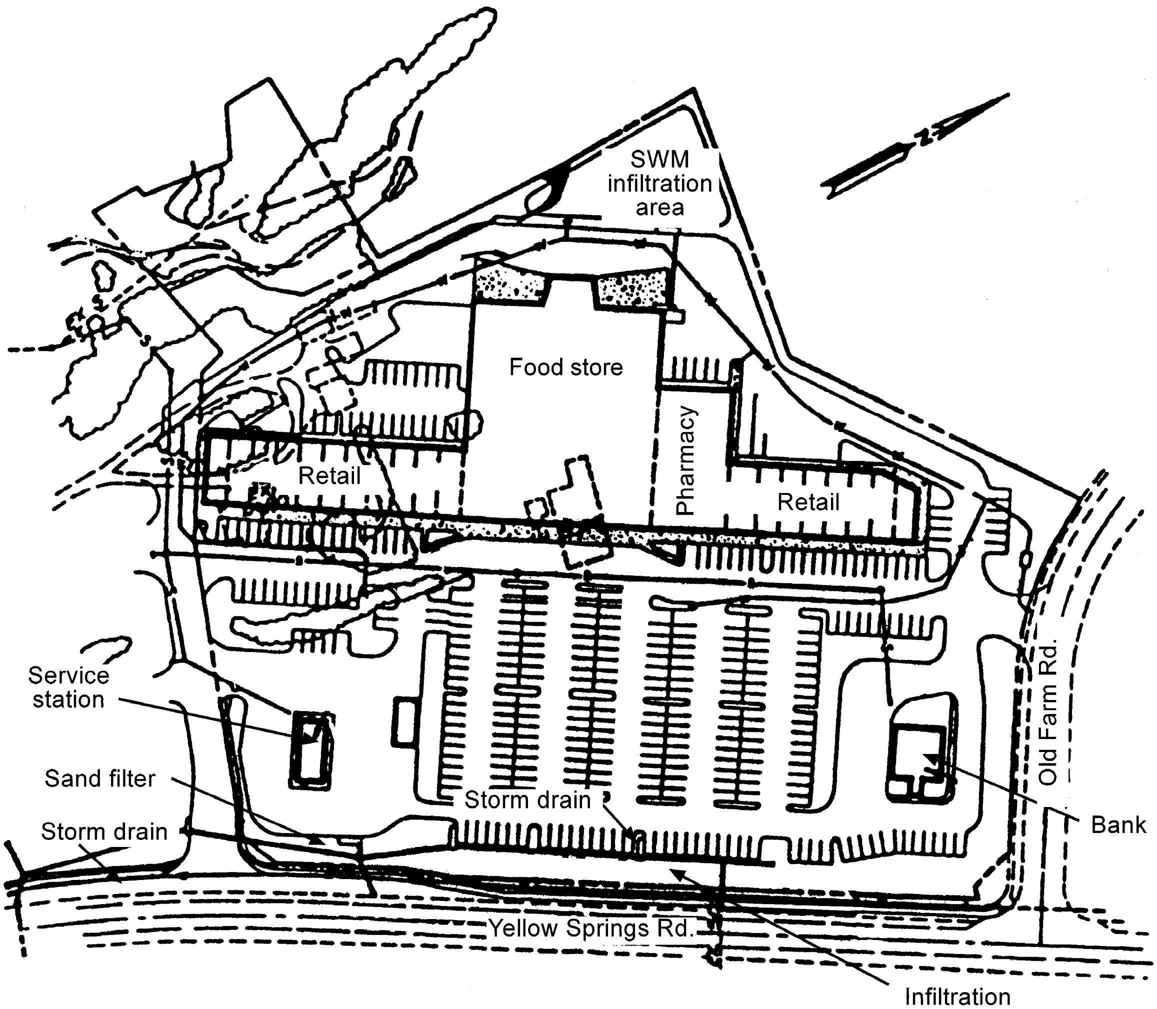


Figure 3.40-3 Retail shopping center: conventional design

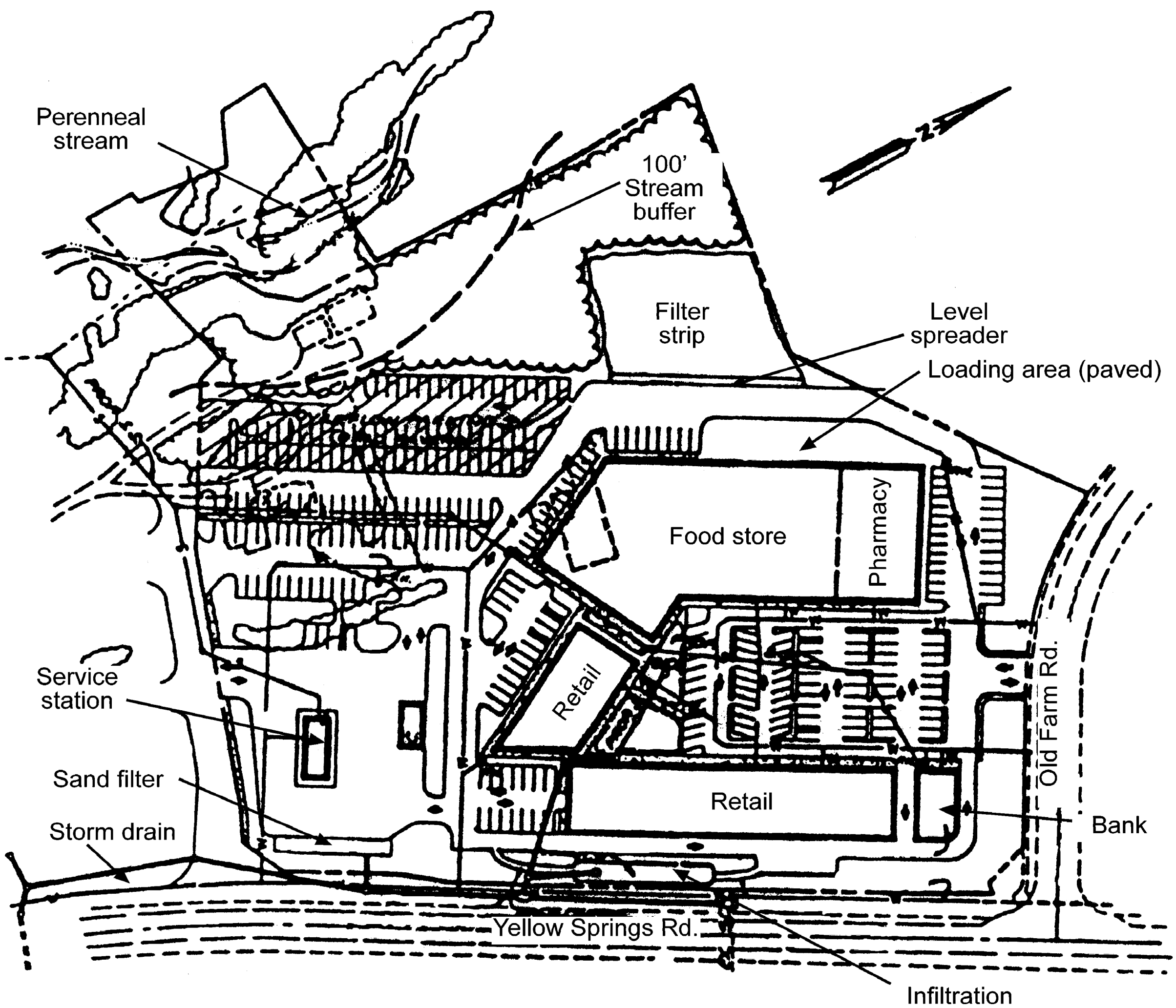


Figure 3.40-4 Retail shopping center: innovative design

3.50 REHABILITATION AND RESTORATION POLICIES

If nonpoint-source pollution has degraded existing water resources, a different process must be used to select practices. However, this is much less desirable than protecting water quality in the first place. Once an area is developed, the options to improve water quality are much more limited. Invariably, the options are also more expensive.

When BMPs are being selected to correct an existing water-quality problem, the process used to arrive at the proper mix of practices includes the following steps:

1. Identify water-quality problems.

Some water-quality problems are easy to identify because they are associated with visible effects, such as streambank erosion or heavy sedimentation in lakes. But water-quality problems can be difficult to define if they are subtle and develop over a period of years. Identifying water-quality problems involves both scientific judgment and public perception. A three-level definition of a water-quality problem was adopted by the Nationwide Urban Runoff Program (NURP) (USEPA, 1983). This definition lists three ways by which water-quality problems can be identified. The three ways are (1) impairment or denial of a beneficial use, (2) violation of a water-quality criterion and (3) local public perception.

The first way to identify water-quality problems involves cases where the water can no longer be used for its intended purpose. An example is a lake that should support swimming, but which can no longer be used for this purpose.

The second way to identify a problem is when criteria such as water-quality standards are violated. Water-quality standards vary, depending upon a number of factors, including designated use. This method of identifying a water-quality problem is especially important when the effects of pollution may not be visible for a number of years. For example, the effects of excessive nutrient loadings from urban runoff in a lake may not be visible until after serious damage has occurred and problems such as frequent algal blooms are present.

The final method of problem identification is public perception. Public perceptions of water-quality problems vary widely because of the many uses that people have for water. Often, public perception involves visible problems, such as turbidity, odor, algal blooms and fish kills. If the water-quality problem is not obvious, an educational effort may be needed to increase public awareness and understanding.

Public perception is especially important when developing a program to control nonpoint source pollution. In most cases, a local unit of government will be the entity that deals with this issue. For a local unit of government to effectively address nonpoint-source problems, the public must be aware of the water-quality problem and support the needed measures. For more information on identifying water-quality problems in lakes, refer to Heiskary and Wilson, 1988.

2. Identify the pollutants causing the problem.

Before nonpoint-source pollution can be controlled, the contributing pollutants and their sources as well as their effects on the water resource must be identified. The identification process often involves water-quality monitoring and a diagnostic study. A water-quality-monitoring plan should be developed that identifies monitoring needs. In all cases, these monitoring plans should be designed by qualified persons. Sampling, laboratory analysis and data analysis should also follow proper procedures.

Computer modeling may have a role in determining pollutant loading, but it is generally not an appropriate substitute for monitoring. However, computer models can be quite effective for comparing relative changes in water quality with the use of various BMPs. When computer models are used, it is important to select the proper model and understand its limitations. The MPCA has prepared a summary of many of the computer models that are available to evaluate nonpoint-source pollution. This summary is available in chapter 8.

For information on existing water-quality-monitoring data for particular areas, contact the MPCA. This agency has water-quality-monitoring data for many locations in Minnesota.

3. Set the water-quality goal.

Once a water-quality problem is identified, a realistic goal for water quality must be set. A realistic goal is one that is attainable, given the land use and physical characteristics of the watershed and available methods of treatment. If an unrealistic goal is set, it may never be achieved or may be prohibitively expensive. Some goals may not even be appropriate for a particular waterbody. Once the point of diminishing returns for water-quality benefits is reached, the cost of additional treatment can increase drastically. The question that must be addressed is, what level of treatment is justified for a given situation?

It is also important to have a realistic expectation of the time needed for water quality improvement. It may take many years before improvements are seen in lakes and ground water. For more information on setting water quality goals, refer to Heiskary and Wilson, 1988.

4. Select appropriate BMPs.

Selection of individual BMPs is very site and situation specific. Chapter 2 and Chapter 4 of this manual provide guidelines for BMP selection.

5. Implement, operate and maintain BMPs.

Before BMPs can be selected, a method of implementation must be chosen. There are several approaches that can be taken to implement urban BMPs. They include:

- information and education programs with voluntary compliance,
- local regulation of certain land-use activities, and
- local government ownership and operation of regional BMPs.

Although educational programs can be an important part of a nonpoint-source-pollution program, their effectiveness can vary greatly. If an education program is to succeed, the public must be convinced that a problem exists, and that their actions can help correct it. Information and education programs should be an ongoing effort. A one-time campaign may result in some short-term improvement with few long-term benefits. Information and education programs can be useful in addressing problems, such as improper use of fertilizer on home lawns.

Local regulation can also be an effective approach. For example, sediment and erosion control on construction sites is an activity that may be most appropriately controlled with regulation. All land users involved in the regulated activity will be required to meet the same criteria.

Several elements have been suggested for successful regulation in a nonpoint-source-pollution program. First, the regulation must be at the local level. Second, the standards for the regulation must be reasonable. Finally, there must be uniform enforcement of the regulations so that developers and others affected will know what it will cost them.

Involvement of local units of government in the ownership and operation of regional BMPs is another alternative that may be appropriate. For practices such as detention ponds, regional structures that control several hundred acres or more may be the best alternative. Some advantages of regional basins are that costs of control are reduced, control of developed areas is possible, and fewer structures will need maintenance (USEPA, 1983).

Also, if peak discharge control is a goal, regional detention facilities can be more effective than on-site structures. Several investigators have concluded that random placement of stormwater detention facilities in a watershed may have little or no effect on peak discharges downstream (Pitt, 1998).

Local units of government incur significant capital costs when regional treatment measures are used. These costs can be recouped by “in-lieu-of fees” charged to developers or by other mechanisms. Because of the economies of scale involved, the cost to developers may end up to be less than with the on-site BMP alternative.

The final program will often include all three of these methods, with each one targeting a specific problem or category of land users. For example, a local unit of government dealing with a nutrient problem in surface water may decide that the following mix is appropriate:

- An education program directed to homeowners about fertilizer use and control of lawn and leaf litter.
- Local ordinances to regulate fertilizer application rates used by commercial applicators on lawns.
- Regulation of sediment- and erosion-control practices on construction sites.
- Construction of detention ponds that also provide flood control.

Operation and maintenance of structural BMPs is crucial, and it must be carefully considered in the planning stages of a project. A detailed maintenance plan should list inspection intervals and regular maintenance as well as identifying responsible persons or organizations.

After BMPs are implemented, an evaluation should be made of their effectiveness. This may involve a monitoring program to determine the benefit to water quality. For educational programs on housekeeping practices, part of the evaluation may be a survey to determine how many residents have changed practices on their property. In any case, an assessment should be made to determine whether additional measures are needed to meet the water-quality goal.

CHAPTER 4

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4.00 BEST MANAGEMENT PRACTICES FOR STORMWATER SYSTEMS

This part includes best management practices (BMPs) that are permanent features of the storm water system. It does not include ponds, which are covered in chapter 5, or construction activities, which are usually temporary and are covered in chapter 6.

4.10 Flow Controls: STORMWATER SYSTEMS

DESCRIPTION AND PURPOSE

When an urban area is developed, natural drainage patterns are modified as runoff is channeled into road gutters, storm sewers and paved channels. These modifications can increase the velocity of runoff, which decreases the time required to convey it to the mouth of the watershed. This results in higher peak discharges and shorter times to reach peak discharge. Figure 1.10-3 shows typical pre- and postdevelopment hydrographs for a watershed that is being developed for urban land uses. The area below the hydrographs represents the volume of runoff. The increased volume of runoff after development is significant because of the increased pollutant loading it can deliver as well as potential flooding and channel-erosion problems.

The infrastructure changes and improvements that are part of the regular life cycle and plan of your city can be more efficient and provide greater public benefit if the landscape ecological structure and amenity value of neighborhoods are part of the overall design. We hope you will use this manual to help you envision the many possibilities for doing more than moving or holding storm water and having more than a nicely paved street when infrastructure improvements are being made in the community.

If you are a local government official or staff member or if you are a developer, involve residents in designing a new, more attractive appearance for neighborhoods. Work with your neighbors to initiate a more wide-ranging and imaginative approach to retrofitting the infrastructure of your community. You will enjoy a more beautiful and vital place to live.

4.11 Flow Controls: SUBSURFACE DRAINS

DESCRIPTION AND PURPOSE

A subsurface drain is perforated pipe, tubing or tile installed below the ground surface to intercept and transport water.

Subsurface drains can be used to remove excess water from wet soils in places where vegetation must be established to provide ground cover. Subsurface drains can also be used to prevent seepage from slopes, which may cause unstable conditions and sloughing. In some cases, subsurface drains can serve as an outlet for detention areas or structures with small drainage areas.

EFFECTIVENESS

Subsurface drains alone do not control erosion problems; however, they may be needed with other practices. For example, a vegetated channel in wet soil conditions may not have a satisfactory stand of grass without subsurface drainage. Because the use of subsurface drains are a component of other measures, the effectiveness of subsurface drains for sediment control is difficult to quantify.

PLANNING CONSIDERATIONS

Subsurface drains are normally used to lower the water table in an area, or to serve as an outlet for small detention structures. The method of installation depends upon the intended use and the characteristics of the soil in which they are installed. Less permeable soils may require an envelope of granular drain material to maximize their effectiveness.

Clogging by tree roots and crushing by vehicle traffic are common causes of drain failures. Where subsurface drains may be subject to these conditions, heavy pipe or other precautions should be considered.

DESIGN RECOMMENDATIONS

Determining the required capacity is one of the first considerations in drain design. When a subsurface drain is installed to control the water table over a broad area, the tile system should be designed to remove at least 0.5 inch of water from the soil every 24 hours. This amounts to 0.021 cubic feet per second (cfs) per acre of area drained. When a surface inlet is included on a tile line, the capacity should be increased to account for this flow. Use manufacturer’s design specifications to determine the sizes of drains required to carry the design flow.

Subsurface drains should be located where they will have maximum benefit. When a drain is installed to dry up an isolated wet area, the drain should be installed through the middle of the wet area. When a broad area must be drained, refer to the Minnesota Drainage Guide, Soil Conservation Service, 1984, for spacing. For interceptor drains on a hillside, install the drain as shown in Figure 4.11-1.

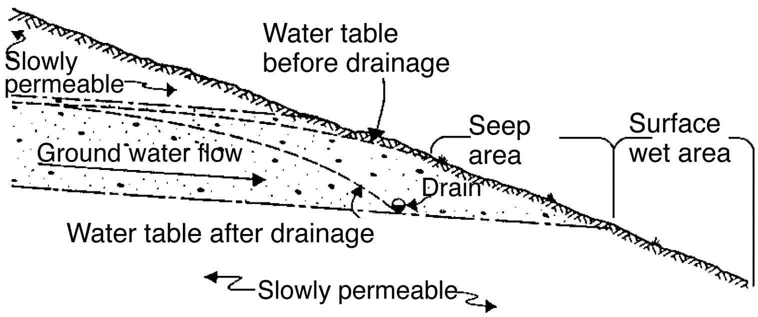


Figure 4.11-1 Interceptor drain for side hill seeps

The minimum velocity that should be used in subsurface drains is 1.4 feet per second (fps). Lower velocities will allow sediment to accumulate in the drain. Maximum recommended velocities are given in Table 4.11-1. On steep grades, where velocities cannot be avoided, protective measures, such as those described in Table 4.11-2, may be required.

FILTERS AND ENVELOPES

In some cases, filters may be needed to restrict fine particles of sand and silt from entering a drain. Table 4.11-2 lists conditions where filters are recommended. Drainage tubing with filter cloth or geotextile around it is commercially available and can serve as a filter. Filters can be effective, but may partially clog with time.

Envelopes are used to improve flow into a subsurface drain and ensure proper bedding support of the drain. Envelopes should always be used for plastic tubing where it is not feasible to form a bedding groove. Envelope material should be gravel, with all of the material passing through a 3/4-inch sieve and less than 10% of the material passing through a #60 sieve. Envelopes should extend at least 3 inches beyond the drain in all directions.

In some cases, surface inlets may be needed to directly transfer surface water to a subsurface drain. One type of surface inlet is a pipe that extends to the surface of the soil with a grating on it. The grating is needed to prevent debris from entering and clogging the drain. The other type of inlet is a gravel inlet or "French drain." This type of inlet is very susceptible to clogging where it carries a sediment load.

At the outlet of a subsurface drain, a minimum of 10 feet (ft) of metal pipe without perforations should be used. The pipe should be set at an elevation above the normal water level and should be fitted with a rodent guard.

Table 4.11-1 Maximum allowable velocities for given soil textures

Descriptive name	Velocity (fps)
Fine sand, sandy loam	2.50
Silt loam, loam	3.00
Clay loam, sandy clay, silty clay loam	4.00
Coarse gravels, cobbles, shales and hard pans	6.00

Table 4.11-2 A classification to determine the need for drain filters or envelopes, and minimum velocities in drains

Unified Soil Classification	Soil Description	Filter Recommendation	Envelope Recommendation	Recommendations for Minimum Drain Velocity
SP (fine) SM (fine) ML MH	Poorly graded sands, gravelly sands. Silty sands, poorly graded sand-silt mixture. Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity. Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Filter needed	Not needed where sand and gravel filter is used, but may be needed with flexible drain tubing and other filter types.	None
GP SC GM SM (coarse)	Poorly graded gravels, gravel-sand mixtures with little or no fines. Clayey sands, poorly graded sand-clay mixtures. Silty gravels, poorly graded gravel-sand silt mixtures. Silty sands, poorly graded sand-silt mixtures.	Subject to local on-site determination.	Not needed where sand and gravel filter is used, but may be needed with flexible drain tubing and other filter types.	With filter: none. Without filter: 1.40 feet per second (fps).
GC CL SP,GP (coarse) GW SW CH OL OH Pt	Clayey gravels, poorly graded gravel-sand-clay mixtures. Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. Same as SP & GP above. Well-graded gravels, gravel-sand mixtures with little or no fines. Well-graded sands, gravelly sands with little or no fines. Inorganic, fat clays. Organic silts and organic silt-clays of low plasticity. Organic clays of medium to high plasticity. Peat	None	Optional May be needed with flexible drain tubing.	None for soils with little or no fines. 1.40 fps for soils with appreciable fines

Source: Soil Conservation Service, USDA

MAINTENANCE

Drains should be checked periodically to see that they are free flowing. Common sources of damage are clogging by tree roots, crushing by vehicle traffic and clogging by debris from surface inlets.

4.12 Flow Controls: STORMWATER-CONVEYANCE CHANNELS

DESCRIPTION AND PURPOSE

A stormwater-conveyance channel is a permanent waterway, shaped and lined with appropriate vegetation or structural material that can carry stormwater runoff. This practice provides a means of transporting concentrated surface runoff without causing damage from erosion or flooding.

This practice generally applies to channels, including road ditches that are constructed as part of a development to transport surface runoff. This practice does not apply to major, continuously flowing, natural streams.

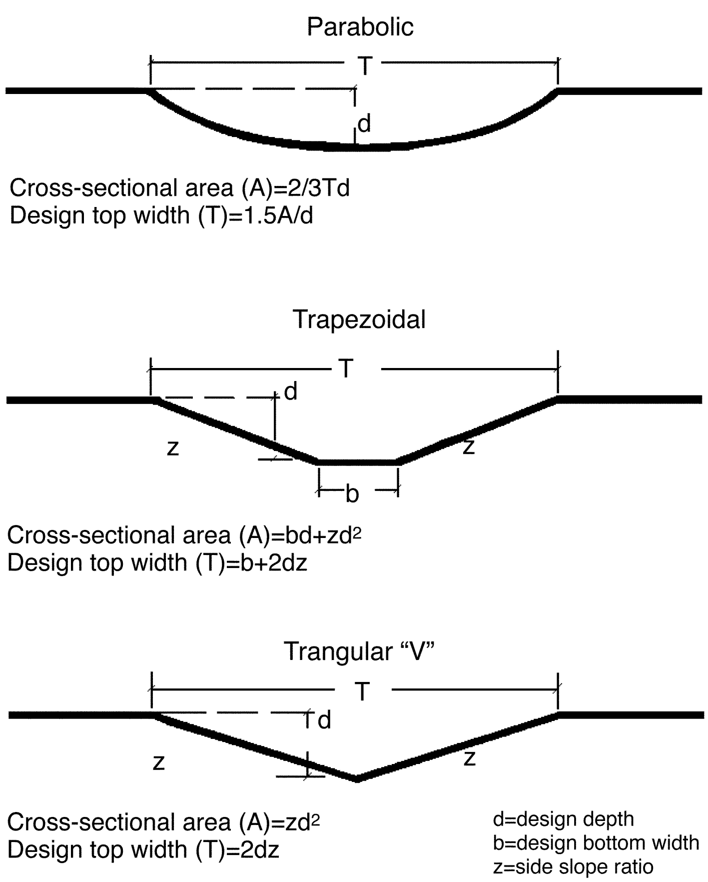


Figure 4.12-1 Storm water conveyance channel cross sections

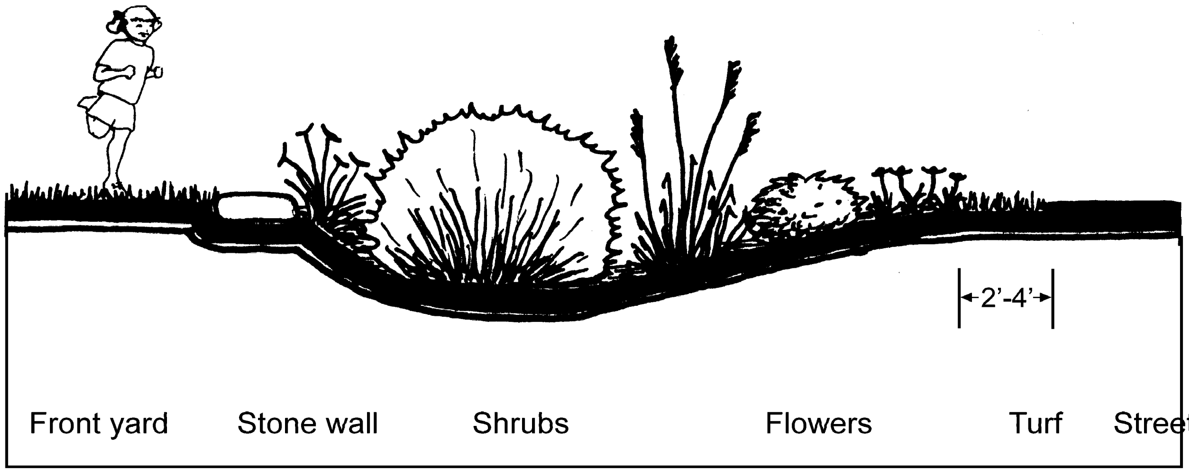
EFFECTIVENESS

Properly designed stormwater-conveyance channels are effective for preventing erosion caused by concentrated flows. They can significantly reduce or eliminate sediment loads originating in the channel area.

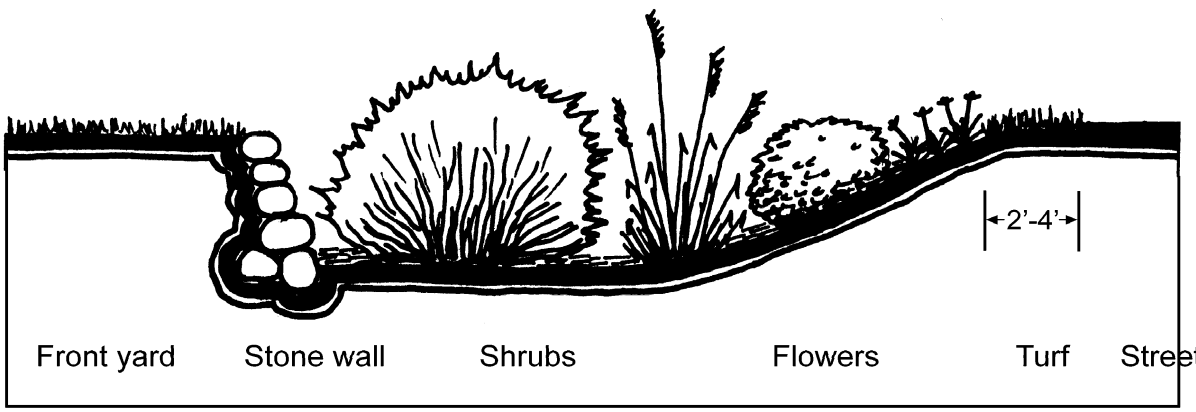
PLANNING CONSIDERATIONS

A number of other factors must be considered when designing a channel. Some of these are availability of land, aesthetics, safety, maintenance requirements and soil characteristics. The type of cross section selected is very important to these considerations. Figure 4.12-1 shows several typical cross sections.

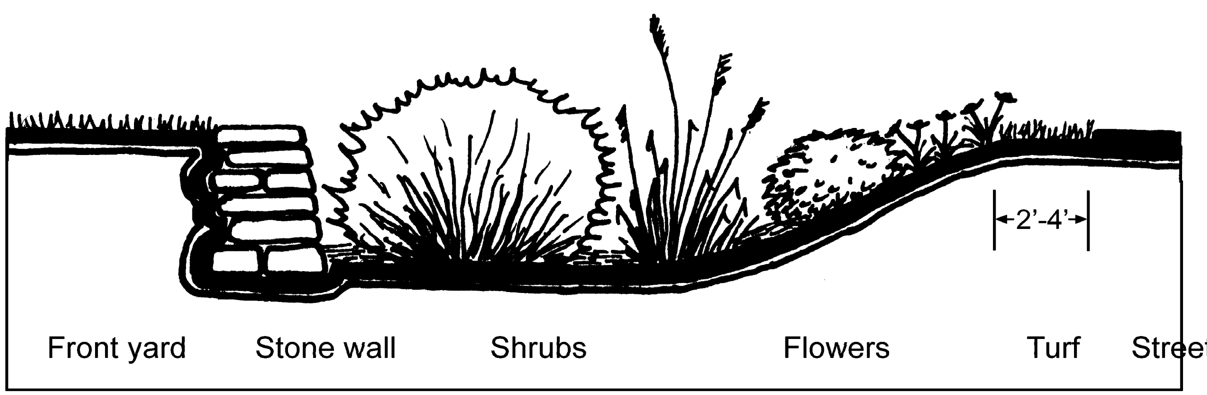
The two main considerations when designing a stormwater-conveyance channel are adequate capacity and sufficient erosion resistance. Also, if vegetation is used for a lining, storm water conveyance channels can help to reproduce predevelopment hydrologic conditions by promoting infiltration and slowing runoff velocities. Figure 4.12-2 shows some examples of



Asymmetrical swale with front yard edge defined by pavers.



Asymmetrical high-volume swale with front yard edge defined by stone wall.



Asymmetrical high-volume swale with front yard defined by masonry wall.

Figure 4.12-2 Vegetated swales (Nassauer *et al.*, 1997)

vegetated channels. For information about other possible water-quality benefits from vegetated channels, see section 4.20.

The parabolic cross section results in a wide, shallow channel that blends in well with natural settings. Trapezoidal channels are normally used where deeper channels are needed to carry large flows. This type of channel is well suited to handling large flows. It also works well with riprap and other structural linings. The triangular (V-shaped) cross section should only be used if the quantity of flow is relatively small. This cross section can result in higher velocities than other shapes, especially when steeper side slopes are used.

Whenever a channel is designed, the stability of the outlet should be checked. If the outlet discharges with a large drop in elevation to the channel bottom, a grade-stabilization structure may be needed. If flow velocities exceed the allowable velocity of the receiving channel, a transition section or other energy-dissipating device may be needed.

DESIGN METHODS

Channel Lining

Channel-lining materials should be used to establish vegetation and as needed to protect the channel from expected high flows. The following guidelines should be understood as maximum values, which should be adjusted on a site-specific basis. The manufacturer and other sources, such as the Minnesota Department of Transportation (MnDOT), Natural Resources Conservation Service (NRCS), University of Minnesota Extension Service and other experts, should be consulted for specific applications.

- **Vegetative linings** can withstand velocities up to 5 fps and shear stresses up to 2.5 pounds (lb) per square ft, depending on the type of vegetation.

- **Erosion-control blankets,** such as excelsior, netting and mulch, should be used to protect new-growth vegetation so it will not be removed by storm flows before it can become established. Erosion-control blankets can be helpful with maximum velocities of under 10 fps and shear forces under 3 lb per square ft. Blankets and mulch can be expected to degrade; therefore, the channel should be designed with vegetation as the main reinforcement (see above).

- **Turf-reinforcement matting** consisting of nondegrading, three-dimensional matrix materials, such as synthetic products or coconut “coir” fabric, should be used with expected velocities of 15 fps and shear stress of 8 lb per square ft.

- **Vegetated structures** (***e.g.***, articulated block, cable concrete, cribwalls), which leave about 20% of the surface open for vegetation, should be used when maximum velocities of 25 fps and/or shear stresses up to 15 lb per square ft are encountered. At greater stresses, other methods may be required.

DESIGN RECOMMENDATIONS

When checking the **capacity** of a channel, the maximum expected retardance should be used, usually when vegetation is at its maximum growth for the year. When checking for **velocity**, the minimum retardance should be used, usually early in the season, while the vegetation is dormant. Paved channels will not have this seasonal variation in retardance, and one retardance can be used for both designs.

Capacity. Unless local regulations require otherwise, all channels should be designed to carry at least the peak flow from the 10-year-frequency storm. Areas adjacent to the channel should be evaluated for property damage or safety hazards that could result from flows in excess of the 10-year-frequency peak. If the consequences of flooding are severe enough, the planner may want to increase the capacity of the channel.

Low-velocity, vegetated waterways may act as sediment traps. In areas where sediment is expected from the drainage area during development, the designer may want to include extra capacity. With this extra capacity, some sediment can accumulate without reducing the design capacity. If sediment storage is desired, an extra 0.3 to 0.5 ft of depth is recommended.

Design Velocity. Design velocities for channels should not exceed the permissible velocity for the type of lining used. Permissible velocities for grass-lined channels are included in Channel Lining above.

For higher velocities, structural linings, such as riprap or concrete, are required (see practices in 4.30, Bioengineering, and 4.40, Structural Stabilization).

As previously mentioned, the outlet velocity should not exceed that of the receiving channel. An energy dissipater or transition section may be required if velocities exceed the allowable velocity of the receiving channel.

Allowable velocity should be checked using the lowest expected retardance.

Cross Section. Vegetated slopes in urban areas should be 4:1 or flatter for maintenance reasons. For lined channels, the slopes can be steeper as long as they are within the capabilities of the soil and the structural lining. For trapezoidal channels with a bottom width greater than 15 ft, precautions should be used to prevent meandering of low flows. Ditch blocks may be used to provide enhanced treatment in some cases.

Drainage. The soil in vegetated channels should be adequately drained so that vegetation can become well established. In poorly drained, wet soils, a subsurface drain or a stone center may be required. Drains are discussed in 4.11, Subsurface Drains. A stone center will provide an erosion-resistant area to carry continuous flows or to protect an area where vegetation cannot be established. Stone centers will provide some drainage, but they are subject to clogging from sediment.

DESIGN PROCEDURE

Vegetated Channels

1. The required channel capacity should be determined using the methods in Natural Resources Conservation Service, Engineering Field Handbook, or other appropriate methods.

2. The type of cross section desired and type of vegetation must be selected.
3. Determine the maximum and minimum retardance for the selected vegetation and the maximum permissible velocity for the soils and vegetation. The maximum retardance is selected for the maximum growth stage and the minimum retardance is typically the next-lower retardance value.
4. Design the channel for stability using the minimum retardance. This procedure will be based upon the maximum permissible velocity.
5. Design the channel for capacity using the maximum retardance value. This will provide the maximum flow depth for the given discharge.
6. Evaluate the design to determine whether it is satisfactory. If it is not, change the cross section or type of lining as needed and design again.

Lined Channels

1. Determine the required channel capacity.
2. Select a trial cross section and lining.
3. Determine the lining *n* value. If a channel is not vegetated, the *n* value may be constant for both stability and capacity analysis.
4. Solve Manning's equation for the trial cross section and an estimated flow depth (see Figure 4.12-3).
5. Modify the cross section or flow depth as required and perform step 4 again until a satisfactory design can be obtained.

MAINTENANCE

Vegetation will require maintenance during establishment for weed control and repair of rills. Any mowing for weed control during the first year should be done at a height of 4 inches to prevent damage to the seedlings. Rills should be promptly repaired to prevent further damage.

Sediment accumulations should be removed from channels as needed. Sediment bars reduce the channel capacity and can deflect flows, causing erosion.

Figure 4.12-3 Shear stress and velocity calculations

$$Velocity = \frac{1.49}{n} R_h^{2/3} S^{1/2}$$

$Where:$

$n = Manning's\ Coefficient$

$R_h = Hydraulic\ Radius$

$S = Slope\ (ft\ per\ ft)$

$$Shear\ Stress = \gamma \times d \times S$$

$Where:$

$\gamma = unit\ weight\ of\ water$

$d = depth\ of\ water$

$S = Slope\ (ft\ per\ ft)$

4.13 Flow Controls: DIVERSION STRUCTURES

DESCRIPTION AND PURPOSE

A diversion is a channel constructed across a slope with a supporting ridge on the lower side. Figure 4.13-1 shows several typical diversion cross sections. Diversions are used to intercept runoff and divert it to stabilized outlets at nonerosive velocities. Diversion structures increase the flow length and reduce the slope for erosion control or divert runoff from downslope areas (see Figure 4.13-2). Temporary diversion structures are often used for construction activities. For information on temporary structures, see chapter 6.

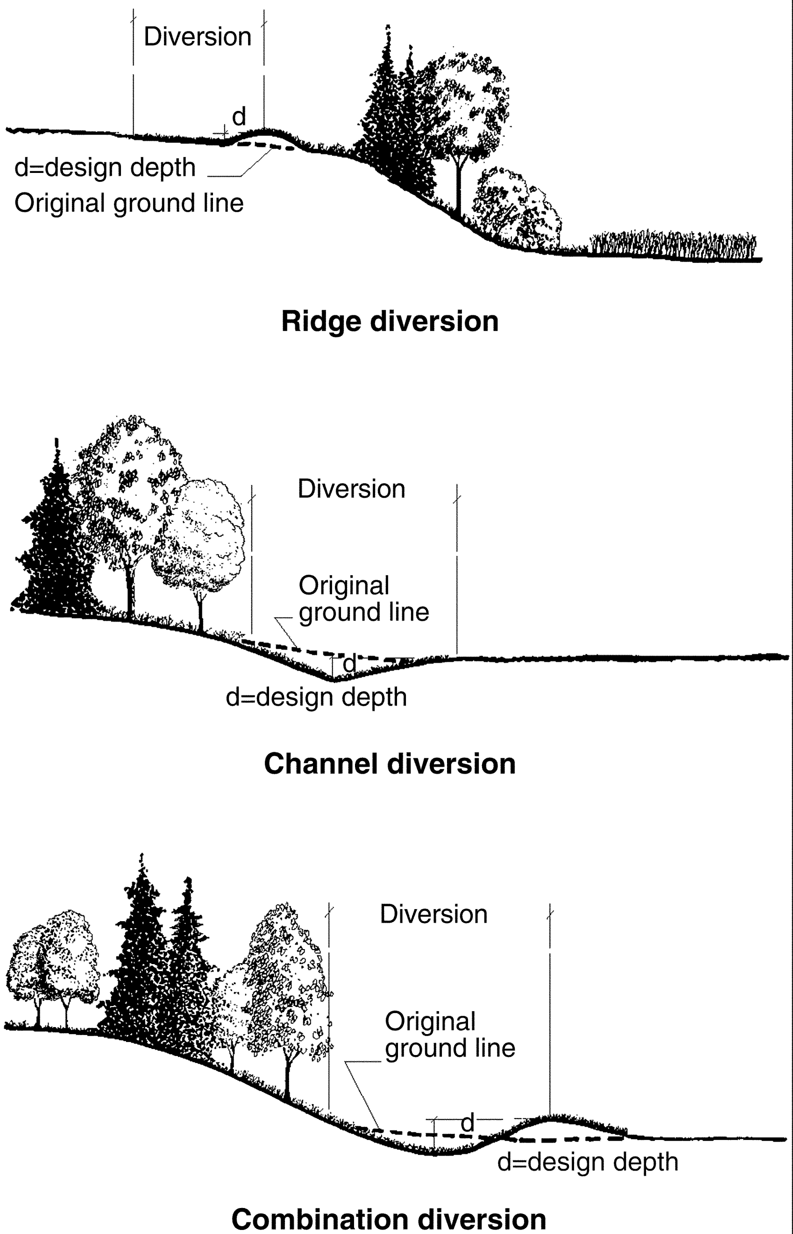


Figure 4.13-1 Typical diversion cross sections

EFFECTIVENESS

Diversions can be very effective for erosion control on steep or long slopes. Diverting runoff will reduce the effective flow lengths or eliminate concentrated flow that would make establishment and maintenance of vegetation difficult. The erosion-control benefit from a diversion will depend upon the length of slope and type of soils in the area being protected.

PLANNING CONSIDERATIONS

Diversions are useful tools for managing surface water flows and preventing soil erosion. On moderately sloping areas, they may be placed at intervals to trap and divert sheet flow before it has a chance to concentrate and cause rill and gully erosion. They may

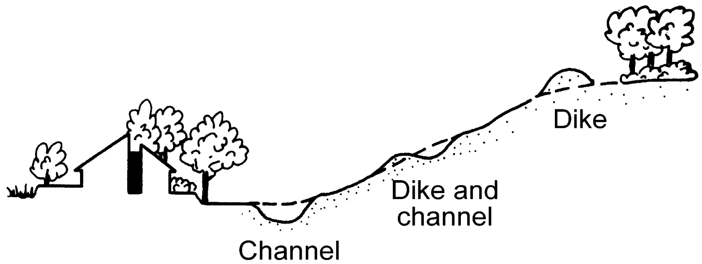


Figure 4.13-2 Use of diversions to protect cut or fill slopes, protect structures or off-site property, or break long slopes

be placed at the top of cut or fill slopes to keep runoff from higher areas off the slope. They can also be used to protect adjacent property, buildings and structures from flooding.

Diversions are preferable over paved or enclosed stormwater-conveyance systems because they simulate natural flow conditions. Flow velocities are kept to a minimum, some settling of solids may be achieved, and infiltration is permitted. When properly worked into the landscape design of the site, permanent diversions can be attractive as well as functional.

It is important to stabilize diversions with vegetation or other erosion-resistant materials as soon as possible after construction. The contributing drainage area of permanent diversions should also be stabilized as soon as possible to prevent excessive sediment deposition in the channel.

DESIGN RECOMMENDATIONS

The capacity of a diversion should be suitable for the area that is being protected. Freeboard is the extra depth above the design depth that is added as a safety margin. Some situations may warrant more stringent criteria.

The cross section may be parabolic, V-shaped or trapezoidal. The side slopes should be no steeper than the stable slope for the soil that is used. Where the diversion will need to be mowed, the slopes should be 3:1 or flatter.

See Practice 4.12, Stormwater-conveyance Channel, for recommendations on maximum velocities and design procedures.

Diversions must have an outlet that has sufficient capacity and is stable. Other practices that may be used at the outlet include Practice 4.14, Level Spreaders; Practice 4.43, Grade-stabilization Structures; or Practice 4.12, Stormwater-conveyance Channels.

MAINTENANCE

Vegetation should be regularly inspected, especially during establishment, and repaired as needed. Excessive amounts of deposited sediment that would reduce capacity or damage vegetation should be removed.

4.14 Flow Controls: LEVEL SPREADERS

DESCRIPTION AND PURPOSE

A level spreader is an outlet for diversions and other concentrated-flow situations, consisting of a wide, level area to evenly distribute water across a slope to prevent concentrated flow. Figure 4.14-1 shows a typical level spreader layout.

EFFECTIVENESS

Level spreaders are not effective treatment by themselves but are useful in areas where concentrated flow could be a concern, such as outlets for swales, or for spreading water before it goes to a filter strip, buffer zone or infiltration device.

PLANNING CONSIDERATIONS

A level spreader should only be used where it can be constructed in undisturbed soil and where it will flow over an area stabilized by vegetation or other erosion-resistant material.

DESIGN RECOMMENDATIONS

The water should not be allowed to reconcentrate after it is released. Care must be taken to make sure that the outlet area is level. Depressions will cause water to concentrate, causing erosion.

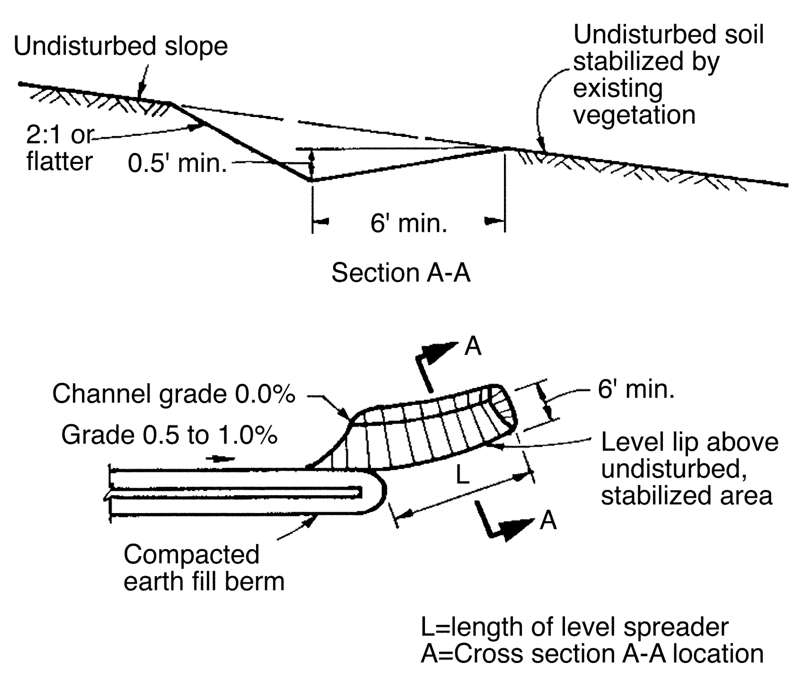


Figure 4.14-1 Level spreader layout and plan view

Flow velocities to the level spreader should be kept low, preferably 1 fps for the 1.25-inch storm, and 2 fps for the 10-year storm. For example, if a diversion is used, the last 20 ft of the diversion, before the level spreader, may need to be reduced to a grade of 1% or flatter, to reduce velocities.

The length of the spreader should be based upon the 10-year-frequency peak flow unless local conditions indicate otherwise.

4.20 Vegetative Stabilization: ROLE OF VEGETATION

EROSION AND FAILURE

Erosion is the removal of soil particles from a surface primarily due to water action. Erosion may also be caused by wind, ice action, boat-induced wave action, uncontrolled runoff, or human and animal activities.

Failure is the collapse or slippage of large masses of soil by action of gravity through additional shear stress or decreased shear strength. Slope failure often occurs on the bank of a stream or lake that has been undercut by erosion at the base of the slope. It can also be a problem in upland areas wherever steep slopes are present, especially where vegetation has been removed or destroyed. Construction activities can cause failure by removing surface cover or the toe of the slope. When a slope fails, it sloughs off either a thin layer or a large mass of soil. Vegetation helps prevent erosion and failure.

FUNCTION OF THE VEGETATIVE CANOPY

Vegetation protects soil from erosion by raindrops, runoff, water currents and wind. Plants also decrease the amount of rainfall directly impacting the ground surface by intercepting and holding a portion of the water on the leaves and stems. As vegetation is removed and impervious surfaces are created, the volume of runoff increases. Runoff volumes in vegetated areas are typically between 10-20% of the average annual rainfall. In urban areas, where surfaces are highly impervious, typical runoff volumes are 60-70% of the average annual rainfall.

Runoff velocities are decreased as the water flows over stalks, stems, branches and foliage. Plants on a bank slope can also act as a sediment trap by collecting transported materials. This improves the water quality of streams, rivers, lakes and ponds. Shrub species commonly used in bioengineering applications are most effective because of their dense, low, spreading growth pattern.

Vegetative cover will also modify the soil microclimate by reducing variations in soil and air temperature and moisture content, thereby reducing aggregate breakdown of the soil and the potential for freeze-thaw damage.

Aesthetics are an important contribution of vegetation in conjunction with other factors, especially in urban situations. Vegetation improves aesthetic and environmental values by providing a more natural cover to the soil, and at less expense than most structural methods. Natural groupings of plants are more acceptable, and will develop over time. Initial stabilization is provided by pioneer species, such as willow. Later, successional species can be interspersed with the initial plantings or allowed to colonize and converge on their own. Plants enrich the character and diversity of the landscape by adding new form, line, texture, harmony, color and contrast. They also can screen out unsightly views.

Plants can heal the wounds of the land caused by erosion or human activity, blending construction with the natural landscape. Other ecological benefits provided by vegetation include (1) improvement in water-retaining capacity of the soil; (2) improvement of water consumption through transpiration; (3) provision of shade and protection from wind; (4) increased production, nesting and feeding habitat for birds, animals and insects and (5) reduction of air and water pollution. Using plants whenever appropriate, rather than hard-surface materials, may reduce maintenance and lead to a more self-sustaining landscape.

FUNCTION OF ROOT SYSTEMS

Vegetative root systems play a major role in the mechanical properties of soil by increasing soil strength and stability. Root networks are flexible linear reinforcements that hold soil particles in place, significantly increasing soil tensile strength and shear strength. Root systems tend to be self-repairing and -regenerating. Roots interweave to form dense, laterally spreading mats that effectively reduce soil erosion. Roots settle out sediment by intercepting water and enhancing infiltration. They also reduce soil water through uptake and transpiration. Many field and laboratory tests have demonstrated the effect of root reinforcement on the shear strength of soils. These tests show that the shear strength of soils increases directly in relationship to the volume of roots in the soil.

While elaborate root systems have good soil-binding properties, a single, large taproot does little to reinforce the soil. Smaller, lateral roots add much to the shear strength and monolithic nature of the root-soil system. Roots generally grow horizontally in the top layers of the soil [0.7-1.0 meter (m) or 2-3 ft]. The majority of roots for shrubby species are confined to the top 1m (3.3 ft) of soil, but a few roots may be found somewhat lower. Grasses, such as big bluestem, have fibrous roots reaching almost 2m (6 ft) deep and other native prairie grasses may reach as deep as 3 to 5m (9 to 15.5 ft).

SPECIFIC EFFECTS OF VEGETATION

Root Reinforcement: Roots mechanically reinforce soil by transfer of shear stresses in the soil to tensile resistance in roots. The intermingled, lateral roots of plants tend to bind the soil into a monolithic mass. On slopes, the vertical root system (*i.e.*, main taproots and secondary sinker roots) can penetrate through the soil mantle into firmer strata below, thus anchoring the soil to the slope and increasing the resistance to sliding. Soil rooting strength is favored by a high concentration of long, flexible roots per unit volume of soil and a relatively high root tensile strength. Deep-rooted species are preferable for stabilizing soil and increasing resistance to sliding on slopes.

Soil Moisture Modification: Evapotranspiration and interception by foliage moderate the buildup of soil-moisture stress. Vegetation also affects the rate of snowmelt, which in turn affects the soil moisture regime. Thus, interception and transpiration by trees in a forest would tend to moderate soils and mitigate or delay the onset of overly dry or waterlogged soil conditions. Conversely, clear-cutting or felling of selected trees tends to produce wetter soils, more erosion and runoff, and faster recharge times following intense rainstorms and during droughts.

Buttressing and Arching. Buttressing, or lateral restraint against shallow slope movement, is provided by firmly anchored, rigid tree trunks. Arching in slopes occurs when soil attempts to move through and around a row of piles (or trees) firmly embedded or anchored in an unyielding layer.

The trees act as both cantilevers and abutments, or "soil arches," that form in the ground, counteracting shear stresses upslope of the trees.

Surcharge. The weight of vegetation on a slope exerts both a downslope (destabilizing) stress and a stress component perpendicular to the slope, which tends to increase resistance to sliding.

VEGETATIVE STRUCTURAL MEASURES

Vegetative structural measures include tree revetments; log, rootwad and boulder revetments; dormant post plantings; piling revetments; planted geotextile revetments; and piling revetments with slotted fencing, jacks or jack fields, rock riprap, stream jetties, stream barbs and gabions. These measures can all utilize vegetation as part of the structural protection.

INTEGRATED SYSTEMS

A major concern with the use of structural approaches to streambank stabilization is the lack of vegetation in the zone directly next to the water. Despite a long-standing concern that vegetation destabilizes stone revetments, there has been little supporting evidence and even some evidence to the contrary. Assuming that loss of conveyance is accounted for, the addition of vegetation to structures should be considered. This can involve placement of cuttings during construction, or insertion of cuttings and poles between stones on existing structures. Timber cribwalls may also be constructed with cuttings or rooted plants extending through the timbers from the backfill soils (NRCS, December 1986).

NATIVE VEGETATION

Grasses introduced from Europe and Asia have been traditionally used to establish vegetative cover on roadsides in the Midwest. However, many experts are now specifying native grasses for critical area seedings. Although slower to establish, native species require less maintenance in the long run than introduced vegetation. They are also better for water quality because they do not require the fertilizer that introduced species require.

While they establish quickly, introduced grasses frequently deteriorate when planted on poor soils. Often their stands thin and weeds invade (see figure 4.20-1).

Introduced grasses may provide good erosion control under favorable soil and moisture conditions. Wildflowers could be added to the seed mixes on many projects.

Because they develop very deep root systems, native grasses provide very good long-term erosion control (see Figure 4.20-2). And, they will often grow on poor soils because they can gain access to nutrients and water that shallower-rooted grasses cannot reach. Therefore, native grasses are desirable for stabilizing soils. (See Henderson *et al.*, 1999, for lists of vegetation.)

The drawback of native grasses is that they establish somewhat slowly. Cover crops may be seeded with native grasses to provide short-term erosion control while they are becoming established. Mulching newly planted sites is also a good idea. Although slower to establish, native vegetation requires less long term maintenance and fertilizers that introduced species require.

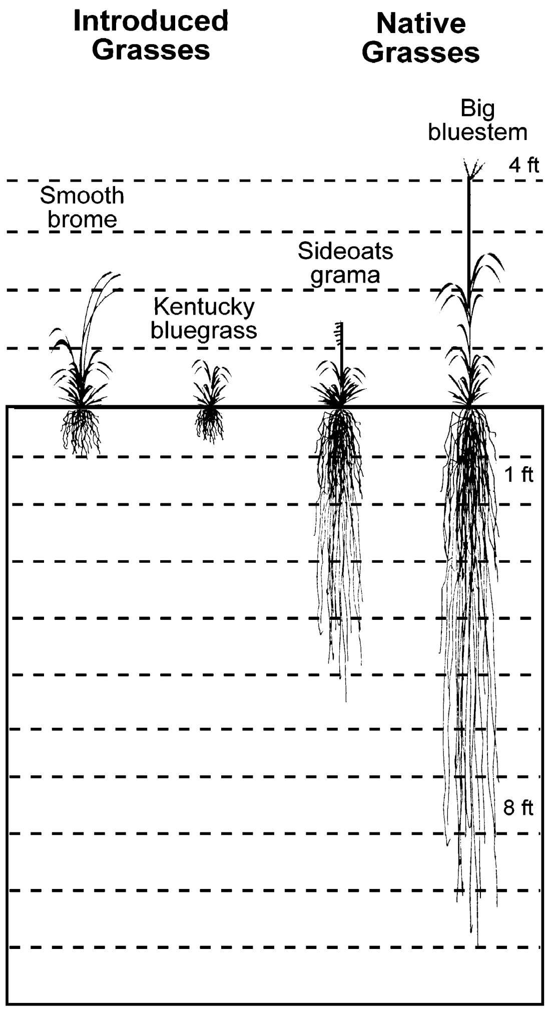
Smooth brome
- Root system reaches 10-15 inches in depth.
- Plant height is 2-3 ft.

Kentucky bluegrass
- Root system reaches 6-8 inches in depth.
- Plant height is about 1 ft.

Grasses introduced from Europe and Asia have been traditionally used to establish vegetative cover on roadsides in the midwestern United States. However, many experts are now specifying native grasses for critical area seedlings.

While they establish quickly, introduced grasses frequently deteriorate when planted on poor soils. Often their sod opens up and weeds invade.

Introduced grasses may provide good erosion control under favorable soil and moisture conditions.



Sideoats grama
- Root system reaches to 5 ft in depth.
- Plant height is 12-18 inches.

Big bluestem
- Root system reaches down to 9 ft in depth.
- Plant height is 4-8 inches.

Because they develop very deep root systems, native grasses provide very good long-term erosion control. And, they will often grow on poor soils because they can gain access to nutrients and water that shallower rooted grasses cannot reach. Native grasses are therefore desirable for stabilizing soils.

Their drawback is that they establish somewhat slowly. Cover crops may be seeded with them to provide short-term erosion control while the native grasses establish. Mulching newly planted sites is also a good idea.

Figure 4.20-1 Stabilizing poor soils: a comparison

First-year Growth of Sideoats Grama and Smooth Brome

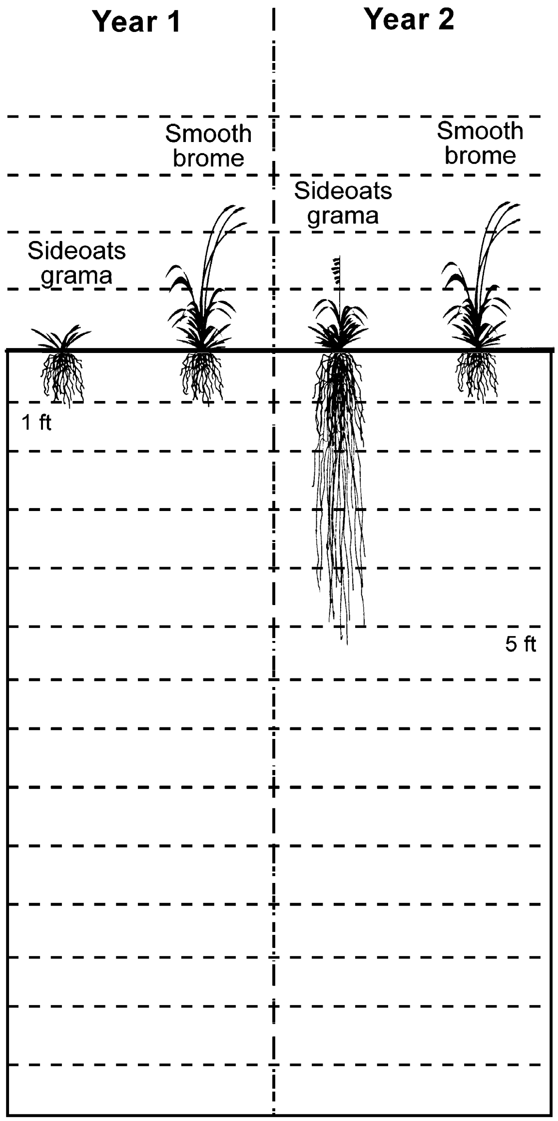
There is often a perception that native grass and wildflower plantings are a failure during the first growing season, even though they are establishing well. This is because

(1) native grasses such as sideoats grama allocate most of their energy to root development during the first growing season, and

(2) many native grasses do not begin growing until late spring or early summer when soil temperatures are warm.

Consequently, the above-ground vegetative growth of sideoats grama is generally much less than smooth brome the first year, even though their root development may be equivalent. Smooth brome will also reach maturity the first season, whereas sideoats grama ususally does not.

Mowing a native grass planting in mid-summer allows sunlight to reach the small native grass seedlings and keeps the site less weedy.



Second-year Growth of Sideoats Grama and Smooth Brome

During the second year of growth, sideoats grama will reach maturity. Its root system will grow to a depth of 5ft or more. Smooth brome only sends roots to a depth of 1ft or less.

Several years are required for a stand of native grasses to reach maturity. During the first two years, native grass stands may appear unkept and weedy.

However, when they are fully established, there are very few weeds which will be able to compete with native grasses for nutrients and water in the soil

Native grasses will eventually starve out, and hold out, undesirable weeds.

Figure 4.20-2 Establishment and growth: a matter of perception

4.21 Vegetative Stabilization: BUFFER ZONES

DEFINITION

For the purpose of this manual, “buffer zones” or “biological buffer zones” means the upland areas adjacent to aquatic areas (*i.e.*, wetlands, lakes, streams) designated by a local unit of government to protect the ecological values and functions of the upland/aquatic system.

Buffer zones are natural areas of vegetation adjacent to or upgradient of water bodies or aquatic systems. A buffer zone is very close in meaning and intent -- but not identical to -- the Natural Resources Conservation Service “Interim Practice for Riparian Buffer Strips, Zone 1.” Buffer zones are related to, but not the same as filter strips. Nor should they be confused with setback requirements (see Figure 4.21-1). Buffer zones are one way to help alleviate the impact of human activities, and they should be an important part of comprehensive site planning.

PURPOSE

The purpose of the buffer zone is to protect and enhance water quality and aquatic habitat. It does this by providing a stable ecosystem next to the water’s edge, by providing a soil/water contact area to facilitate nutrient-buffering processes, by providing shade to moderate sunlight, by stabilizing water temperature, by encouraging the production of beneficial and unique vegetation, and by contributing necessary detritus and large, woody debris to the stream ecosystem. The buffer zone also provides soil stability along streams to the depth of rooting, and creates a pleasing visual appearance.

BUFFER BENEFITS

Buffers protect water quality in many ways. The presence of dense stands of grass or forest leaf litter and debris increases soil cover, which protects the soil against the erosive energy of rain, wind and overland flows from storm water. Plants with dense, fibrous root systems help keep soils in place during flood events. Such vegetation can also increase infiltration. Plant uptake of nutrients may reduce nutrient loading to a water body. Buffers also remove sediment by physically filtering out particles that are suspended in the storm water from upland sources. Shading by trees, shrubs or tall grasses reduces the temperature of the overland stormwater flow and the water body being protected. Reducing water temperatures in the summer is important to maintaining healthy aquatic life because temperature is one of the factors that control the water’s ability to hold dissolved oxygen. The higher the temperature, the less dissolved oxygen that can be retained. When vegetation is left in place, damage from foot and vehicle traffic and other activities that dislodge or disturb soils is prevented.

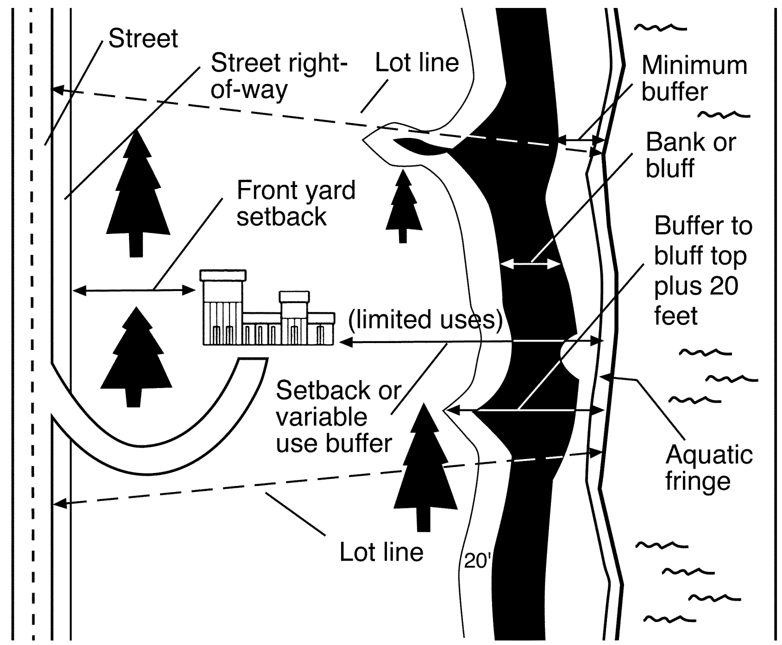


Figure 4.21-1 Buffers and setbacks

FUNCTIONS

Some commonly recognized functions of buffer zones include (adapted from Castelle *et al.*, September-October 1994):

1. stabilizing soils, along streams, lakes and wetlands, and preventing erosion;
2. filtering suspended solids, nutrients, and harmful or toxic substances;
3. moderating the microclimate of the system;
4. supporting and protecting fish and wildlife habitat and diversity; and
5. providing migration corridors.

Although a buffer zone will help stabilize soils and banks, other stabilization measures may still be necessary. When appropriately applied, bank erosion will be minimized. The buffer is most effective when it extends beyond the stream or lake banks and fringe area of wetlands. These buffers vary in width since their sizes are dependent on available land, topography, and land uses and on the selected goals for the buffer. However, more complex combinations of herbaceous and woody native species suited to an area are the most effective riparian buffer for a variety of goals. These complex buffers allow a natural diversity of plants in the same buffer area to accomplish several goals. These goals include water-quality protection, wildlife habitat, forest longevity, aesthetics, and healthy, long-lived areas in the landscape.

The buffer zone ordinance must address reasonable use of the areas while minimizing the potential for impacts. Permits and variances processes should be established that allow for roads, utilities and other reasonable uses, if conducted with minimal environmental impact.

Upland and aquatic systems are intricately interconnected physically, chemically and biologically. Thus, they affect each other, and impacts to one can impact the other. The aquatic system includes the wetland fringes, an area where soils are often saturated and periodically inundated. Because of the nearness of surface water, which produces peculiar water and soil conditions, vegetation in wetland fringe and adjacent upland areas is often very different from that of other areas. This is especially true in larger, low-gradient streams, where cutoff oxbows, backwaters, and extensive, high water tables create unique biological communities.

In turn, upland areas influence aquatic areas through the shape of stream channels, controlling the type, rate and amount of material passing through the system, and providing a primary source of kinetic and potential energy and nutrient inputs to the system. Changes in these factors often lead to changes in the species composition and age structure of plant, fish and wildlife populations.

RECOMMENDED STANDARDS

In general, buffer effectiveness increases with buffer width. As buffer width increases, the effectiveness of removing sediments, nutrients and other pollutants from surface-water runoff increases. As buffer width increases, direct human impacts, such as dumped debris, cutting vegetation, etc., decrease. A field study of wetland buffers in Seattle showed that 95% of buffers less than 50 ft wide suffered a direct human impact within the buffer, while only 35% of buffers wider than 50 ft suffered direct human impact (Thomas R. Schueler, April 1995).

Most scientists agree that wetland buffers are essential for wetland protection. Appropriate buffer widths are based on several variables, including:

- the functions and values of the aquatic system (such as storm water management and habitat value), and its sensitivity to disturbance;
- the characteristics of the buffer (*e.g.*, forested, grass, steep slope);
- types of surrounding land use and ownership, and impacts on the wetland; and
- desired buffer functions.

Appropriate buffer widths vary according to the desired buffer functions. For example, temperature moderation may not require wide buffers like some wildlife habitat or water-quality functions. Buffer widths for wildlife may be generalized, but specific habitat needs of wildlife species depend on individual habitat requirements.

The dimensions of the buffer strips may be adjusted by the local government based upon the quality of the wetland, local topographic conditions, and the type and design of development being proposed. Table 4.21-1 provides minimum and maximum dimensions for the buffer strip. The use of a meandering buffer strip, to maintain a natural appearance, is encouraged. Structure setbacks are also described. Each lot provides sufficient area to accommodate the applicable front yard setback, deep building pad, and a rear yard area. All of these elements must be provided outside of designated aquatic systems and buffer-strip areas. A model ordinance is available from the Minnesota Pollution Control Agency (MPCA).

Review of scientific literature on wetland buffers suggests the following <u>minimum</u> buffer widths for protecting these functions:

- Storm water management: 25 or more ft (depends on vegetation, slope, density and type of adjacent land use and quality of receiving water)
- Protection from human encroachment: 50 to 150 ft
- Bird habitat preservation: 50 or more ft (depends on species and type of use)
- Protection of threatened, rare or endangered species: 100 or more ft (depends on species and type of use)

RELATED ISSUES

Why not Wetland Conservation Act (WCA) or Shoreland Ordinances?

The WCA does not protect the fringe adjacent to the aquatic system nor does it protect wetlands from excavation or other changes. The Minnesota Department of Natural Resources (MDNR) protected water permit program regulates alterations below the ordinary high water elevation but does not protect aquatic systems above (beyond) it.

Shoreland ordinances protect many designated shoreland areas -- typically lakes, rivers and streams -- but most waters are not protected. For example, there are over 800 water bodies in Eagan but only 40 of them are protected under the MDNR protected waters and shoreland protection programs (Rick Brasch, city of Eagan).

Buffer zone and shoreland ordinances are similar in purpose but not the same, since shoreland ordinances relate primarily to setbacks on buildings and structures while buffer zones relate to habitat and vegetation around aquatic systems. The minimum setback should be no less than any applicable MDNR shoreland ordinance requirement from the ordinary high water level. A setback should also be provided next to the buffer zone to provide access to buildings and structures that will not disturb the buffer area.

LOCAL IMPLEMENTATION

Local units of government are generally responsible for implementation of buffer zone concepts. Although buffer zones should be developed in accordance with scientific principles and ecological needs, they must be understood and supported locally. To be properly implemented, local units of government must understand the need and support the concepts that make buffer zones effective (see SWAG, September 1997).

4.22 Vegetative Stabilization: STREAMBANK AND LAKESHORE STABILIZATION

DESCRIPTION

This practice involves the stabilization and protection of eroding lakeshore or streambanks with vegetation.

PURPOSE

The purpose of this practice is to protect lakeshore streambanks from the erosive forces of wave action and flowing water and to provide a natural, pleasing appearance.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where sections of shoreline or streambank are subject to erosion. Vegetative stabilization is generally applicable where streambank full-flow velocity does not exceed 4 ft/sec, or wave action is less than 1 ft and soils are erosion resistant. Above 4 ft/sec, riprap or structural measures are generally required, but can often be used in combination with bioengineering methods (biotechnical stabilization) when appropriate.

PLANNING CONSIDERATIONS

Upstream development accelerates streambank erosion by increasing the volume and rate of runoff, which increases the frequency and duration of bankfull flow. In stable watersheds, with little or no development, the channel forming discharge has a 9-month to two-year recurrence interval (Leopold *et al*., 1964). However, in urbanizing watersheds, bankfull flow occurs more often, eroding streambanks that were previously stable.

Changing lake levels can be a significant source of erosion for lakeshore properties. Streambanks and lakeshore may be stabilized by vegetation, by structural means, or by combinations of these two measures. Vegetative measures are generally preferred because vegetation provides habitat for fish and wildlife and is aesthetically pleasing. Natural plant communities that are adapted to the site provide a self-maintaining cover that is less expensive than structural alternatives (see section 4.20). Planting vegetation is also less damaging to the environment than installing structures. Therefore, vegetation should always be considered first.

Plants provide erosion protection to lakeshore and streambanks by:

- reducing the energy in the moving water – cushioning wave action or reducing stream velocity,
- binding soil in place with a root mat, and
- covering the soil surface, protecting it from high flows or waves.

In streams, vegetation should be considered in calculating the carrying capacity of the channel so that it does not affect flooding. Therefore, maintenance needs and the consequences of flooding should be considered.

Streambank and lakeshore projects may need state, federal or local permits. So, check with the appropriate agencies for their requirements.

DESIGN CRITERIA

Evaluate erosion potential of the shoreline or streambank to determine the best alternative solutions, considering:

- frequency of lake level change or bankfull flow based on anticipated watershed development or other factors,
- channel slope and flow velocity in streams and wind fetch in lakes,
- soil conditions,
- anticipated energy of the water affected by factors such as wave height or present and anticipated channel *n* values,
- channel bends and bank conditions, and
- identification of stable areas and trouble spots. (Steep channel reaches; high, erosive banks and sharp bends may require structural stabilization measures, such as riprap, while the remainder of the bank may require only vegetation.)

Where bank stabilization is critical and wave energy or stream velocities appear too high for vegetation, use structural measures (see 4.30, Bioengineering, and 4.40, Structural Stabilization).

Consider the natural zones of a plant community when selecting plant species. Zones are distinguished by site conditions, such as bank shape and steepness, and by variations in water depth, duration of flow, and flow rate (see Figure 4.22-1).

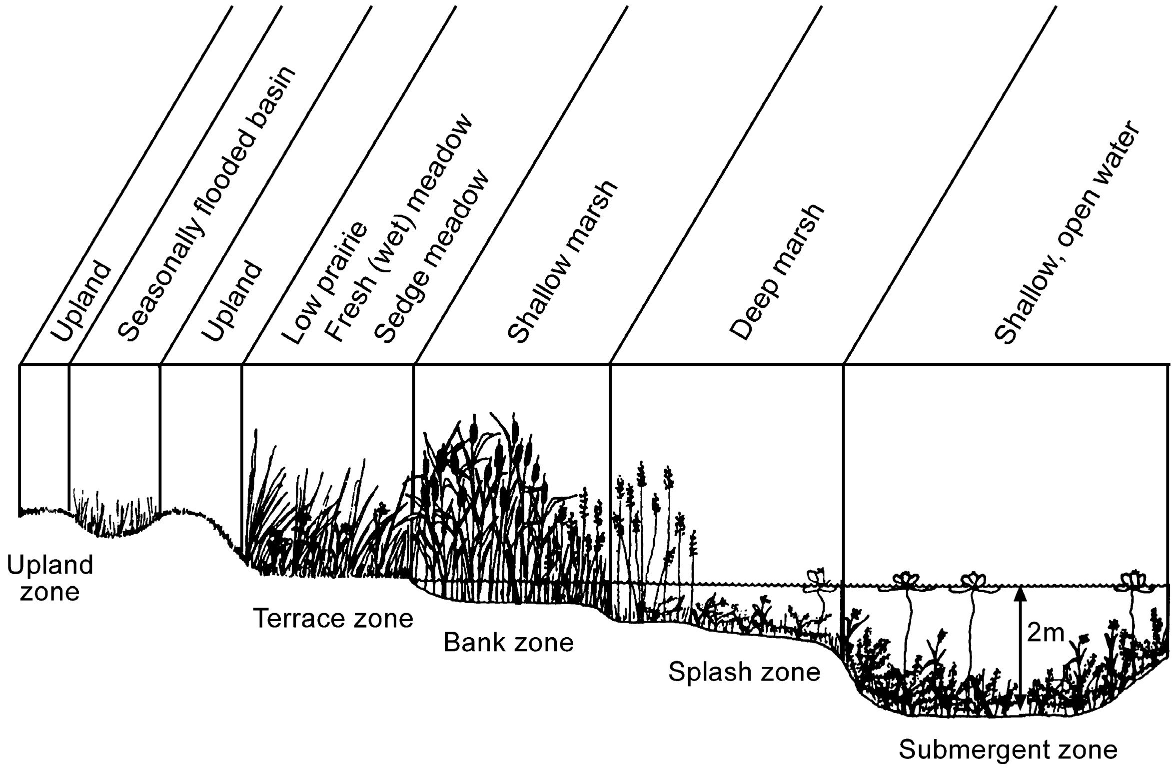
Ensure that measures will not be undermined by checking that bank and channel bottoms are stable before stabilizing the banks.

Keep flow velocities and wave action nonerosive for the site conditions.

Provide mechanical protection (*e.g.*, riprap) as needed, such as on the outside of channel bends.

Since plantings are generally not fully effective for three growing seasons, grasses should be seeded immediately before shrub planting to provide some initial streambank protection. Temporary erosion-control blankets may be necessary to establish vegetation.

Where practical, grade eroded banks to 2:1 or flatter before planting because streambanks are difficult to plant, even when they are gently-sloped. This is especially true in the case of gravelly or tight banks. Where mattocks or shovels are unsatisfactory, the best tool is a dibble bar, a heavy, Select species for the correct zone. The vegetation type is listed across the top, as listed in Eggers and Reed (1987) and other documents. Seed and plant mixtures should be obtained from professionals.



Upland zone: Areas normally subjected to erosive action by rain or wind and typically not flooded.

Terrace zone: The elevation not subjected to erosive action by water except during occasional flooding.

Bank zone: The elevation above the normal high-water level. This zone is exposed to wave-wash, erosive river currents, ice/debris movement and animal or human foot traffic.

Splash zone: The elevation between the normal low-water flow rate and high-water flow rate. This high-stress zone is exposed to wave-wash, erosive river currents, ice/debris movement, wet-dry cycles, freeze-thaw cycles, and fluctuating water depths.

Submergent zone: This vegetation is typically under water.

Figure 4.22-1 Vegetation zones

metal tool with a blade and a ft pedal. The dibble bar is thrust into the ground to make a hole for the plant. (There are also other ways to plant bank vegetation.)

Planting in clumps. The oldest and most common method of planting reeds is planting in clumps. Cut stems of the reed colony to several inches. Dig clumps out of the ground and place in holes prepared in advance in the area to be stabilized. Plant clumps at a depth where they will be normally submerged to a maximum of two-thirds their height.

Planting rhizomes and shoots. Less material is needed for planting with rhizomes and shoots. Slips of some species can be taken from existing beds during the dormant season. Cut off the stems, then carefully remove rhizomes and sprouts from the earth without bruising the buds or the tips of the sprouts. Place in holes or narrow trenches at the average summer water level, so that only the sprouts are protruding above the soil.

Planting stem cuttings. It is possible to plant stem cuttings of common reed along slow-moving streams. With a dibble bar or some other planting tool, set three slips in holes about 12 inches deep and 1 ft apart.

Reed rolls. Along flowing streams, reed rolls are the most effective method of establishing reed-bank vegetation. Plants are placed in coconut fiber or other types of rolls 1 ft apart. Dig a trench 18 inches wide and 12 inches deep, parallel to the stream. It may be necessary to place planks braced with short stakes along the sides of the trench to keep it open. Place wire netting, such as 0.5-inch hardware cloth or filter fabric, across the bottom and up both sides of the trench between the upright planks. Place the rolls in the trench, then backfill with material such as coarse gravel, sod, soil or other planting medium.

Fascine rolls. Fascine rolls are made of brushwood and unbranched, woody shoots. Place branches on filter cloth sheets that are filled with coarse gravel, soil and available organic material and tightly wire. Place the wired bundles in a trench dug along the contour 6 to 12 inches deep. Dig the trench just above the water level so the plants can get moisture. Covering fascine rolls improves the contact with the ground and retards moisture loss. Fascine rolls may also be wired without filter cloth sheets, similar to reed rolls (Figure 4.22-2).

Willow mattresses. Willow mattresses are made by interweaving willow branches. Mattresses consist of 4 to 8-inch-thick layers of recently cut branches held together by interweaving wire or other branches at intervals of 24 to 32 inches. Lay the mattresses perpendicular to the direction of the current or sloping slightly downstream, with the base end of the branches oriented downwards. If several sections of mattresses are necessary to cover an eroding slope, the tops of the lower layers should cover the bases of the upper layers. Anchor the bottom mattress at the base in a trench dug on the low boundary of the shrub zone. Cover the mattresses with 2 to 10 inches of earth or gravel.

Combination with protective facing. In many places, the bank is not adequately protected by vegetation until the roots are fully developed, and additional temporary protection must be provided. There is a wide choice of methods and materials, including the planting of woody plants in the crevices of stone facing, or geosynthetic materials.

MAINTENANCE

Vegetated streambanks are always vulnerable to new damage, and repairs may be needed periodically. Check banks after every high-water event, and fix gaps in the vegetative cover at once with structured materials or new plants, mulched if necessary. Fresh cuttings from other plants on the bank may be used, or they can be taken from mother-stock plantings. Test the soil to see whether nutrients are needed. Protect new plantings from livestock or wildlife where this is a problem.

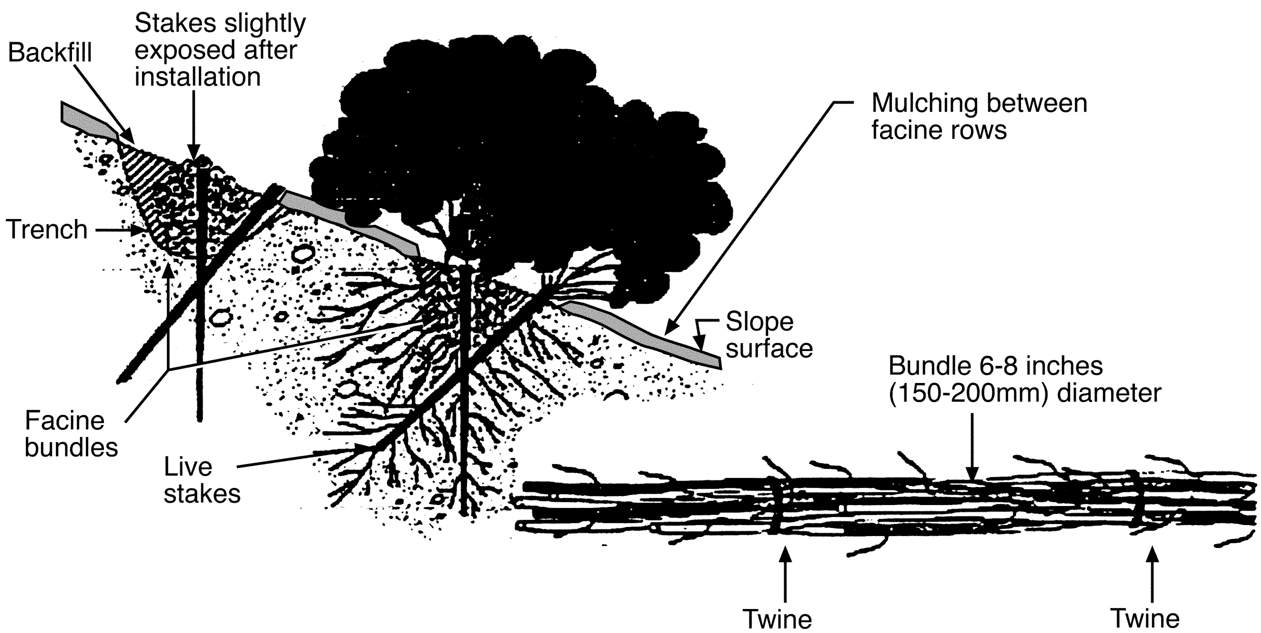


Figure 4.22-2 Wattling or live facines

4.23 Vegetative Stabilization: TREE REVETMENTS

DESCRIPTION

A tree revetment is constructed from whole trees (lacking their root systems, or rootwads) that are usually cabled together and anchored by earth anchors or piling that is buried in the bank (Figure 4.23-1).

APPLICATIONS AND EFFECTIVENESS

A tree revetment:

- uses inexpensive, readily available materials to form semipermanent protection.
- captures sediment and enhances conditions for colonization by native species.
- has self-repairing abilities following damage by flood events if used in combination with soil bioengineering techniques.
- Is not appropriate near bridges or other structures where there is high potential for downstream damage if the revetment were to dislodge during a flood event.
- has a limited life and may need to be replaced periodically, depending on the climate and durability of tree species used.
- may be damaged in streams where heavy ice flows occur.
- may require frequent maintenance to replace damaged or deteriorating trees.

PLANNING CONSIDERATIONS

Tree revetments are made from whole tree trunks laid parallel to the bank, and cabled to piles or deadman anchors. Eastern red cedar (Juniperus virginiana) and other coniferous trees are used on small streams, where their springy branches slow flow and trap sediment. The principal drawback of tree revetments is that they use large amounts of cable and may become dislodged and cause damage downstream.

Some projects have successfully used large trees in conjunction with stone to provide bank protection as well as improved aquatic habitat. The logs eventually rot, resulting in a more natural bank. The revetment stabilizes the bank until woody vegetation has matured, during which time the channel can return to a more natural pattern.

In most cases, tree stabilization projects use combinations of techniques in an integrated approach. Toe protection often requires the use of stone, but much less stone will be needed if large logs can be used. Likewise, stone blankets on the bank face can be replaced with geogrids or supplemented with interstitial plantings. Most upper bank areas can usually be stabilized with vegetation alone, although anchoring systems might be required. For design purposes, see the USDA, NRCS, National Engineering Handbook, part 653.

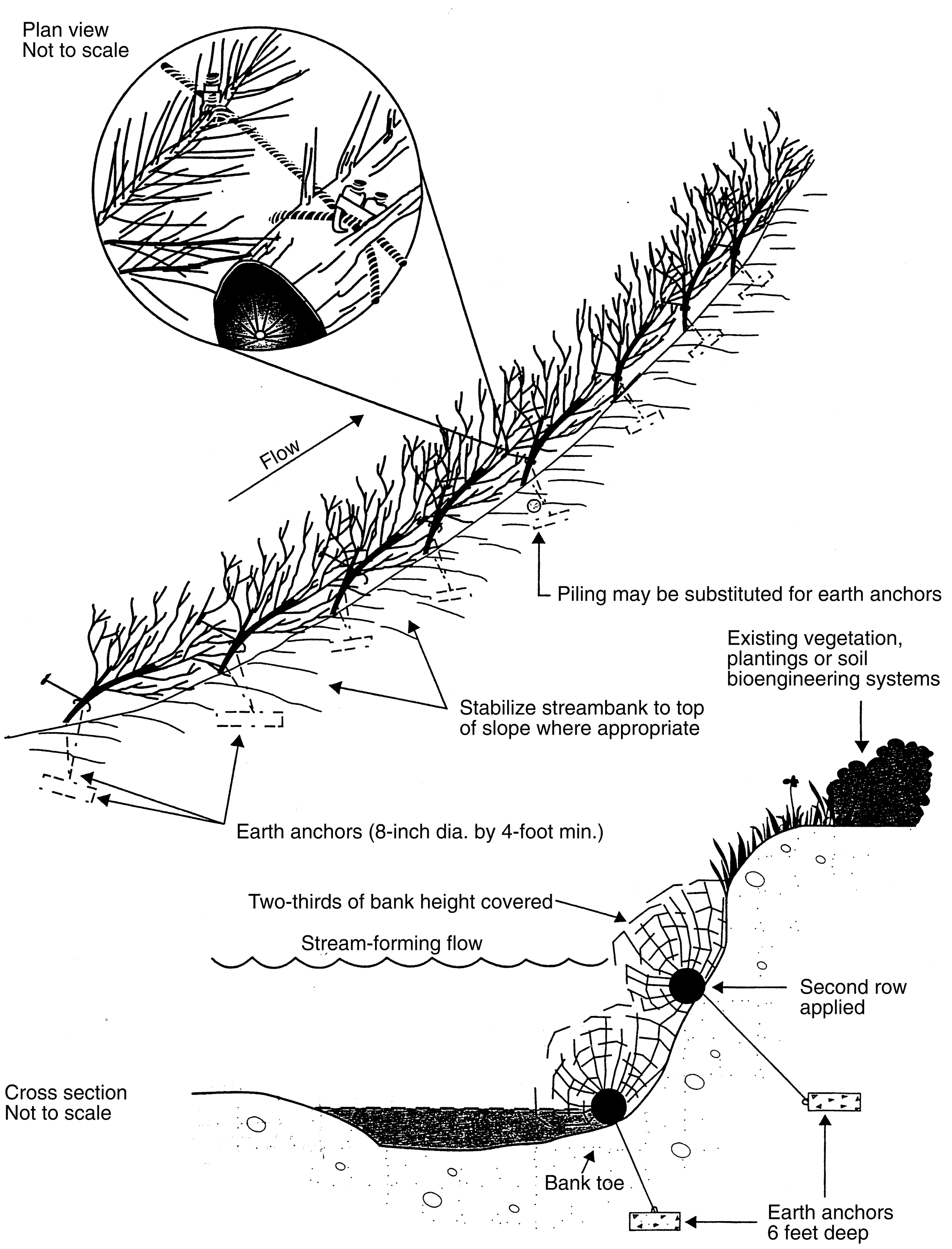


Figure 4.23-1 Tree revetment details

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

CONSTRUCTION GUIDELINES

- Lay the cabled trees along the bank with their bases oriented upstream.
- Overlap the trees to ensure continuous protection to the bank.
- Attach the trunks by cables to anchors set in the bank. Pilings can be used in lieu of earth anchors in the bank if they can be driven well below the point of maximum bed scour. The required cable size and anchorage design are dependent upon many variables and should be customized to fit specific site conditions.
- Use trees that have a trunk diameter of 12 inches or larger. The best type are those that have a brushy top and durable wood, such as douglas fir, oak, hard maple, or beech.
- Use vegetative plantings or soil bioengineering systems within and above structures to restore stability and establish a vegetative community. Tree species that will withstand flooding should be staked in openings in the revetment below stream-forming flow stage.

4.24 Vegetative Stabilization: LOG ROOTWADS

DESCRIPTION

These revetments are systems composed of logs, rootwads (root systems) and boulders selectively placed in and on streambanks (Figure 4.24-1). They can provide excellent overhead cover, resting areas and shelters for insects and other fish-food organisms, a substrate for aquatic organisms, and increased stream velocity that results in sediment flushing and deeper scour pools. Several of these combinations are described in Rosgen (1994) and USDA, NRCS, National Engineering Field Handbook, part 653.

APPLICATIONS AND EFFECTIVENESS

Log rootwads:

- are used for stabilization and to create in-stream structures for improved fish-rearing and spawning habitat.
- are effective on meandering streams with out-of-bank flow conditions.
- will tolerate high boundary shear stress if logs and rootwads are well anchored.
- are suited to streams where fish-habitat deficiencies exist.
- should be used in combination with soil bioengineering systems or vegetative plantings to stabilize the adjacent banks.

PLANNING CONSIDERATIONS

Rootwads may not be aesthetically pleasing, and may be a hazard to recreational navigation.

These projects may need state, federal or local permits, so check with the appropriate agencies.

DESIGN

Large logs with intact rootwads are placed in trenches cut into the bank in such a manner that the rootwads extend beyond the bank face at the toe. The logs are overlapped and/or braced with stone to ensure stability, and the protruding rootwads effectively reduce flow velocities at the toe and over a range of flow elevations. A major advantage of this approach is that it re-establishes one of the natural roles of large, woody debris in streams by creating a dynamic, near-bank environment that traps organic material and provides colonization substrates for invertebrates and refuge for fish.

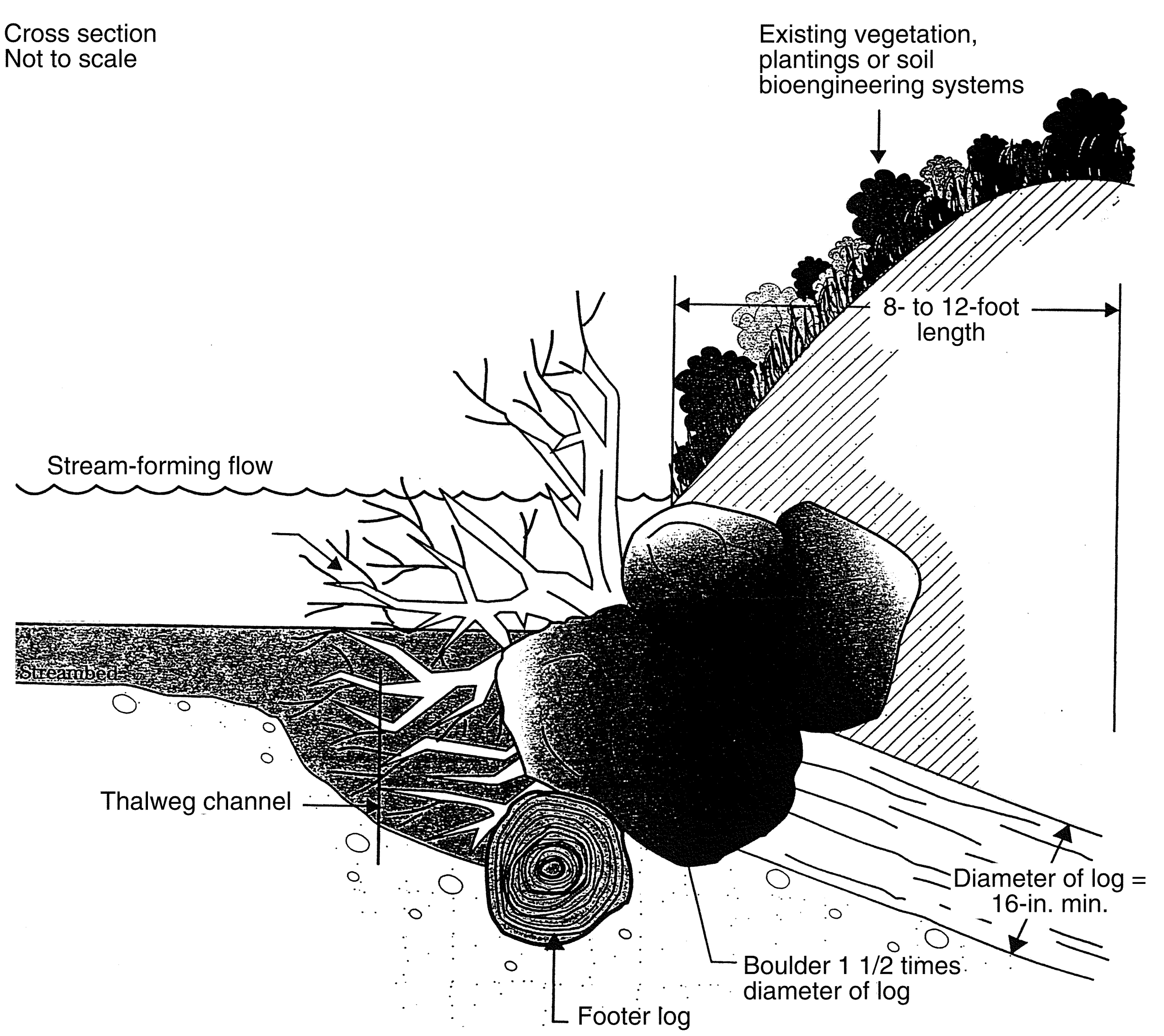


Figure 4.24-1 Log, rootwad, and boulder revetment details (Source: USDA, NRCS, August 26, 1998)

4.25 Vegetative Stabilization: VEGETATED GEOTEXTILE REVETMENTS

DESCRIPTION

Geotextiles have been used to control erosion on road embankments and other upland settings, usually in combination with seeding or with plants placed through slits in the fabric.

PURPOSE

The typical streambank use for these materials is in the construction of vegetated geogrids, which are similar to brush layers except that the soil fill between the layers of cuttings are encased in fabric, allowing the bank to be constructed of successive “lifts” of soil, alternating with brush layers. This approach allows reconstruction of a bank and provides considerable erosion resistance. Cylindrical fiber bundles can be staked to a bank with cuttings or rooted plants inserted through or into the material.

PLANNING CONSIDERATIONS

Vegetated material fiber textiles, permanent geogrids or other nondegradable materials can also be used where geotechnical problems require drainage or additional strength.

These projects may need state, federal or local permits, so check with the appropriate agencies.

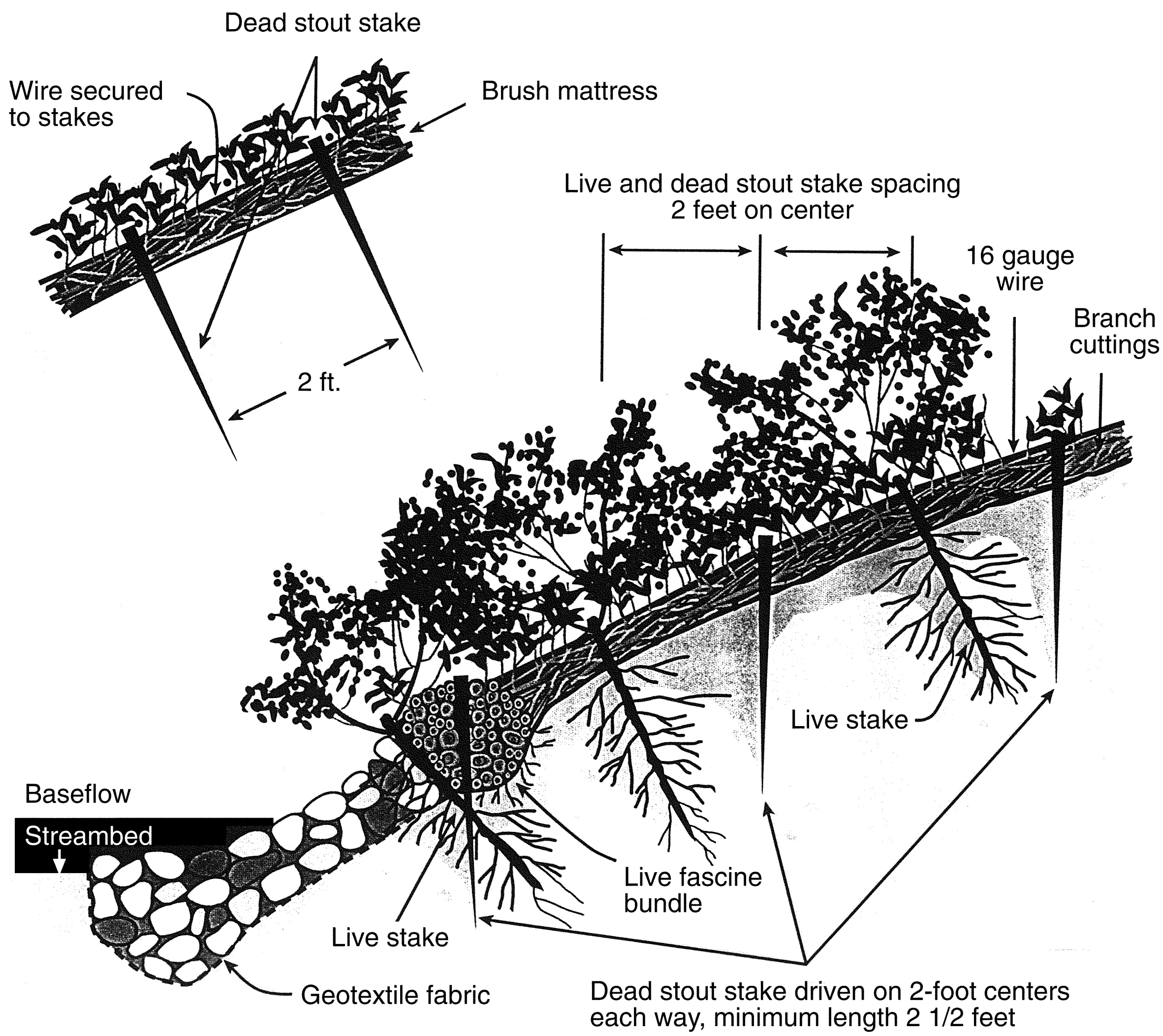


Figure 4.25-1 Vegetative stabilization: vegetated geotextile revetments (Source: USDA, NRCS, August 26, 1998)

4.26 Vegetative Stabilization: TREES, SHRUBS, VINES AND GROUND COVERS

DEFINITION

Vegetative stabilization is stabilizing disturbed areas by establishing a vegetative cover of trees, shrubs, vines, or ground covers.

PURPOSE

To stabilize the soil with vegetation other than grasses or legumes. To provide food and shelter for wildlife, protect water quality, provide visual screening, windbreaks for energy conservation, control snow drifting and improve aesthetics.

CONDITIONS WHERE PRACTICE APPLIES

Trees, shrubs, vines and ground covers may be used on steep or rocky slopes where mowing is not feasible or desired, as ornamentals for landscaping or in shaded areas, where it is difficult to maintain cover using normal landscaping techniques.

PLANNING CONSIDERATIONS

Woody plants and ground covers provide alternatives to grasses, forbs and legumes as low-maintenance, long-term erosion control. The initial establishment cost is often higher than using grass, but this is recovered in reduced long-term maintenance expenses. Strategically placed trees and shrubs reduce energy costs for buildings by reducing heating and cooling needs. Larger-scale windbreaks can provide energy conservation benefits for entire communities. For example, a multirow windbreak north and west of a cluster development could substantially reduce winter heating needs.

It is important to select woody species based upon site-specific characteristics and the intended purpose of the planting. The person selecting the plants must be knowledgeable in the requirements of each plant to assure optimum survival and growth. Plants that are well suited to a site are less likely to have insect and disease problems and will live longer. The vendor must use proper site-preparation and planting techniques. A poorly prepared site or poorly planted tree will result in a plant predisposed to a lifetime of problems.

Aids to help select the correct plants are available from several sources. The Minnesota Department of Transportation (MnDOT) has an excellent CD-ROM. The Minnesota Department of Natural Resources Forestry Division has lists of native species for various sections of the state (ecological subsections). Northern States Power Company has species lists related to power line interests and preventing associated problems. The University of Minnesota Extension Service has many publications on woody plants, vines and ground covers. Lists of plants and methods of planting for lakeshore are also available (Henderson *et al*., 1999).

It is not practicable to make these vegetative plantings from seed. Germination is undependable, and the seedlings will have great difficulty competing with the grassy ground covers. A grassy ground cover should be established to prevent erosion and to control undesirable weeds while the woody cover is becoming established. The large variety of plant species does not allow recommendations for each species to be given here. General guidelines will be presented and will need to be fine-tuned after the specific site plan has been developed.

Trees. Trees are usually defined as single-stemmed, woody plants over 25 ft tall at maturity. Trees are among the best soil stabilizers, but require years to grow into a cover adequate to meet sediment-control objectives. The tree planting must be established with an interim sediment-control method. A ground cover of grass or other herbaceous material is usually established over the entire project area and then individual planting spots are created for the trees.

Site Preparation. All undesirable vegetation should be removed if the site has not been previously graded. An interim sediment-control method should be installed using grass or herbaceous plants. Native grasses or something like ryegrass and timothy is preferred over conventional turfgrass species. Individual planting sites need to be created as required by the trees being planted. For bare root trees, this is usually a spot about 3 ft square. For trees that are placed with a tree spade or balled and burlaped (B&B) trees, the planting hole should be equal in size to the dirt ball.

Plant Sources. Trees are rarely seeded. Results are unpredictable and the surrounding vegetation easily outgrows the seedlings. Unless the seedlings are very tolerant of shade, they generally die. Natural seeding into the area from adjacent trees is highly variable. Trees that start this way are generally short-lived and a plan to eventually replace them is necessary.

The use of nursery-grown seedlings and saplings is the preferred method. Select species adapted to the site and suitable for the intended purpose. These can be bare-root, B&B, tree-spaded or container-grown. The larger the tree being planted, the more care it will require and the longer it will take to recover from transplant shock. Instead of purchasing trees, it may be possible to use a tree spade and move trees from one part of the project to another. On a site being cleared of trees, it is possible to move elected trees to a temporary holding site and then plant them elsewhere after grading has been completed.

Planting Time. Dormant-season planting is preferred. Early spring is the most common with small, bare-root seedlings. Fall and spring are common planting times for B&B, tree-spaded and container-grown stock. Avoid planting trees while they are actively growing. Fall planting in silt or clay soils can result in frost heaving the trees out of the ground over winter because they do not have time to establish a root system to anchor themselves. Generally, each of these types of planting stock is available only at certain times of the year.

Planting Methods. All planting shall be done in accordance with MnDOT, or other appropriate, guidelines. See Inspection and Contract Administration Guidelines for Minnesota Department of Transportation Landscape Projects" for details (February 1997).

Spaded trees should have a dirt ball equal to 12 inches of ball for each inch of trunk diameter. Care should be taken during transport to prevent damage to the branches by tying or wrapping them.

B&B stock should be planted at the depth of the root collar. This may be different than the soil depth of the dirt ball because trees are often "hilled" with dirt during the growing process. Planting too deeply results in unhealthy trees. The hole shall be big enough to easily hold the tree at the proper depth. Remove all tying materials and fold the burlap down as far as possible so the roots can expand easily.

Container-grown stock is similar to B&B stock in that the seedling has dirt attached to its roots, but it has been grown in a pot or other container. Container-grown trees need adequately sized holes and should be planted at the same depth they were growing in the pot. Containers vary in size from a few cubic centimeters to pots 3 ft in diameter.

Bare-root stock does not have dirt protecting the roots. These trees are shipped in peat moss or moisture-proof containers to prevent their roots from drying. Do not let the roots dry while the planting is under way; keep damp moss or a mud slurry around the roots until the tree is in the ground. Bare-root trees should only be planted in the spring or fall while they are dormant. Store them in a cool, shaded location until they can be planted. Be certain they are moist, and water as necessary to keep them healthy in the shipping container. Bare-root seedlings can be easily planted with a tree-planting bar. This tool is a 3/8-inch-thick steel plate, 3 to 4 inches wide by 12 inches long, on a 36-inch handle. It makes a V-shaped hole that the seedling is placed into. Dirt is then packed around the roots. Figure 4.26-1 shows hand planting with a tree-planting bar. Water and mulch around the tree immediately after planting.

For all planting methods, a soil fertility test is desirable. In severely disturbed areas, the use of fertilizer, compost, hormones or ectomycarrihizal fungi will almost certainly be needed. Trees prefer a soil pH of about 6.5, so the use of lime or other alkaline materials should be avoided. Compost can be added to the hole as described in the MnDOT guidelines (February 1997).

Staking should be generally avoided; if necessary, use only two stakes on opposite sides and tie the tree loosely. Some wind movement is desirable to strengthen the stem.

On larger sites, a tractor-drawn tree planter may be an effective planting method. It results in distinct rows that may not give the desired aesthetic look. Soft or wet soils or steep slopes may prevent the use of tractor-drawn equipment. In such cases, only smaller, bare-root seedlings can be used.

Mulch can be woodchips, shredded bark or man-made materials, such as landscape fabric. The use of stone as mulch is discouraged because it absorbs too much heat. Place woodchip or bark mulch 4 or 6 inches deep in a 2- to 3-ft diameter area, keeping the tree in the center. Do not pile mulch

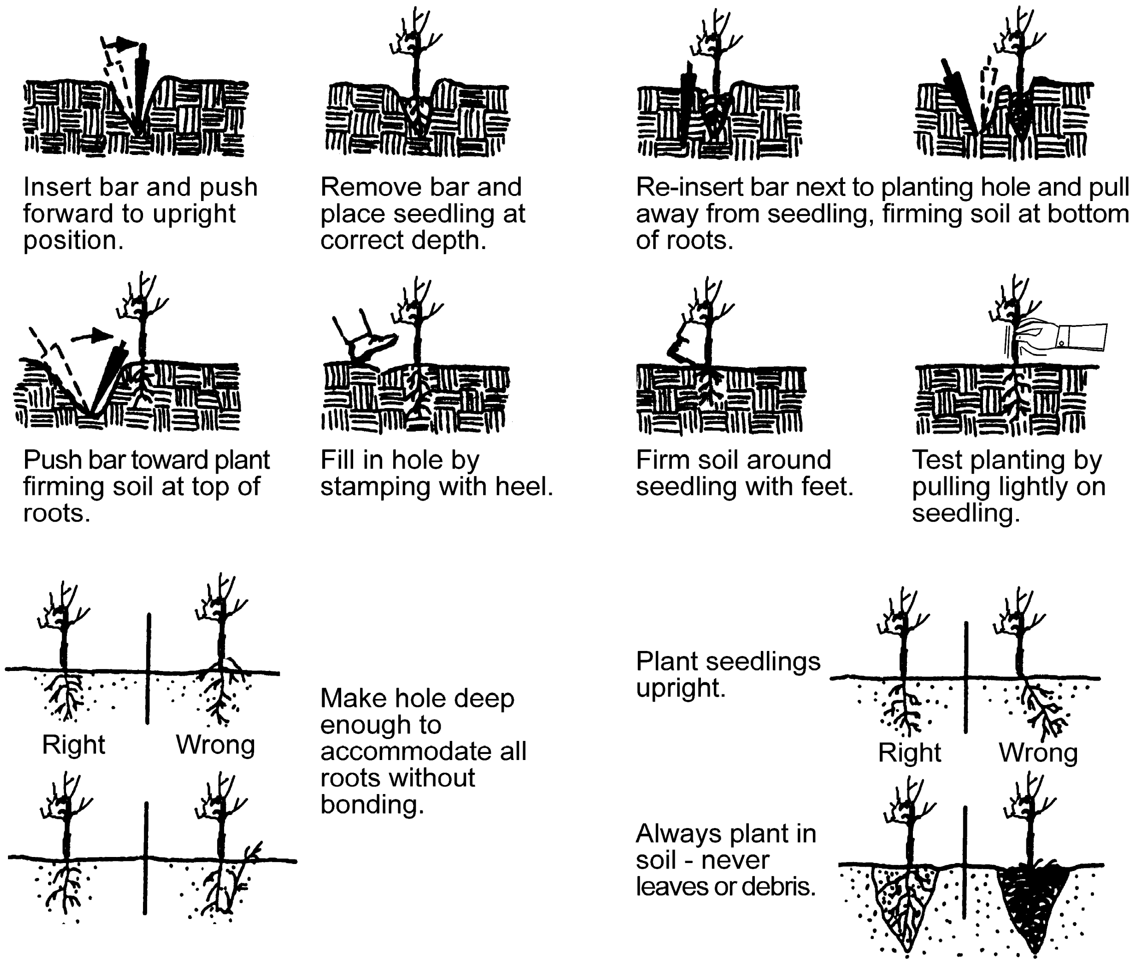


Figure 4.26-1 Planting bare-root seedlings (modified from Virginia Division of Forestry)

against the stem, as it can cause wood-rotting fungi to damage the tree. Landscape fabric can be used in 3-ft square pieces with a center cutout for the tree. This should be fastened to the ground with earth staples or by piling dirt along the edges.

Shrubs, Vines and Ground Covers. Shrubs vary in form from upright, single-stem to sprawling, multistem plants. Vines are climbing woody plants that cling to other plants or objects. Ground covers, as defined by landscapers, are low-growing, woody or herbaceous plants that spread to produce a dense, continuous cover. They can be an alternative to turfgrass. These categories can be used in conjunction with other types of plantings to increase diversity as well as by themselves.

As supplemental plantings, they can be used to:

- increase the aesthetic value of plantings,
- provide screening,

- enhance windbreaks for dust and snow control,
- provide food and cover for wildlife, and
- accelerate landscape diversity.

These plants should be selected using the same criteria as for trees. Species have varying degrees of shade tolerance, growth rates and form. There are deciduous and evergreen types that can be used. Preferably, shrubs should be used with other types of vegetation to stabilize an area. Crownvetch and other aggressive species should be avoided. Vines and ground covers may be a good choice where shade makes it difficult to establish trees or turf. Many species provide an attractive cover that does not require mowing. Certain species become very effective barriers to pedestrian traffic as they become impenetrable.

After-planting Maintenance. All larger trees used for planting should have a one- or two-year guarantee; any trees that do not survive should be replaced by the nursery. Pruning may be necessary to assure proper plant form and to remove damaged branches.

Annual inspections will reveal any additional needs for weed control by mowing, spraying or hand-pulling. Check for any deterioration in mulch and replace as needed. Mulch mats may need to be refastened so they stay in place.

Check for damage caused by rodents and white-tailed deer. It may be necessary to place tree tubes around the plants to reduce or prevent this type of damage.

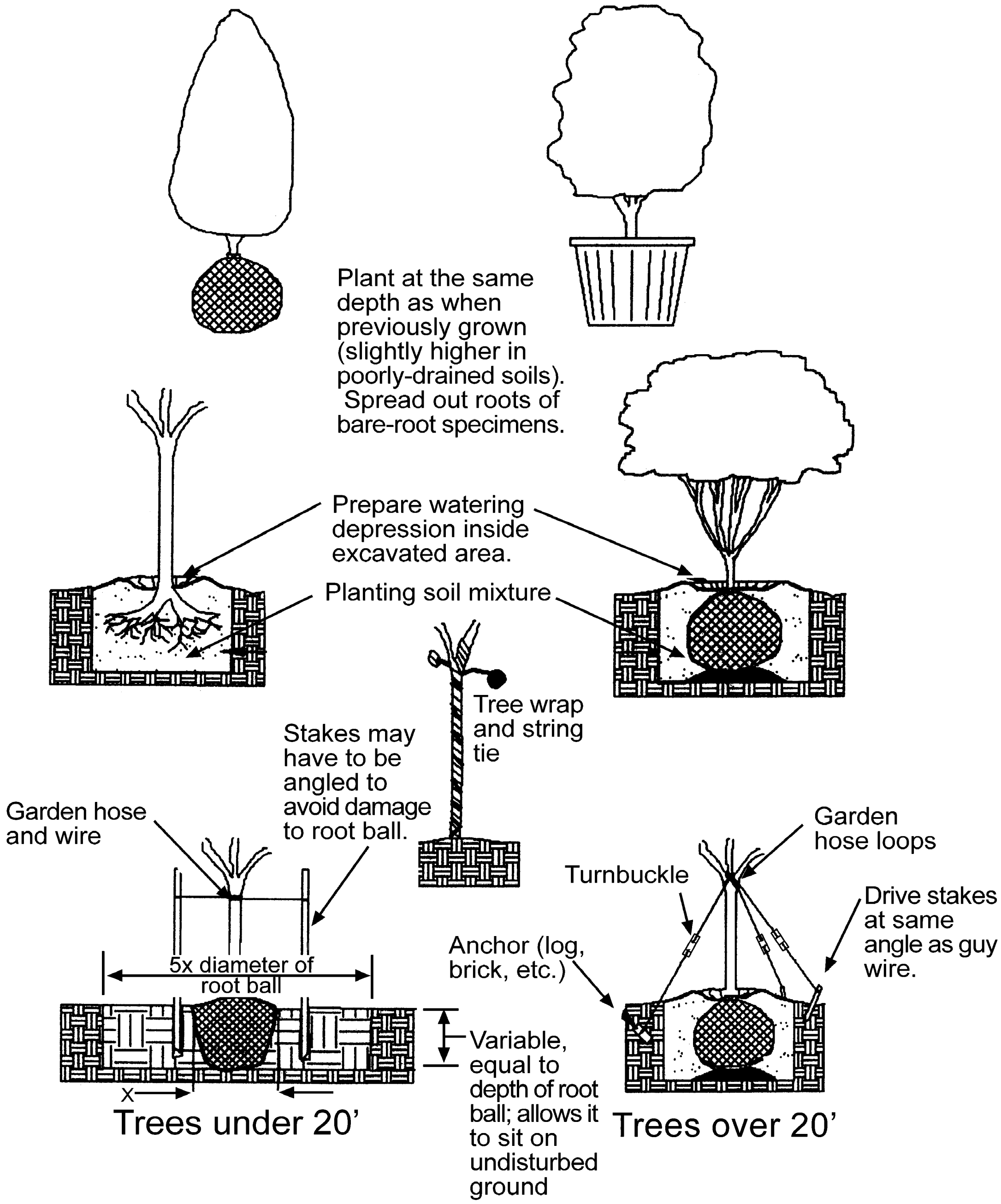


Figure 4.26-2 Planting balled-and-burlapped and container-grown trees (modified from Virginia Division of Forestry)

4.30 Bioengineering

TRADITIONAL PRACTICES COMPARED TO SOIL BIOENGINEERING

Where there is a need to provide soil stabilization, traditional engineering approaches have prescribed structural approaches as the standard solution. For example, the traditional method for stabilizing the banks of rivers and streams and controlling bank erosion is to place riprap along the banks. Erosion control on slopes is often achieved by terraces, rock gabions, retaining walls or other measures which effectively provide structural integrity, inspectability and flood access. However, these measures may reduce the natural functions of the biological communities in which they are placed, especially at the interface between water and land.

Soil bioengineering provides an alternative. It uses biological elements (plants) alone or in combination with mechanical elements (structures) to provide slope protection and prevent erosion. Bioengineering promotes use of native vegetation, emphasizing natural, locally available material, including earth, rock, timbers and vegetation (woody and herbaceous), in contrast to manufactured materials, such as steel and concrete (see SWAG, 1998).

BIOENGINEERING ADVANTAGES

1. Soil bioengineering solutions are less disruptive and leave a more natural appearance, an advantage in areas where the natural environment needs to be protected or enhanced, such as rivers, streams, wetlands, floodplain forests, parks, scenic corridors and wildlife habitats.

2. Soil bioengineering techniques improve water quality by providing plants which:
   - remove solids,
   - moderate water and air temperatures,
   - provide uptake of nutrients, and
   - enhance wetlands and natural vegetation as shore protection.

3. Soil bioengineering can preclude extensive grading and earthwork. It can be a practical alternative where heavy equipment cannot be used because of limited access.

4. Vegetation used in bioengineering provides wildlife habitat, including food, nesting and cover.

5. Soil bioengineering measures are usually less expensive to install and maintain than traditional practices.

6. With proper supervision, bioengineering techniques can be installed by unskilled or volunteer labor in many situations.

7. Ideally, once installed, the techniques can become stronger over time. Bioengineering structures are flexible, self sustaining and self repairing.

BIOENGINEERING DISADVANTAGES

1. Biotechnical methods and techniques alone do not solve all erosion problems. Some situations may require traditional structural engineering approaches which may be supplemented by bioenhancements (see Table 4.30-1).

2. The success of the project can be affected by climatic conditions and time of year because of periods of wet and dry weather, flooding duration or drought, and uprooting by freezing, thawing and action of ice.

3. Failure can be due to depredation by activities of humans, wildlife or livestock.

4. Bioengineering techniques are labor intensive.

5. An establishment period is necessary, during which frequent inspections and periodic maintenance must be conducted.

6. Cuttings must be installed when they are dormant. This limits the installation period to spring or fall, with spring being the preferred season in Minnesota.

RANGE OF BIOENGINEERING APPROACHES

In Table 4.30-1 we present a range of bioengineering approaches that we feel would be appropriate to consider in the development of a project.

Soil bioengineering is also known as "green" engineering, or "soft" engineering. Soil bioengineering techniques take advantage of rapidly growing root systems to reinforce the soil and bind soil particles together. Soil bioengineering emphasizes the use of plants as structural barriers to soil movement, including live staking, live fascines and other methods where the plantings are an integral part of the reinforcement system (Gray, 1996).

Surface plantings can be considered the conventional erosion control measures, including vegetative controls, such as seeding, sodding, or mulching. They have long been used for surface soil stabilization, but they generally are not intended to function on a deeper structural level (see section 6.20).

Biotechnical stabilization utilizes structural or mechanical elements in combination with biological elements to stabilize slopes and reduce erosion. Structures such as vegetated cribs, planted revetments and geogrid soil structure systems are included in this category (Gray and Sotir, 1996) (see section 6.50).

Bioenhancement, also called biorestoration or bioreclamation, has as its primary purpose habitat or aesthetics, but it may have some soil-stabilization benefits. Bioenhancement includes the use of biological features that improve habitat, aesthetics or the function of traditional surface erosion-control measures. These include vegetated structures, such as rock gabions or concrete structures, where biological material is planted to moderate temperatures, provide habitat or provide enhancements to

Table 4.30-1 Range of bioengineering approaches in order of importance of plants to soil stability[1]

Category	Examples	Role of vegetation	Appropriate upland uses	Appropriate stream/lake uses
1. Soil Bioengineering				
Woody and herbaceous plants used as reinforcement, as barriers to soil movements.	Live staking Live fascine Brush layer Branch-packing Live cribwall Live gully repair Fiber rolls Mats, blankets & mulches	Same as conventional plantings but also, to reinforce soil, transpire excess water, & minimize downslope movement of earth masses. Reinforces fill into monolithic mass. Improves aesthetics and habitat of structure.	Control of rills and small gullies. Control of shallow (translational) mass movement. Filter sediment, improve resistance to low to moderate earth forces.	Wave height 0.3 meter (1 ft) or less; stream velocity of 1.3 meters per second (4 fps) or less.
2. Surface Plantings				
Plantings that prevent surface erosion and prevent runoff of sediment	Grass seedlings, transplants, sods, forbs, mulch	Bind and restrain soil Filter soil from runoff. Intercept raindrops Maintain infiltration. Moderate ground temperature and control weeds.	Control water and wind erosion. Minimize frost effects.	Little or no velocity or wave action
3. Biotechnical Stabilization				
Structures in combination with plants to arrest or prevent slope erosion and failure.	Vegetated rock gabion. Vegetated rock wall. Plantings in wall or revetment joints or slope face. Tiered structures with bench planting. Geogrid reinforced soils	Reinforce fill into monolithic mass. Improve appearance and performance of structure. Stop or prevent erosion & shallow sloughing on or at the slope face or above the toe.	Improved resistance to low to moderate earth forces. Control erosion on cut & fill slopes subject to scour & undermining. Filter sediment.	Stream velocity of 1.3 to 4 meters per second (4-12 feet per second); wave heights up to 3 ft; checked by stability and water surface profile calculations.
4. Bioreclamation/enhancement/restoration[2]				
Plantings to serve other purposes than erosion control	Aesthetic tree plantings. Reclaimed mine lands Constructed duck ponds	Aesthetics, habitat and temperature moderation. Primary purpose is not to help structural stability or prevent erosion.	Wetland restoration, reconstruct habitat after severe disturbances, adopt specific habitat elements for specific purposes, provide comprehensive reconstruction.	Same uses as upland but adopted to aesthetic and habitat need of the site.

Adapted from:
[1]USDA Natural Resources Conservation Service, October 1992. *Engineering Field Handbook*. Chapter 18, "Soil Bioengineering for Upland Slope Protection and Erosion Reduction."
[2]Gillilan, Scott (September-October 1995).

mitigate negative effects that may have occurred in the project area. These plantings do not function primarily as soil protection but they enhance the affected environment of the project (Gillilan, September-October 1995).

4.31 Bioengineering: WILLOW POSTS

DESCRIPTION

The willow post method involves vertically inserting dormant willow posts, 3-5 inches (75-130mm) in diameter, 10 to 14 ft (3-4m) long, to below the depth of channel scour. The posts should be placed in a staggered pattern with a spacing on the average of 3 to 4 ft (1-1.3m) apart. Insert posts butt end first into the ground to allow rooting to occur. Posts inserted top end first will not root. This warning applies to any situation where willow is used.

Recommended Uses

- Willow posts are well suited for eroding streambanks.
- Use where access for heavy equipment exists.
- Use in full sun, where the post can be driven below water line and depth of streambed scour.

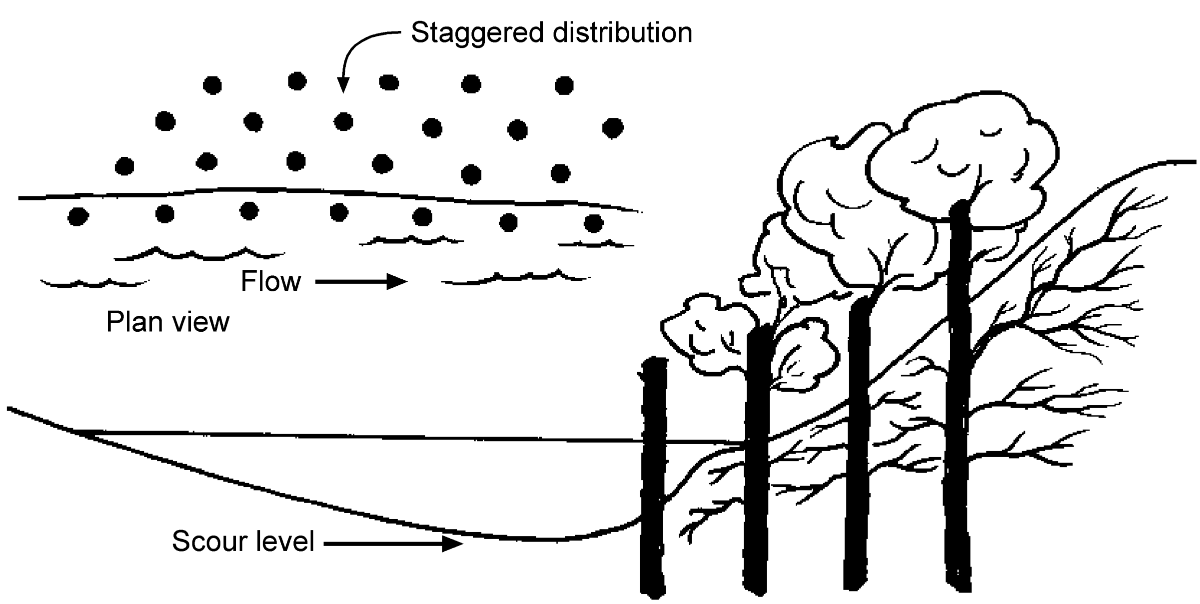


Figure 4.31-1 Willow posts

How It Works

Posts inserted into the channel simply act as barriers to retard velocities at the bank. Posts inserted into the bank will form roots that may bind the bank soil and adjacent posts. Lateral branch growth also interlocks adjacent posts to slow velocity above base-flow elevations. Some vegetation should be established between the posts for additional stabililization. The site should be inspected after heavy rainfall, and maintenance provided as needed. The first row should be considered sacrificial.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

4.32 Bioengineering: LIVE STAKES

DESCRIPTION AND PURPOSE

Live staking involves the insertion of dormant vegetative cuttings, 1 to 3 ft (.3-1.0m) long, into the ground, butt end first. If correctly handled and prepared and planted under favorable climatic conditions, the live stake will root and grow.

Recommended Uses

- Live stakes may be most appropriate for the repair of small earth slumps and at the toe of shallow slopes.
- Use for anchoring surface erosion control materials, such as filter blankets.
- Use to stabilize areas between other bioengineering measures, such as live fascines.

How It Works

A system of live stakes creates a living root network that stabilizes the soil by reinforcing it and binding soil particles together. Live stakes placed in the channel or in the lakebed may also provide a physical means of slowing velocities or breaking wave action. The stakes that are placed in water too deeply to root and grow are sacrificed to provide reduced water velocities near the stakes closer to the bank.

These projects may need state, federal or local permits, so check with the appropriate agencies.

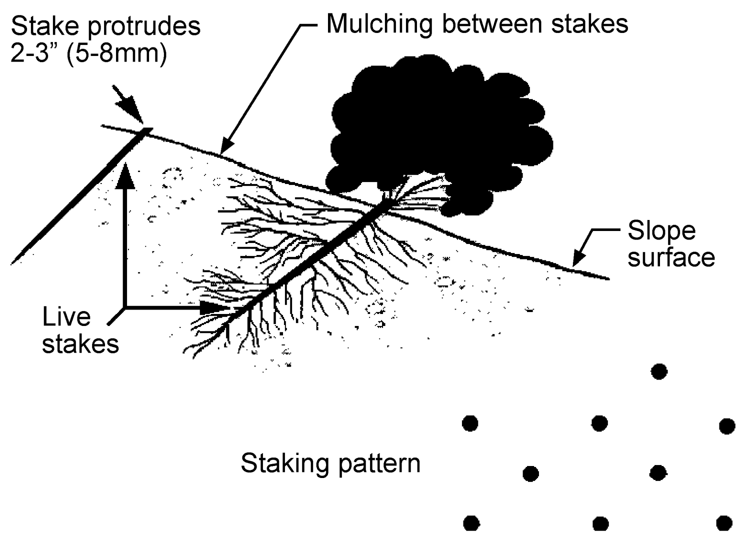


Figure 4.32-1 Live stakes

4.33 Bioengineering: WATTLING OR LIVE FASCINES

DESCRIPTION AND PURPOSE

This technique involves using long branch cuttings bound together into a cylindrical bundle. The wattles or fascines are installed in shallow trenches on the contour of the slope, where they will root and begin to stabilize the slope.

Recommended Uses

- Use to protect slopes from shallow slides 1 to 2 ft (.3-.6m) in depth.
- Surface erosion (sheet and small rill) is immediately reduced upon installation.
- Wattles are well suited to difficult digging conditions.
- Use where minimal site disturbance is required.
- Wattles can be used for upland slopes or for shoreline protection.

How It Works

Long bundles of live, dormant willows or dogwoods are laid in shallow trenches dug along the contour of a slope. This immediately breaks the length of the slope into shorter slopes between the wattles. The wattles will intercept soil particles moving downslope. If properly harvested, prepared and installed, the wattles will sprout and root, further increasing stability of the soil. As with all vegetative techniques, raindrop erosion is reduced and the microclimate is improved, making it easier for further vegetative succession and plant establishment. Vegetation will also help dry out a wet slope through evapotranspiration.

These projects may need state, federal or local permits, so check with the appropriate agencies.

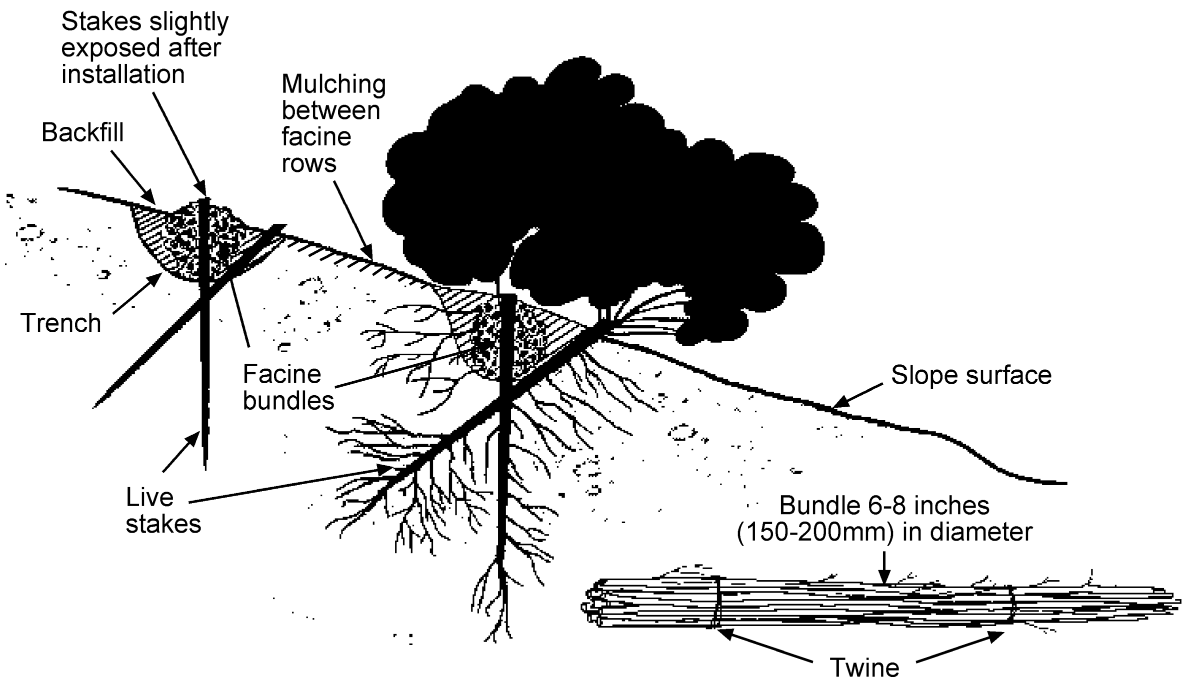


Figure 4.33-1 Wattling or live facines

4.34 Bioengineering: BRANCH PACKING

DESCRIPTION AND PURPOSE

Branch packing consists of alternating layers of live, dormant branch cuttings and compacted backfill to repair small, localized slumps and holes in slopes.

Recommended Uses

- Branch packing is effective for earth reinforcement and mass stability of small earthen fill sites less than 4 ft (1.3m) deep and 5 ft (1.6m) wide.
- Branch packing repairs holes in earthen embankments other than dams where water retention is common.
- Use branch packing where immediate soil reinforcement is needed.

How It Works

Reinforcing aspects of the intertwined branches and soil layers act much like geogrid meshes in stabilizing a mass of soil. This structural reinforcement is immediately provided upon construction. The protruding branches produce a filter barrier, increase infiltration and reduce slope length, thus reducing erosion and scour. Live branch cuttings serve as tensile inclusions for reinforcement upon installation. Trapped sediment fills localized slumps or holes while the roots spread throughout the backfill and into the surrounding earth, forming a unified mass.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

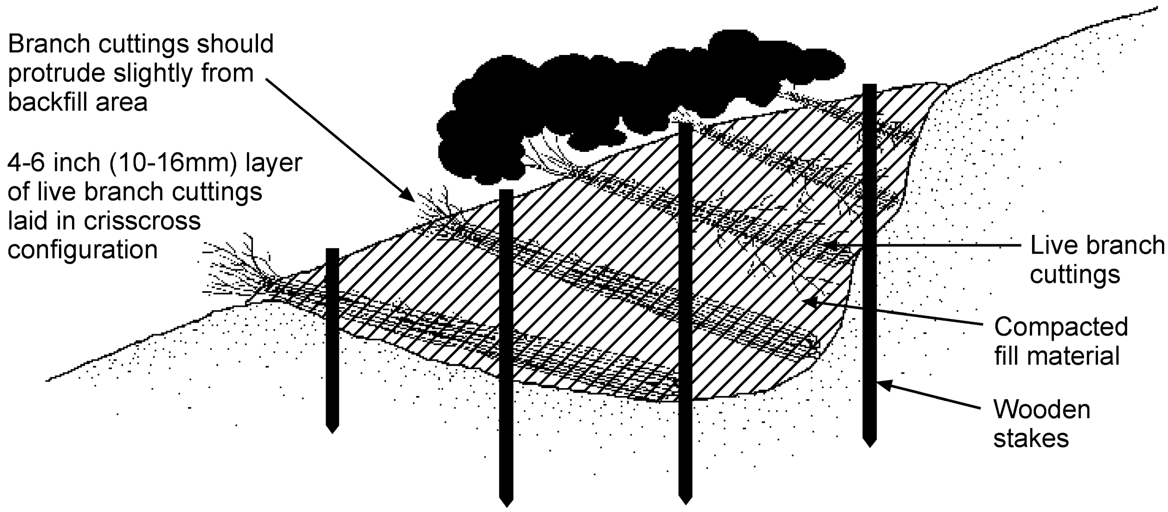


Figure 4.34-1 Branch packing

4.35 Bioengineering: BRUSH LAYERING

DESCRIPTION AND PURPOSE

Brush layering is the placement of dormant, vegetative cuttings into small benches excavated into a slope. Benches range from 2 to 3 ft wide, and the orientation of the layer of branches is more or less perpendicular to the slope.

Recommended Uses

- Use brush layering on slopes up to 2:1 in slope, but not higher than 15 ft (4.5m).
- Use brush layering where reinforcement deeper than that obtained by the relatively shallow live fascine method is needed.

How It Works

The perpendicular orientation to the slope makes this method effective in reinforcing earth and mass stability of the slope. As roots develop, significant resistance is added against sliding and shear displacement. The construction of the benches on the contour of the slope breaks the slope into shorter slopes, interrupted by the rows of brush layer. Added slope stability, debris- and sediment-retention capabilities, and moisture-regulation potential, in addition to the modified microclimate of a layered slope, will aid in seed germination and natural revegetation. The slope of the benches can be adjusted to allow for more or less infiltration into the soil profile.

These projects may need state, federal or local permits, so check with the appropriate agencies.

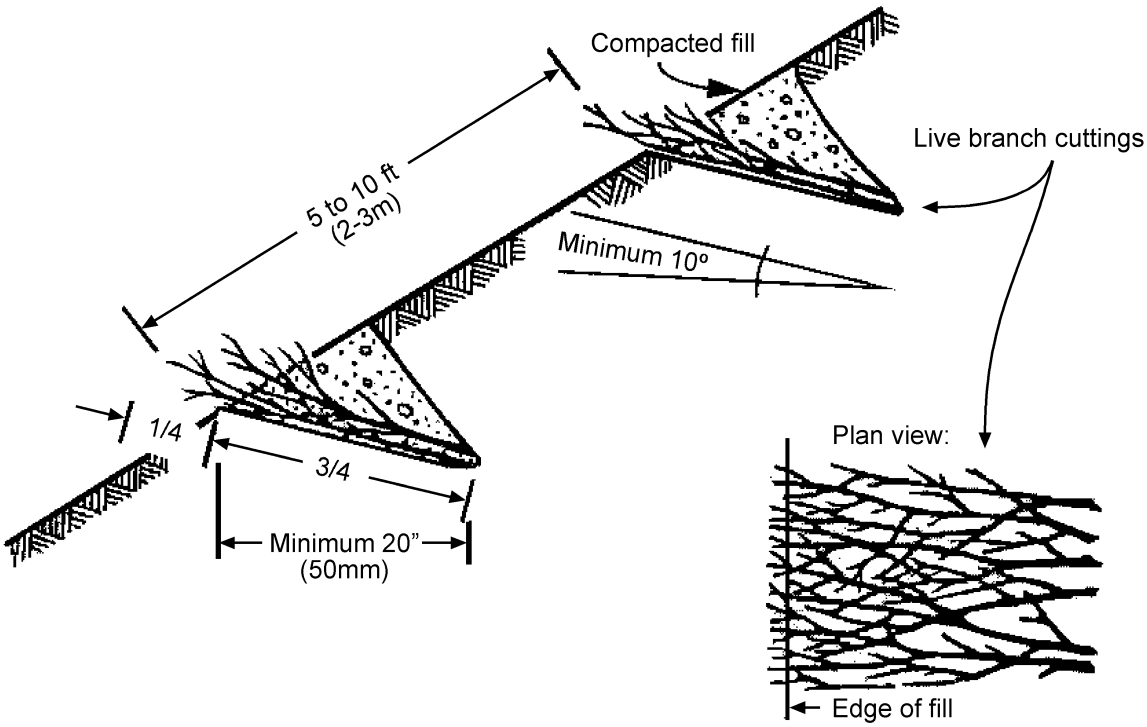


Figure 4.35-1 Brush layering

4.36 Bioengineering: LIVE GULLY REPAIR

DESCRIPTION

Live gully repair is similar to branch packing in that alternating layers of live, dormant branch cuttings and compacted soil are used to repair small rills and gullies.

Recommended Uses

This practice is recommended for the repair of small rills and gullies that are a maximum of 2 ft wide, 1 ft deep and 15 ft (4.5m) long.

How It Works

The installed branches immediately reinforce the compacted soil and reduce the velocity and concentration of flowing water. Live branch cuttings serve as tensile inclusions for soil reinforcement. As root growth into the soil proceeds, the repaired area becomes unified with the natural slope. Foliage on the branches will improve the microclimate of the repaired area and provide for enhanced natural revegetation. The exposed branch tips also catch and retain sediment while breaking up the slope.

These projects may need state, federal or local permits, so check with the appropriate agencies.

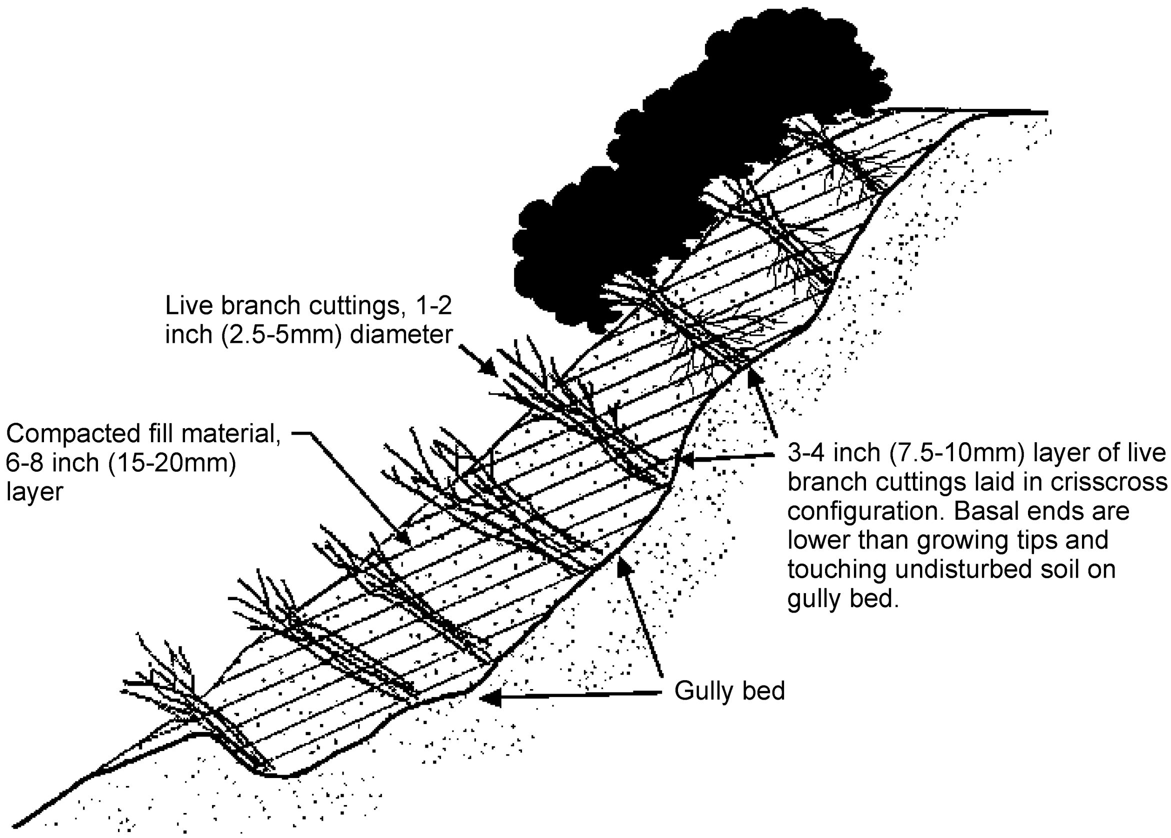


Figure 4.36-1 Live gully repair

4.37 Bioengineering: LIVE CRIBWALL

DESCRIPTION

A live cribwall consists of a hollow, box-like, interlocking arrangement of untreated logs or timbers that have been tied together. The structure is filled with suitable backfill material and layers of live branch cuttings.

Recommended Uses

- A live cribwall is appropriate at the base of a slope, where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Use a live cribwall where total crib height of 6 ft (1.8m) will be sufficient. Live cribwalls are not intended for resisting large, lateral earth stresses.
- Live cribwalls are useful where space is limited and a more vertical structure is required.
- Use a live cribwall where immediate erosion protection is desired.

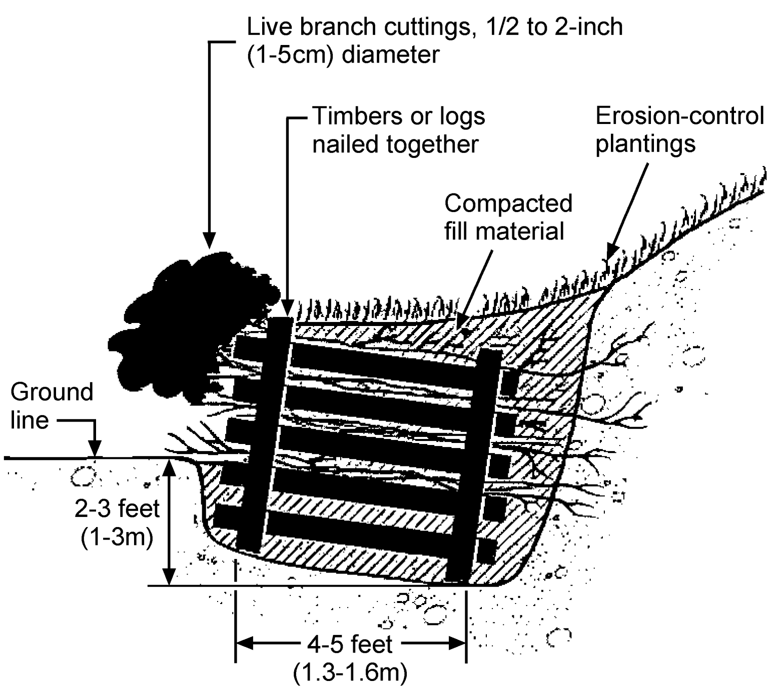


Figure 4.37-1 Live cribwall

How It Works

The live cribwall acts as an effective barrier to erosion as soon as it is constructed. The branch cuttings root inside the crib and eventually grow into the slope, binding the structure to the native soil. The growing vegetation gradually takes over the structural functions of the wooden crib members.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

4.38 Bioengineering: RELATED STABILIZATION PRACTICES

A-Jacks. An A-jack is a jack-shaped, interlocking concrete device. The size may be about 2-ft (.6 m) to much larger. A-jacks are entrenched in adjacent rows along the base of an eroding bank. Plants are interplanted among the A-jacks. The concrete provides a stable protection from high flows while allowing plants to become established.

Breakwaters. Temporary or permanent breakwaters may be needed to protect new plantings from currents and waves caused by boats or wind. These may be of rock, fiber rolls, bundled brush or fencing that has been staked in place.

Fiber Rolls and Natural Fiber Erosion-Control Blankets. These products use straw, wood or coconut fibers. They can be used to establish vegetation in low-flow-velocity applications and in shallow water while vegetation is being established.

Hydraulically Applied Mulches. These include a variety of sprayed materials that hold soil temporarily while vegetation is established (see section 6.50).

Joint Planting. Joint planting involves tamping live cuttings of rootable plant material into the soil between the joints or open spaces in rocks that have been placed on a slope. This practice is also called “vegetated riprap.”

Live Soft Gabions. These are basket-like structures in which successive layers of soil and plants are held in a place by a geogrid and filter fabric. The geogrid holds the soil while the plants become established.

Lunkers. A lunker is a long, bracket-shaped structure typically installed below the water line along a streambank. The lunker is constructed of thick planks in such a way that its interior is open to the flow of water at both ends and on the stream side. The planks make up the top and bottom layers. This structure provides toe protection while providing fish habitat.

Turf-reinforcement Mat (Geosynthetics). These can be used to permanently help reinforce vegetation in moderate intermittent-flow conditions (see section 6.50).

Vegetated Rock Walls. This combination of rock and live branch cuttings is used to stabilize and protect the toes of steep slopes. These differ from conventional retaining structures in that they are placed against relatively undisturbed soil and are not intended to resist large, lateral earth pressures.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements. Check with knowledgeable professionals for appropriate uses and applications for all these products.

4.40 Structural Stabilization: STRUCTURAL PROTECTION

DESCRIPTION AND PURPOSE

Structural streambank and lakeshore bank protection is the stabilization of banks with structural measures. Structural materials that can be used include wood, riprap, reinforced concrete, modular concrete blocks, walls or gabions.

These measures are commonly used where banks have become unstable due to changed hydrologic conditions or disturbance from construction. They can be used at key control points such as at outfalls and bridge piers, or for structure protection. They generally should be used after hydraulic controls have been considered.

A number of general designs for bank-protection works are presented here. We have arranged these designs by type: revetments, retaining walls and reflectors. These designs should be adapted to the site by a qualified engineer.

EFFECTIVENESS

When properly installed, structural streambank protection devices can prevent virtually all erosion from the treated area. Structural measures are usually used to protect features considered important or costly to replace, such as bridges or lakeshore houses.

PLANNING CONSIDERATIONS

The planner should consider the entire watershed and the impact that the measure will have long term. Bank-erosion problems and possible solutions vary considerably from site to site. Structural measures are expensive, but, if properly installed, they can provide a long-term solution to erosion problems. A variety of materials can be used for structural protection. Structural streambank protection measures should always be designed by a qualified engineer.

Structures often change the biological features of the aquatic system. Vegetative measures should be incorporated into the design as much as possible.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

DESIGN WARNINGS

1. **Provide adequate protection for the toe of the structure so it will not be undermined.** Most failures of shore-protection works have resulted from "toe failure," or erosion under the lowest part of the structure. The failure of the bulkhead in Figure 4.40-1 could have been prevented with adequate toe protection. Toe protection must be substantial enough to prevent the original ground under the structure from washing through the toe-protection blanket, and extend far enough water-ward of the structure to prevent undermining.

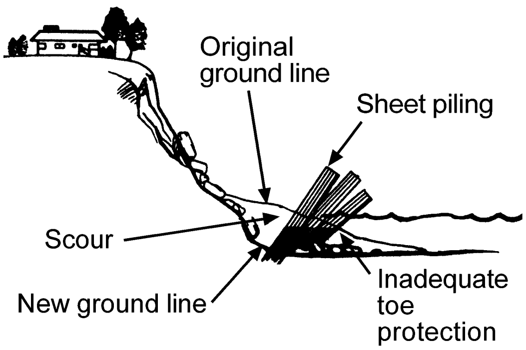


Figure 4.40-1 Inadequate toe protection (source: U.S. Army Corps of Engineers)

2. **Check foundation conditions.** The type of foundation may govern the selection of the type of protection. For example, a rock bottom will not permit the use of sheet piling. A filter material must be placed on a highly erodible embankment to prevent the fine material from washing through the voids in the structure. A soft foundation material will result in excessive settlement of the structure. Clay underlayers may allow all or part of the structure to slide. See Figure 4.40-2.

3. **Use material that is heavy and dense enough that waves will not move individual pieces of the protection.** The second most common failure is to use undersized material; flooding streams and storm waves have tremendous power and can move a lot of material in a short time. Small stones or small pieces of concrete will be moved around and carried away by small events. Larger events will be even more destructive. The bank revetment in Figure 4.40-3 was constructed of undersized stone that was carried down the slope by large waves.

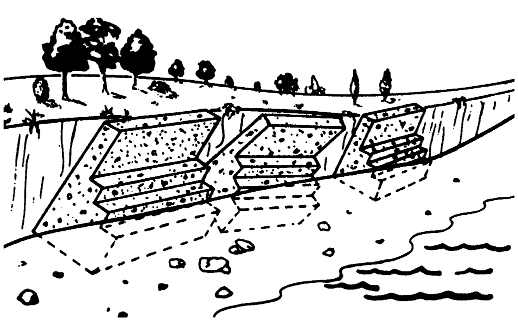


Figure 4.40-2 Inadequate foundation conditions (source: U.S. Army Corps of Engineers)

4. **Secure both ends of the shore protection against flanking.** Erosion will continue adjacent to any installed measure. If no protection exists next to the installed protection, build one with more material at the ends than in the center and place it well back into the bluff. If an existing structure has been flanked, such as the one shown in Figure 4.40-4, correct it by placing additional material at the ends and tying the measure directly into the bluff.

Figure 4.40-3 Inappropriate material sizing (source: U.S. Army Corps of Engineers)

5. **Build the structure high enough that waves cannot overtop it.** Spray overtopping is alright, but not overtopping by waves. Many failures have occurred because the structure was not built high enough and erosion could continue behind the structure as though it were not there, as is illustrated in Figure 4.40-5.

6. **Install a filter blanket or nonerodible bed.** Make sure that voids between individual pieces of protection material are small enough that underlying material cannot be washed out by waves. The protection materials must be thick enough to make a long passage for wave energy to reach the underlying materials. A layer or two of filter material should be placed between the underlying ground and the protective material.

Each stabilization project is unique, and the plans for each one must be tailored to the site. The following guidelines should be considered in the design.

1. Protective measures to be applied should be compatible with improvements planned or being carried out by others.

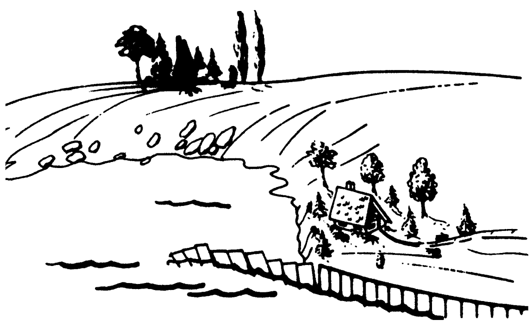


Figure 4.40-4 Inadequate flank protection (source: U.S. Army Corps of Engineers)

2. Channel-bottom scour should be controlled, by either natural or artificial means, before any permanent type of bank protection can be considered feasible. This is not necessary if the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bottom scour. Otherwise, structural measures may be undermined by scour causing them to fail.
3. Streambank protection should be started and ended at a stabilized or controlled point on the stream.
4. Structural measures must be stable during the design flow and should be capable of withstanding extreme events without serious damage.
5. Special attention should be given to maintaining and improving habitat for fish and wildlife. The use of bioengineering principles should be included in the design. Vegetative enhancements should be included in all projects.

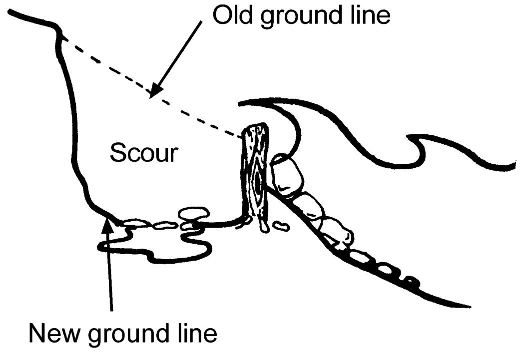


Figure 4.40-5 Overtopping (source: U.S. Army Corps of Engineers)

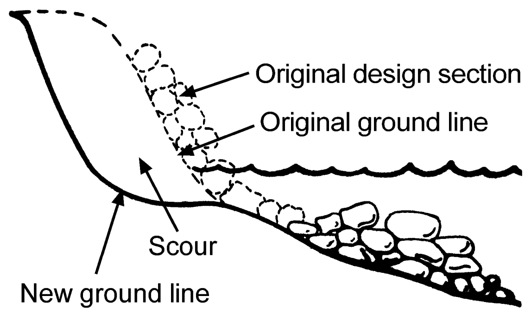


Figure 4.40-6 Inadequate scour protection (source: U.S. Army Corps of Engineers)

STREAMBANK-PROTECTION METHODS

Revetment

A revetment is a structural support or armoring that protects an embankment from erosion. Reinforced concrete or grouted concrete may be used, but revetments must be tied in to stable banks upstream and downstream and installed to a depth below anticipated scour. Concrete and grouted riprap can be very stable, but may be subject to major damage if failure occurs.

Retaining Walls

Retaining walls are vertical walls that retain soil. They are often constructed of sheet piling, timber or concrete. Walls are subject to erosion because they do not dissipate wave or flow energy gradually. They are also subject to the gravity and hydrostatic pressures that build up in the soil behind them. Care must be taken in the design and installation of these structures. Riprap toe protection is one of the more effective measures to prevent failure.

Deflectors

Deflectors include structural barriers that project into a stream to divert flow away from eroding sections of the streambank. Deflectors may be constructed of any stabilizing materials, such as bioengineering measures, riprap, or structural concrete, as necessary for the application. Revetments, wing walls, break waters, groins, jetties, hard points or armored points are some of the methods. If improperly installed, deflectors may interfere with sediment-transport processes, resulting in increased erosion downstream or downwind.

4.41 Structural Stabilization: GABIONS

DEFINITION

Gabions are rock-filled, rectangular wire baskets. These pervious, semiflexible building blocks can be used to armor the bed and/or banks of channels or act as deflectors to divert flow away from eroding channel sections (Figure 4.41-1). Design and install gabions in accordance with manufacturer's standards and specifications.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

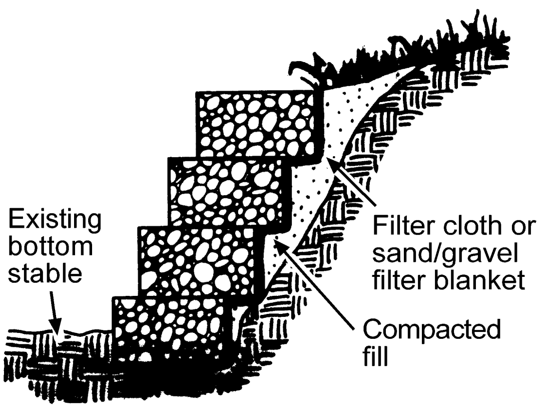


Figure 4.41-1 Gabions may be stacked to protect steep stream banks.

INSTALLATION

- Starting at the lowest point of the slope, excavate loose material 2 to 3 ft below the ground elevation until a stable foundation is reached.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Place the fabricated wire baskets in the bottom of the excavation and fill with rock.
- Place backfill between and behind the wire baskets.

Vegetated rock gabions

Vegetated rock gabions are used to improve aesthetics while providing permanent and stable structures.

Construction guidelines

Branches should range from 0.5 to 1 inch in diameter and must be long enough to reach beyond the back of the rock basket structure, into the backfill.

Place live branch cuttings on the wire baskets, perpendicular to the slope, with the growing tips oriented away from the slope and extending slightly beyond the gabions. The live cuttings must extend beyond the backs of the wire baskets, into the fill material. Place soil over the cuttings and compact it.

Repeat the construction sequence until the structure reaches the required height (see Figure 4.41-2).

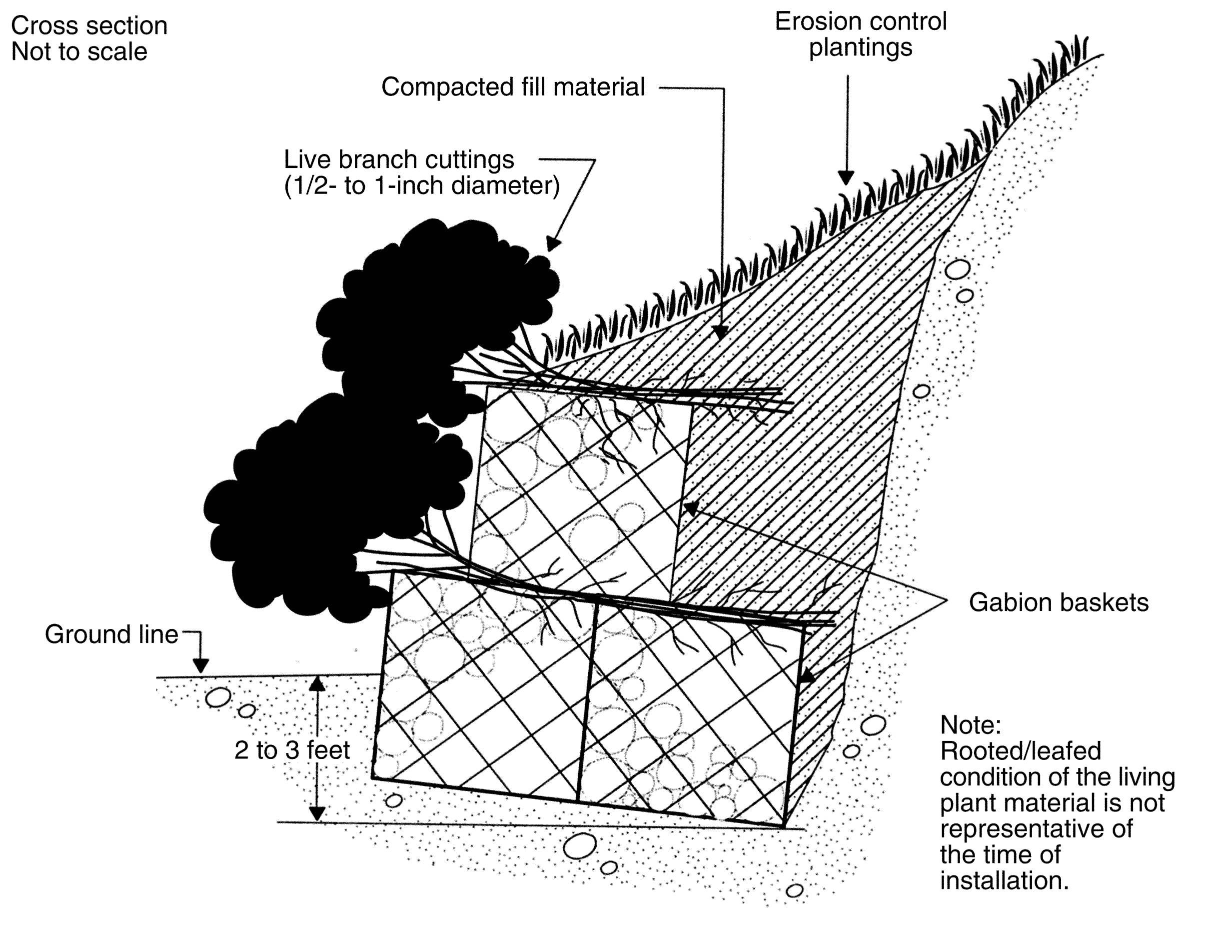


Figure 4.41-2: Vegetated rock gabion details (source: USDA, NRCS, August 26, 1998)

4.42 Structural Stabilization: GRID PAVERS

DEFINITION

Grid pavers are modular concrete units with interspersed void areas that can be used to armor a streambank while maintaining porosity and allowing the establishment of vegetation. These structures may be obtained in precast blocks or mats held together with cables or geotextile fabric. They may come in a variety of shapes (Figure 4.42-1), or they may be formed and poured in place. Keep design and installation in accordance with manufacturer's instructions.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

MAINTENANCE

Stabilize all areas disturbed by construction as soon as the structural measures are complete. Inspect and maintain on a regular basis. Check the edges of the structure and be sure that scour is not occurring under the block.

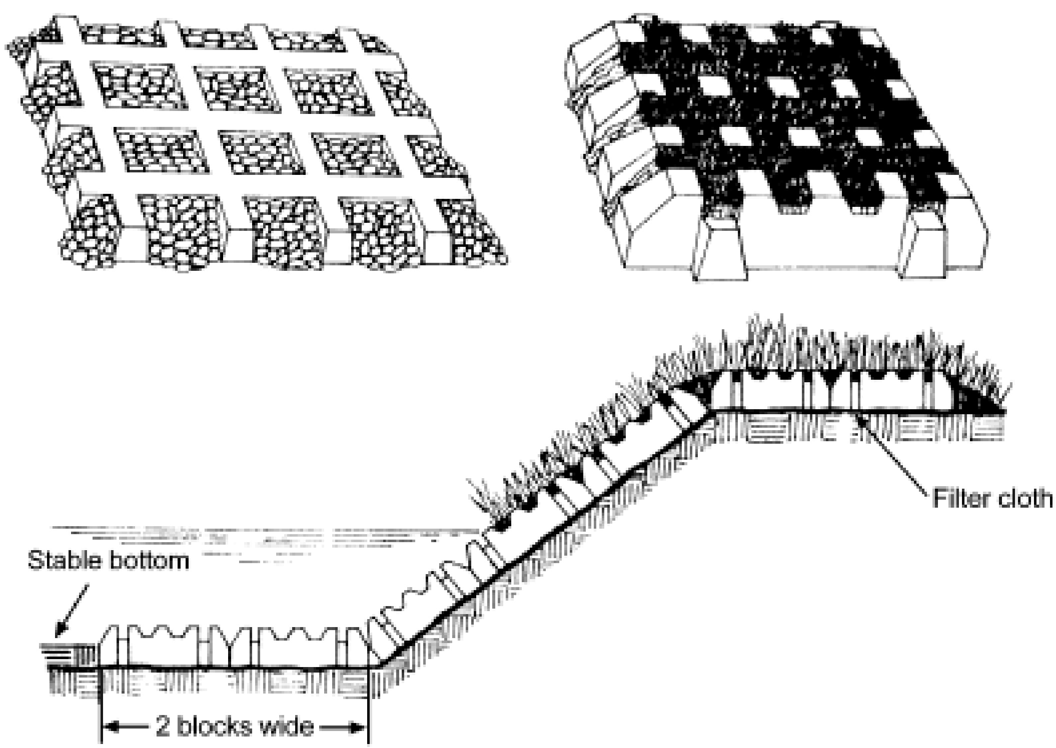


Figure 4.42-1 Voids in grid pavers may be filled with sand or gravel and established in vegetation. (Source: Virginia Department of Conservation and Recreation.)

4.43 Structural Stabilization: GRADE-STABILIZATION STRUCTURES

DEFINITION

A grade-stabilization structure is a structure designed to reduce channel grade in natural or constructed watercourses.

PURPOSE

A grade-stabilization structure can be used to prevent erosion of a channel that results from excessive grade in the channel bed. This practice allows the designer to adjust a channel grade to fit soil conditions.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where structures are required to prevent head cutting or stabilize gully erosion. Specific locations are:

- where head cutting or gully erosion is active in natural or constructed stream channels;
- where beds of intersecting channels are at different elevations; and
- where a flatter grad is needed for stability in a proposed channel or water disposal system.

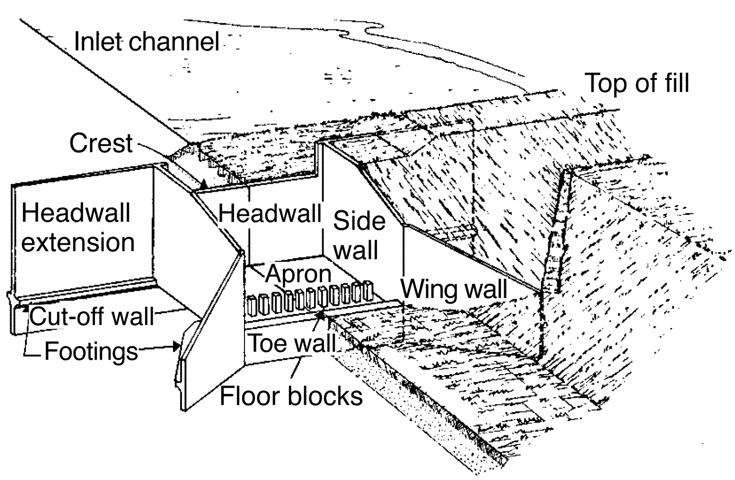


Figure 4.43-1 Full flow drop spillway

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Grade stabilization structures (see Figure 4.43-1) are usually installed as part of a vegetated water-disposal system. If the channel grade is erosive with a vegetative liner, the designer should consider using nonerodible channel liners (riprap or paving), or a vegetated channel in combination with grade-stabilization structures. In deciding which type of system to use, the designer should consider:

- the differences in channel depths, widths and spoil disposal,
- the effect the deeper channel will have on the water table, especially near the structure,

- entrance of surface water into the deeper channel system, and the need for an emergency bypass, at structure locations,
- side slope stability,
- outlet velocities,
- environmental impacts,
- site aesthetics, and
- cost comparisons, including maintenance.

In general, shallow channels stabilized with riprap or concrete are preferred to deeper earth channels that require grade-stabilization structures.

Grade-stabilization structures are often used to stabilize progressive head cutting in an existing channel. Make an on-site evaluation to determine that the channel upstream and downstream from the proposed structure will be stable for the design-flow conditions. Base the stability evaluation on clear water flow, as another head cut may begin below the structure once sediment sources upslope are controlled.

Grade-stabilization structures may be vertical drop structures, concrete or riprap chutes, gabions or pipe drop structures. Permanent ponds or lakes may be part of a grade-stabilization system.

Where flows exceed 10 cubic feet per second (cfs) and grade drops are higher than 10 ft, consider concrete chutes. This type of grade-control structure is often used as an outlet for large water impoundments.

Where flows exceed 100 cfs and the drop is less than 10 ft, a vertical drop weir constructed of reinforced concrete or sheet piling with concrete aprons is generally recommended. Small flows allow the use of prefabricated, metal drop spillways or pipe overfall structures.

Pipe drop grade-stabilization structures are commonly used where channels intersect at different elevations, especially where flows are less than 50 cfs. Pipe drop structures also make convenient permanent channel crossings.

DESIGN CRITERIA

Designs for grade-stabilization structures can be complex and usually require detailed site investigations. The design may require a qualified engineer familiar with hydraulics and experienced in structure design.

Location of structure. Locate the structure on a straight section of channel with no upstream or downstream curves within 100 ft.

Ensure that the foundation material at the site is stable, relatively homogeneous, mineral soil with sufficient strength to support the structure without uneven settling. Piping potential of the soil should be low.

Ensure that flood-bypass capability is available at the site to protect the structure from flows greater than design capacity. Protect the area where bypass flow enters the channel downstream.

Consider diversion of flow for dewatering during construction as part of site evaluation.

Capacity. As a minimum, design the structure to control the peak runoff from the 10-year storm or to meet the bankfull capacity of the channel, whichever is greater.

Ensure that bypass capacity prevents structural failure from larger storms, based on the expected structure life and consequences of failure. Large structures require greater design factors because of safety considerations.

Grade elevations. Set the crest of the structure's inlet at an elevation that will stabilize the grade of the upstream channel. Set the outlet section at an elevation that will provide a stable grade downstream to ensure stability.

Structural dimensions. The *National Engineering Handbook* (Drop Spillways, section 11, and Chute Spillways, section 14), prepared by the USDA, NRCS, gives detailed information useful in the design of grade stabilization structures (see Figure 4.43-2).

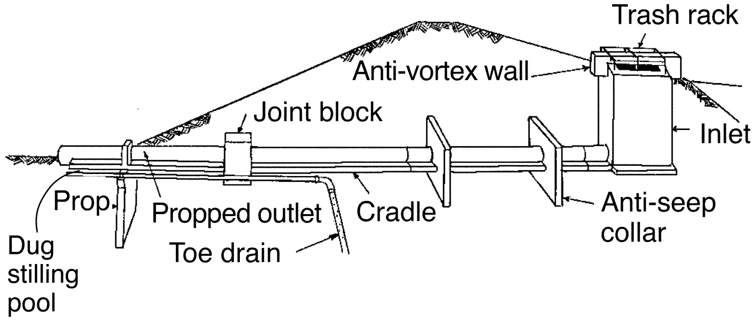


Figure 4.43-2 Drop inlet spillway

Foundation drainage. Foundation drainage is needed to reduce hydrostatic loads on drop spillway structures. New products, such as prefabricated plastic, drainage devices, are available that provide positive drainage, are easy to install, and may be less costly than conventional drainage methods.

Outlet conditions. Keep the velocity of flow at the outlet within the allowable limits for the receiving stream. Place a transition section consisting of properly sized riprap at the toe of the structure to prevent erosion of the channel bed (see part 4.45, Outlet Stabilization Structure).

CONSTRUCTION SPECIFICATIONS

- Divert all surface runoff around the structure during construction so that the site can be properly dewatered for foundation preparation and construction of headwalls, apron drains and other structural appurtenances.

- Ensure that the concrete conforms to standards for reinforced concrete. Make adequate tests, including breaking test cylinders, to see that the concrete meets all design specifications for the job. Failure of a large grade-stabilization structure may be costly and extremely hazardous.

- Hand compact backfill in 4-inch layers around the structure.

- Make the end of the riprap section as wide as the receiving channel, and make sure the transition section of riprap between the structure end sill and the channel is smooth.

- Ensure that there is no overfall from the end sill along the surface of the riprap to the existing channel bottom.

- Locate emergency bypass areas so flood flow in excess of spillway capacity enters the channel below the structure without serious erosion or damage to the structure.

- Stabilize all disturbed areas as soon as construction is complete.

Since these structures are located in watercourses, take special precautions to prevent erosion and sedimentation during their construction.

MAINTENANCE

Once a grade-stabilization structure has been properly installed and the area around it stabilized, maintenance should be minimal. Inspect the structure periodically and after major storms throughout the life of the structure. Check the fill around the structure for piping, erosion and settlement and to ensure that good protective vegetation is maintained. Check the channel at the structure entrance and outlet for scour and debris accumulation that may cause blockage or turbulence. Check the structure itself for cracking or spauling of the concrete, uneven or excessive settlement, piping and proper drain functioning. Check emergency bypass areas around the structure for erosion, especially where flow re-enters the channel. Repair or replace failing structures immediately.

4.44 Structural Stabilization: PAVED FLUMES (CHUTES)

DEFINITION

A paved flume, or chute, is a small, concrete-lined channel that can be used to convey water on a relatively steep slope.

PURPOSE

Use a paved flume, or chute, to conduct concentrated runoff safely down the face of a cut or fill slope without causing erosion.

CONDITIONS WHERE PRACTICE APPLIES

Use paved flumes where concentrated storm runoff must be conveyed from the top of a cut or fill slope to the bottom, as part of a permanent erosion-control system. Paved flumes serve as stable outlets for diversions, drainage channels, or natural drainageways that are located above relatively steep slopes. Restrict paved flumes to slopes of 1.5:1 or flatter (see Figure 4.44-1).

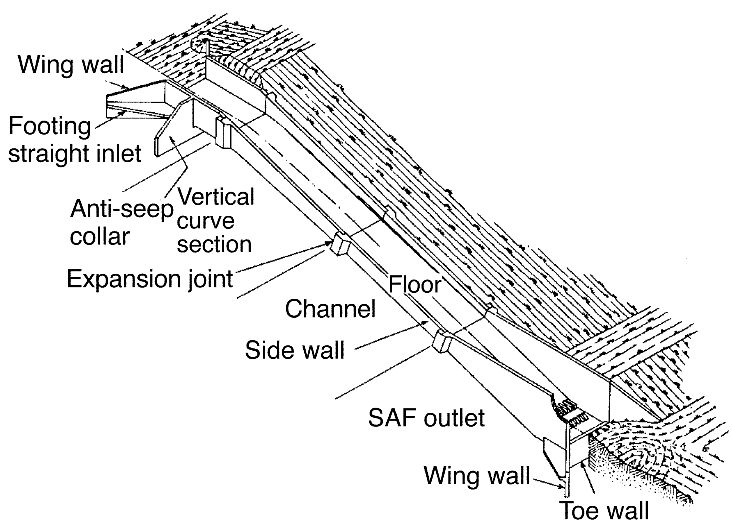


Figure 4.44-1 Chute spillway

PLANNING CONSIDERATIONS

Conveying storm runoff safely down steep slopes is an important consideration when planning permanent erosion-control measures for a site. Paved flumes are often selected for this purpose, but other measures, such as grassed waterways, riprap channels and closed storm drains, should also be considered. Evaluate the volume, velocity and duration of flow; degree of slope; soil and site conditions; visual impacts; construction costs and maintenance requirements to decide which measure to use.

When planning paved flumes, give special attention to flow entrance conditions, soil stability, outlet energy dissipation, downstream stability, and freeboard or bypass capacity. Setting the flume well into the ground is especially important, particularly on fill slopes.

The upper portion of the slope alongside paved chutes are often grassed. Grassed side slopes save on materials and improves appearance. The paved portion carries the design flow, and the grassed area provides freeboard.

DESIGN CRITERIA

Capacity: Consider peak runoff from the 10-year storm as a minimum. Provide sufficient freeboard or bypass capacity to safeguard the installation from any peak flow expected during the life of the structure.

Slope: Ensure that the slope of a chute does not exceed 1.5:1 (67%).

Cutoff walls (curtain walls): Provide cutoff walls at the beginning and end of paved flumes. Make the cutoff wall as wide as the flume, extend it at least 18 inches into the soil below the channel, and keep it at least six inches thick. Reinforce cutoff walls with 3/8-inch steel reinforcing bars placed on 6-inch centers.

Concrete: Keep concrete in the flume channel at least 5 inches thick and reinforce it with 3/8-inch steel bars. Ensure that the concrete used for flumes is a dense, durable product and sufficiently plastic for thorough consolidation but stiff enough to stay in place on steep slopes. As a minimum, use a mix certified as 3,000 lb/inch^2.

Cross Section: Ensure that flumes have a minimum depth of 1 ft with 1.5:1 side slopes. Base bottom widths on maximum flow capacity.

Alignment: Keep chute channels straight because they often carry supercritical flow velocities.

Drainage filters: Use a drainage filter diaphragm and pipe bedding to prevent piping and reduce uplift pressure wherever seepage or a high water table may occur.

Inlet Section: Ensure that the inlet to the chute has the following minimum dimensions: side walls 2 ft high; length, 6 ft; width, equal to the flume channel bottom; and side slope, same as flume channel side slopes.

Outlet Section: Protect outlets for paved flumes from erosion. Use an energy dissipater to reduce high chute velocities to nonerosive rates. In addition, place riprap at the end of the dissipater to spread the flow evenly over the receiving area. Other measures, such as an impact basin, plunge pool or rock riprap outlet structure, may also be needed (see Part 4.45, Outlet Stabilization Structure).

Small flumes: Where drainage areas are 10 acres or less, the design dimensions for concrete flumes may be selected from Table 4.44-1.

Table 4.44-1 Flume dimensions

Drainage[1] Area (acres)	Minimum. Bottom Width (ft)	Minimum Inlet Depth (ft)	Minimum Channel Depth (ft)	Maximum Channel Slope (ft)	Maximum Side Slope (ft)
5	4	2	1.3	1.5:1	1.5:1
10	8	2	1.3	1.5:1	1.5:1

[1]Due to complexity of inlet and outlet design, drainage areas have been limited to 10 acres per flume.

CONSTRUCTION SPECIFICATIONS

- Construct the subgrade to the elevations shown on the plans. Remove all unsuitable material and replace them with stable materials. Compact the subgrade thoroughly and shape it to a smooth, uniform surface.
- Keep the subgrade moist while the concrete is being poured. On fill slopes, ensure that the soil next to the chute for at least 3 ft is well-compacted.
- Place concrete for the flume to the thickness shown on the plans and finish it in a workmanlike manner.
- Form, reinforce, and pour together cutoff walls, anchor lugs and channel linings.
- Take adequate precautions to protect freshly poured concrete from extreme temperatures to ensure proper curing.
- Provide transverse (contraction) joints to control cracking at approximately 20-ft intervals. Joints may be formed by using a 1/8-inch-thick, removable template or by sawing to a depth of at least 1 inch.
- In very long flumes, install expansion joints at intervals not to exceed 50 ft.
- Place filters and foundation drains, when required, in the manner specified and protect them from contamination when pouring the concrete flume.
- Properly stabilize all disturbed areas immediately after construction.

MAINTENANCE

Inspect flumes after each rainfall until all areas adjoining the flume are permanently stabilized. Repair all damage immediately. After the slopes are stabilized, flumes need only periodic inspection and inspection after major storm events.

4.45 Structural Stabilization: OUTLET STABILIZATION STRUCTURES

DEFINITION

An outlet stabilization structure is a structure designed to control erosion at the outlet of a channel or conduit.

PURPOSE

An outlet stabilization structure can be used to prevent erosion at the outlet of a channel or conduit by reducing the velocity of flow and dissipating the energy.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where the discharge velocity of a pipe, box culvert, diversion, open channel or other water-conveyance structure exceeds the permissible velocity of the receiving channel or disposal area.

PLANNING CONSIDERATIONS

The outlets of channels, conduits and other structures are points of high erosion potential because they frequently carry flows at velocities that exceed the allowable limit for the area downstream. To prevent scour and undermining, an outlet stabilization structure is needed to absorb the impact of the flow and reduce the velocity of nonerosive levels.

Structural outlet stabilization should be designed by an engineer. A riprap-lined apron is the most commonly used practice for this purpose because of its relatively low cost and ease of installation (see part 4.53).

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

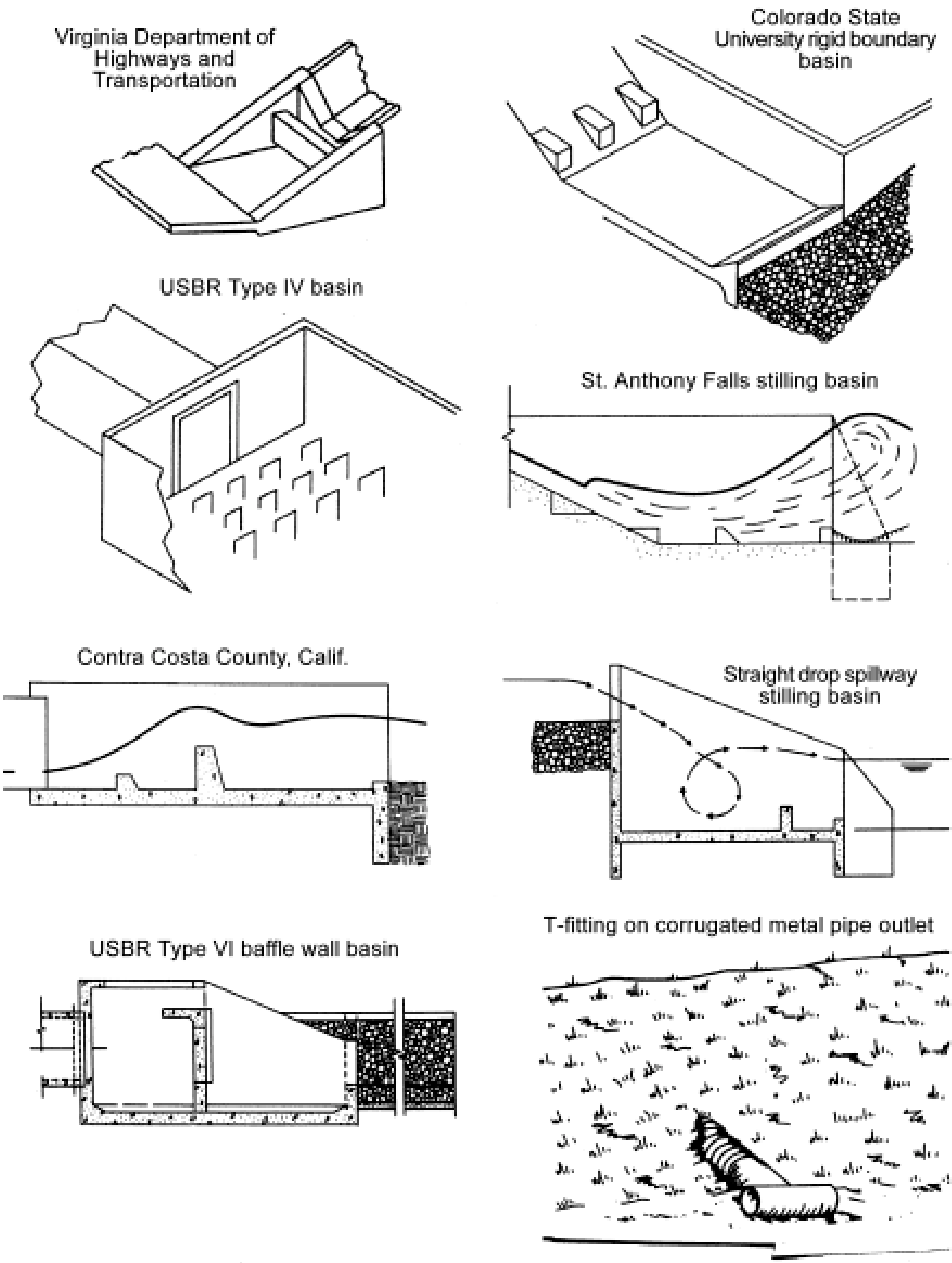


Figure 4.45-1 Alternative structures for energy dissipation at an outlet

4.50 Riprap Stabilization: RIPRAP

DESCRIPTION AND PURPOSE

Riprap is heavy stone placed on the stream or lake bank to provide protection against erosion. Riprap is a permanent, erosion-resistant protective layer. It is intended to protect soil from erosion in areas of concentrated flow or wave energy. Riprap may also be used to stabilize slopes that are unstable because of seepage problems.

EFFECTIVENESS

When properly designed and installed, riprap can prevent virtually all erosion from the protected area.

PLANNING CONSIDERATIONS

Riprap is normally used where erosive forces exceed the ability of the soil or vegetative cover to resist those forces. Riprap can be used for pipe outlet protection, channel lining and scour protection. Riprap is also commonly used for wave protection on lakes. See part 4.52 on riprap design for lake shore protection.

Riprap may be unstable on very steep slopes, especially when rounded rock is used. For slopes steeper than 2:1, consider using materials other than riprap for erosion protection.

If riprap is being planned for the bottom of a permanently flowing channel, the bottom can be modified to enhance fish habitat. Habitat can be provided by constructing riffles and pools that simulate natural conditions. The riffles promote aeration and the pools provide deep waters for habitat.

When working within flowing streams, measures should be taken to prevent excessive turbidity and erosion during construction. Bypassing base flows or temporarily blocking base flows are two possible methods.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

DESIGN RECOMMENDATIONS

Riprap should be designed and installed according to applicable MDNR requirements. For design purposes, we recommend the MnDOT standard specifications or the recommendations in the USDA's SCS, Loose Riprap Protection, Minnesota Technical Release 3 (TR3).

1. Gradation

A well-graded mixture (a mixture composed of a variety of rock sizes rather than one, uniform size) of rock should be used for riprap. Riprap sizes are generally specified in both weight and average diameter. The table below (Table 4.50-1) lists the standard MnDOT riprap gradations.

Table 4.50-1 Minnesota Department of Transportation standard riprap gradations

		Riprap Class (percent of total weight smaller than given weight)					
Size (inches)	Weight (lb)	I	II	III	IV	V	
30	2,000					100	
24	1,000				100		
21	650					75	
18	400			100			
15	250				75	50	
12	120		100	75	50		
9	50		75	50			
6	15	100	50			10	
4	5				10		
3	2	50		10			
2			10				
1		10					

When a rock gradation is specified other than a standard gradation, it must allow a range in sizes. Based upon the median size (d_{50}), Table 4.50-2 can be used as a guide to determine the gradation.

Table 4.50-2 Riprap gradation ranges

Size of stone	Percent of total weight smaller than the given size
2.0 to 2.5 x d_{50}	100
1.6 to 2.1 x d_{50}	85
1.0 x 1.5 x d_{50}	50
0.3 x 0.5 x d_{50}	15

2. Riprap depth

All stones used should lie within the riprap blanket to provide the maximum resistance against erosion. Protruding stones can alter the flow across the channel. Oversize stones, even in isolated spots, may cause riprap failure by precluding mutual support between individual stones, providing large voids that expose filter and bedding materials and creating excessive local turbulence that removes smaller stones. Small amounts of oversize stone should be removed individually and replaced with proper-size stones. The following criteria apply to the riprap layer thickness:

- The thickness should not be less than 1.25 times the diameter of the upper limit D100 (W100) stone. However, for practical placement, the thickness should not be less than 12 inches.
- The thickness determined by either 1 or 2 above should be increased by 50% in all sections when the riprap is placed underwater in water deeper than 3 ft to provide for uncertainties associated with this type of placement.
- An increase in thickness of 6 to 12 inches, accompanied by an appropriate increase in stone sizes, should be provided where riprap revetment will be subject to floating debris, ice or waves from boat wakes or wind.

Experiences in Minnesota have shown that these thicknesses are adequate regardless of whether a granular filter or a geotextile is used with the riprap.

3. Material quality

Riprap must be hard, dense and durable. It should be resistant to weathering, free from overburden, spoil, shale and organic material. Rock or rubble that is laminated, fractured, porous or otherwise physically weak is unacceptable for slope protection. The material specification for riprap should be referenced in construction documents.

4. Allowable side slopes

The stability of the riprap on the side slope of a channel is dependent on the angularity of the rock. The more angular the rock, the higher the angle of repose. The riprap stability is related to the side slope, rock size, angularity of the rock and the angle of repose. The maximum (steepest) slope for riprap is recommended to be 2:1 (that is, 2 ft horizontally for every ft of vertical height). For small areas, such as around existing culverts or transitions where slopes steeper than 2:1 cannot be avoided, slopes up to 1:1 can be tolerated, provided that the riprap thickness and size are increased. Very angular rock must be used and carefully installed. The thickness should be increased by 10% for 1.5:1 side slopes and by 20% for 1:1 side slopes. The minimum D50 that can be used on slopes steeper than 2:1 is 4 inches. This must be angular rock, not rounded.

5. Edge treatment

The edges of riprap revetments are subject to additional forces by being adjacent to other materials. The top, toe and flanks require special treatment to prevent undermining.

6. Flanks

The flanks of the revetment should be designed as illustrated in Figure 4.50-1. If the riprap ends at a bridge abutment or other secure point, special flank protection is not needed. If the riprap does not terminate at a stable point, the cross section shown as 4.50-2, Method B, should be considered for the downstream edge as well.

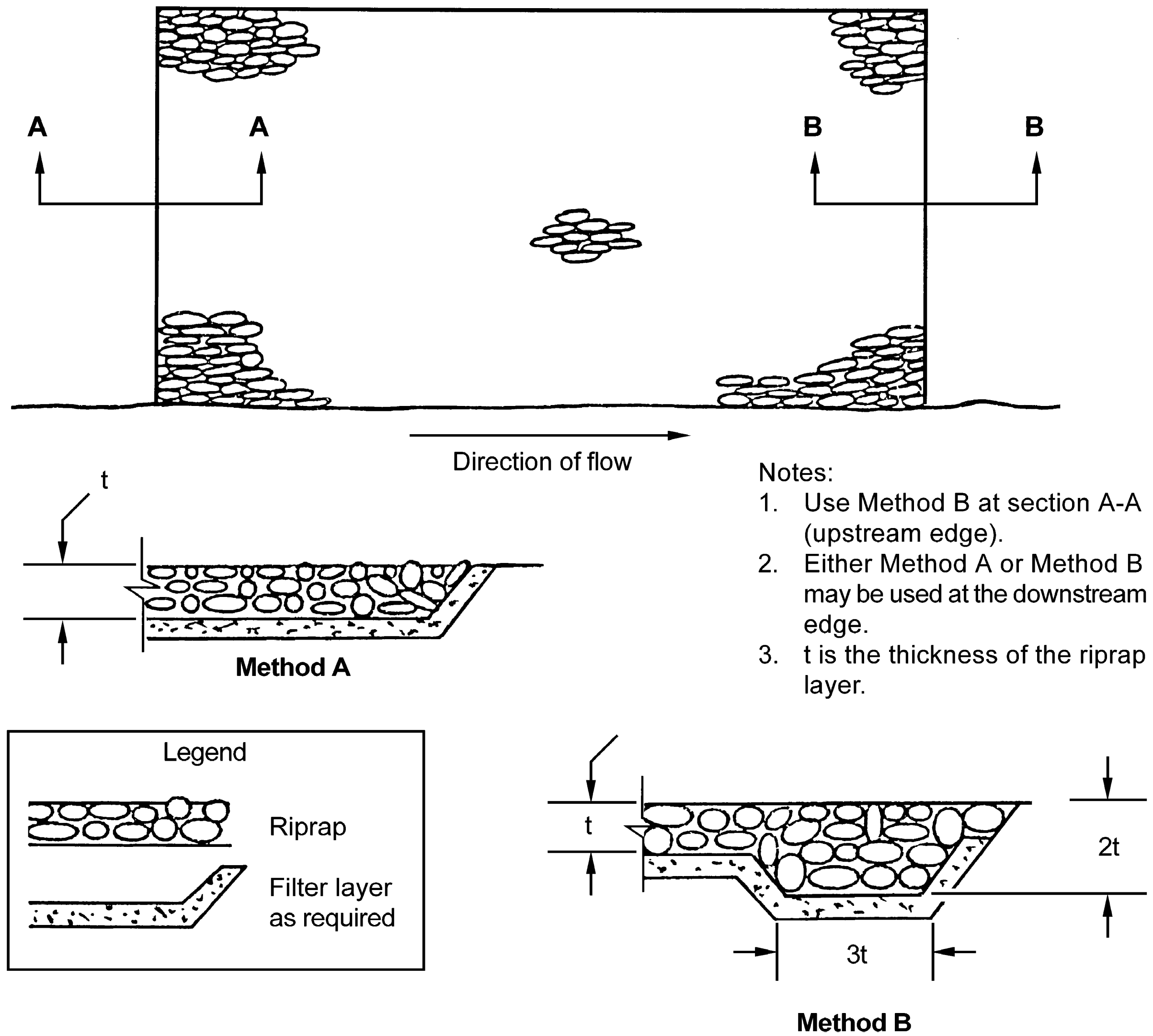


Figure 4.50-1 Riprap end protection

7. Toe

Undermining of the revetment toe is one of the primary causes of riprap failure. Figure 4.50-2 shows toe protection alternatives. It is preferable to design the toe as illustrated in Figure 4.50-2 Method A. The toe material is placed in a toe trench along the entire length of the riprap blanket. Where a toe trench cannot be dug, the riprap blanket may terminate in a thick, stone toe at the level of the streambed (Figure 4.50-2, Method B). Care must be taken during the placement of the stone to ensure that the toe material does not mound and form a low dike. A low dike along the toe could result in flow concentration along the revetment face, which could stress the revetment to failure.

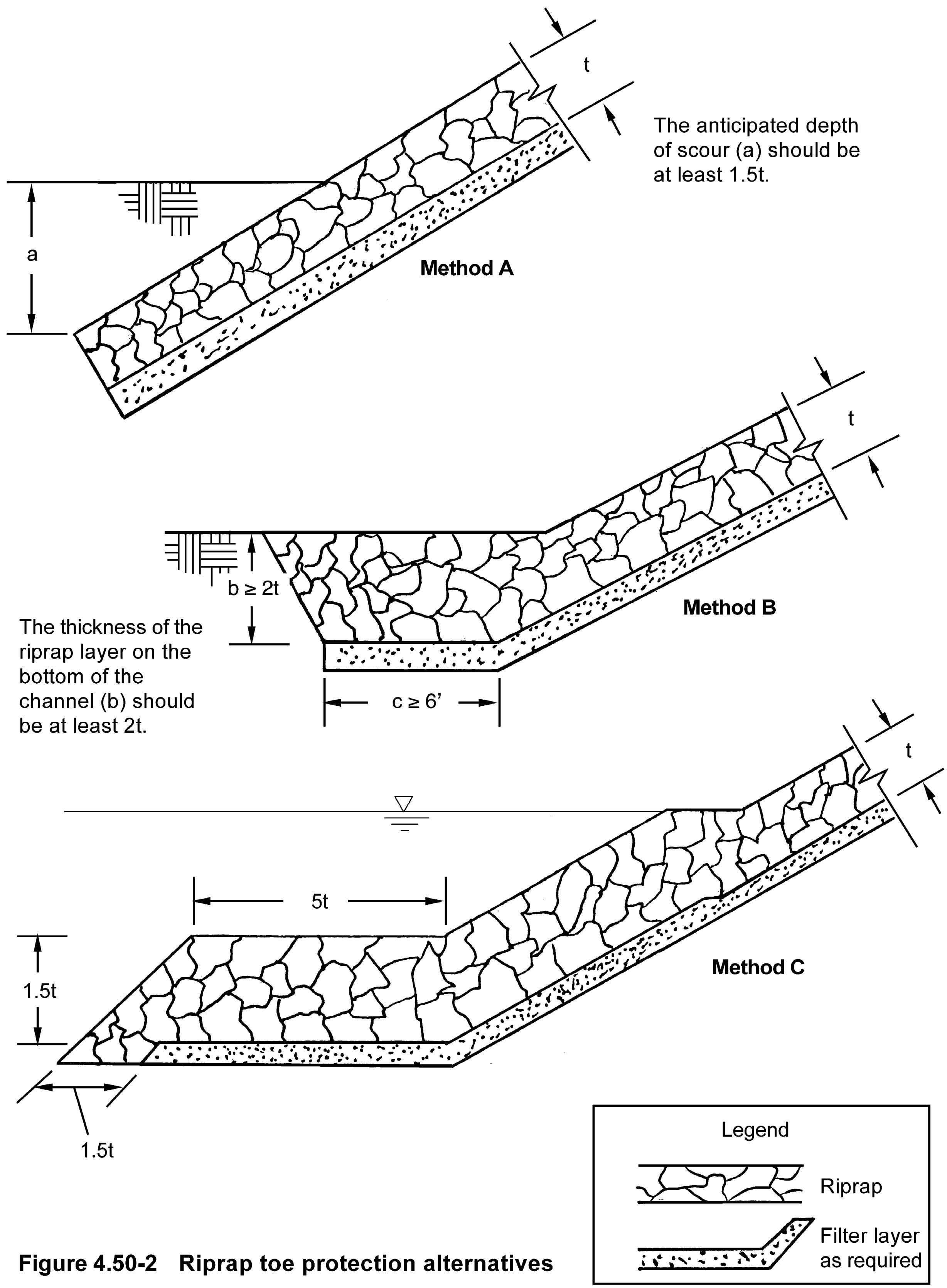


Figure 4.50-2 Riprap toe protection alternatives

Also, care must be exercised to ensure that the channel's design capacity is not impaired by placement of too much riprap in a toe mound.

The size of the toe trench or alternate stone toe is controlled by the anticipated depth of scour along the revetment. As scour occurs (and in many cases it will), the stone in the toe will launch into the eroded area. See Figure 4.50-3. Observation of the performance of these types of rock toe designs indicates that the riprap will launch to a final slope of approximately 2:1. The volume of rock required for the toe must be equal to or exceed one and one-half times the volume of rock required to extend the riprap blanket (at its design thickness and on a slope of 2:1) to the anticipated depth of scour.

8. Bedding selection criteria

Riprap should be placed on a strong, stable, erosion-resistant base. Erosion of the base may occur from surface or seepage water flowing down the slope and from the surging action of waves or flowing water. Riprap reduces the growth of erosion-controlling vegetation. Minor erosion that would be simple to repair on the surface will be more expensive and difficult to repair when it occurs beneath the riprap. Riprap needs a strong, stable foundation to prevent shifting of the stone.

First, consider if the base materials are adequate to bed the riprap. Coarse-grained soil is needed, with enough gravel of a size large enough to resist movement. Base soils that have a maximum of 20% fines and a minimum of 40% gravel do not need bedding. A soil with less gravel might be adequate where some near-surface erosion of the fines and sands could be allowed to build a gravel surface layer. Where the natural materials do not have the necessary characteristics, a bedding material must be used.

The layer immediately below the riprap should meet the bedding criteria given as equations 4.50-1 and 4.50-2. If a filter is needed, the bedding must meet the filter criteria (equations 4.50-3 through 4.50-5) or else filter layers are needed below the bedding.

$d15b > D15R/40$ **(Equation 4.50-1)**

$D15R/5 < d85b$ **(Equation 4.50-2)**

Where:
d15b = particle size of bedding where 15% of the gradation by weight is smaller than this size,
D15R = dimension of riprap where 15% of the gradation by weight is smaller than this size, and
d85b = particle size of bedding where 85% of the gradation by weight is smaller than this size.

No published guidelines exist for bedding. One design rule often used is Equation 4.50-3. This is the same as the basic filter design rule. The bedding-riprap system does not act like a base-filter system because the riprap is too thin to act like a filter. Riprap thickness is usually one to one and one-half times the maximum riprap particle size. The thickness of a filter is 10 to 100 times, and more of the maximum filter particle size and consequently has many void openings. The gravel

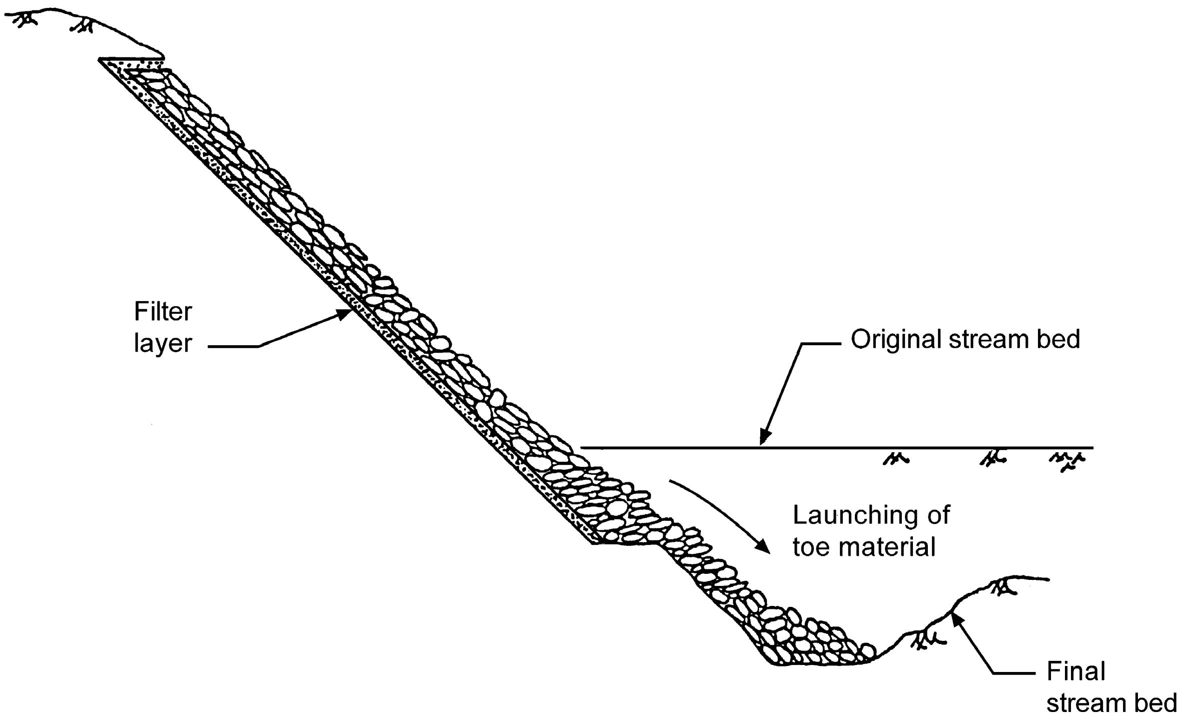


Figure 4.50-3 Launching toe material

particles must be heavy enough to resist movement on their own. The filter rule seems to produce bedding large enough to be stable. One advantage in using this rule is, as more severe conditions require larger riprap, the bedding particles also become larger. If bedding needs to be permeable, a maximum limit of 5% nonplastic fines should be allowed. Bedding is generally 6 to 12 inches thick. The 6-inch thickness is used for smaller riprap and the 1-ft thickness for larger rock. This thickness is increased by 50% when the riprap is placed under water more than 3 ft deep.

$$\frac{\text{D15 (coarser layer)}}{\text{d85 (finer layer)}} < 4 < \frac{\text{D15 ((coarser layer)}}{\text{d15 (finer layer)}} < 40 \qquad \textbf{(Equation 4.50-3)}$$

9. Filter selection criteria

A filter is used when base materials may pipe through the riprap. A determination will need to be made whether a piping potential exists.

If careful consideration of seepage gradients and soils show that no piping potential exists, then a filter may not be needed. If it is determined that a filter is necessary, the filter may be designed according to the information in NRCS's TR3 (USDA, SCS, 1977b).

10. Granular filters

Equation 4.50-3 (above from TR3) indicates the relationship necessary between layers of filter, between the filter and the riprap, or between the filter and the base material. The left side of the inequality is intended to prevent piping through the filter, the center portion provides for adequate permeability for structural bedding layers, and the right portion provides a uniformity criteria. Equation 4.50-4 gives an additional guideline for riprap/filter compatibility.

d50 (finer layer) > D50 (coarser layer)/40 **(Equation 4.50-4)**

d5 (courser layer) > #200 sieve **(Equation 4.50-5)**

If a single layer of filter material will not satisfy the filter requirements, one or more additional layers of filter material must be used. The grain-size curves for the various layers should be approximately parallel to minimize the infiltration of fine material from the finer layer to the coarser layer. Not more than 5% of the filter material should pass a No. 200 sieve. The thickness of the filter blanket should range from 6 inches to 15 inches for a single layer, or from 4 to 8 inches for individual layers of a multiple-layer blanket. Where gradation curves of adjacent layers are approximately parallel, the thickness of the blanket layers should approach the minimum. The thickness of individual layers should be increased above the minimum proportionately as the gradation curve of the material comprising the layer departs from a parallel pattern.

The thickness of the filter layer should be increased by 50% in all sections when the filter is placed underwater in water deeper than 3 ft to provide for uncertainties associated with this type of placement.

11. Filter Fabric

For the purpose of riprap application, filter fabric means nonwoven geotextile filter fabric. Nonwoven geotextiles consist of polypropylene fibers that are needle-punched into a high-tensile-strength fabric that shows excellent physical and hydraulic properties for applications such as soil separation, filtration and protection. Typical applications include pipe wrapping, French drains, soil separation, riprap stabilization and liner protection. Synthetic fabric filters have found considerable use as alternatives to granular filters. The primary justification for fabric filter over a granular filter is economic. Geotextiles may be less costly, especially where a source of gravel is not convenient. Many manufacturers offer an extensive line of geotextiles. Care should be taken to select the appropriate one for the site.

The function of fabric filters is to provide both drainage and filtration. In other words, the fabric must allow water to pass (drainage) while retaining soil properties (filtration). Both functions must be considered and perform properly during the design life of the measure. Filter fabrics, like granular filters, require engineering design. Unless proper fabric piping resistance, clogging resistance, and construction strength requirements are specified, it is doubtful that desired results will be obtained. Installation of the fabric must be monitored closely as well for a successful measure. Tips for successful installation are given below.

- Heavy riprap may stretch the nonwoven filter fabric as it settles, eventually causing bursting of the fabric. A 4- to 6-inch layer of gravel bedding should be placed on the fabric for riprap dropped more than 3 ft.

- The nonwoven filter fabric should not extend channelward of the riprap layer. It should be wrapped around the toe material as illustrated in Figure 4.50-4. This is sometimes called a "Dutch toe."

- Adequate overlaps must be provided between individual nonwoven filter fabric sheets. For light-weight revetments, this can be as little as 18 inches, and may increase to as much as 3 ft for large, underwater revetments.

- The nonwoven filter fabric should be overlapped during placement to eliminate tension and stretching under settlement.

- Securing pins with washers are recommended at 2- to 5-ft intervals along the midpoint of the overlaps.

- Proper stone placement on the nonwoven filter fabric requires beginning at the toe and processing up the slope. Dropping stone from heights greater than 2 ft can rupture fabrics (greater drop heights are allowable under water). A 6-inch layer of sand/gravel will cushion the impact and protect the fabric as the rock is dropped.

- The surface on which the nonwoven filter fabric is placed should be reasonably smooth and free of holes, depressions, projections, mud and running water.

- The length of the nonwoven filter fabric should be placed parallel to the direction of flow.

Detailed criteria for the design of geotextile filters are presented in USDA, SCS, TR3 or MnDOT specifications. Any of this work may require federal, state or local permits.

MAINTENANCE

Riprap should be inspected annually and after major storms. If riprap has been damaged, repairs should be made promptly to prevent a progressive failure. If repairs are needed repeatedly at one location, the site should be evaluated to see whether original design conditions have changed. Channel obstructions, such as trees and sediment bars, can change flow patterns and cause erosive forces which may damage riprap.

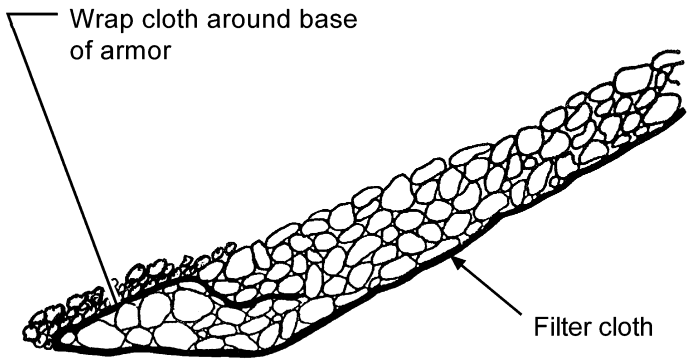


Figure 4.50-4 Dutch toe

4.51 Riprap Stabilization: CHANNEL RIPRAP

DEFINITION

Channel riprap is an erosion-resistant lining of riprap designed for the conveyance and safe disposal of excess water in a channel.

PURPOSE

Riprap is the most commonly used structural material for stabilizing streambanks. When possible, slope banks to 2:1 or flatter, and place a gravel filter or filter fabric on the smoothed slopes before installing riprap. Place the toe of the riprap at least 1 ft below the stream channel bottom or below the anticipated depth of channel degradation. Where necessary, riprap the entire stream cross section. It is important to extend the upstream and downstream edges of riprap well into the bank and bottom. Extend riprap sections the entire length between well-stabilized points of the stream channel.

CONDITIONS WHERE PRACTICE APPLIES

The practice applies where design flow velocity exceeds 4 ft per second (ft/sec) so that a channel lining is required, but conditions are unsuitable for grass-lined channels. Specific conditions include:

- Channels where slopes over 5% predominate; continuous or prolonged flows occur; potential for damage from traffic (people or vehicles) exists; or soils are erodible and soil properties are not suitable for vegetative protection.
- Design velocity exceeds that allowable for a grass-lined channel.
- Property value justifies the cost to contain the design runoff in a limited space.
- Channel setting warrants the use of special paving materials.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Flexible liners are preferred to rigid liners, and riprap is often the flexible liner of choice. Riprap is preferred primarily on the basis of cost, but it has several additional advantages:

- Riprap liners can be designed to withstand most flow velocities by choosing stable stone size.
- Riprap adjusts to unstable foundation conditions without failure.
- Failure of a riprap liner is not as expensive to repair as failure of a rigid liner would be.
- The roughness of riprap reduces outlet velocity and tends to reduce flow volume by allowing infiltration.

Rigid liners, such as concrete or flagstone, can carry large volumes of water without eroding. However, they are more expensive to design and construct, are less forgiving of foundation conditions, and introduce high energies that must be controlled and dissipated to avoid damage to channel outlets and receiving streams.

Channels combining grassed side slopes and riprap or paved bottoms may be used where velocities are within allowable limits for grass lining along the channel sides, but long-duration flows, seepage or a high-velocity flow would damage vegetation in the channel bottom.

Side slope: Side slopes should be based on a slope stability analysis.

Hydraulic grade line: Ensure that the design water surface in the channel meets the design flow elevations of tributary channels and diversions. Ensure that it is below safe flood elevations for homes, roads or other improvements.

4.52 Riprap Stabilization: SHORELINE RIPRAP

DEFINITION

Shoreline riprap is riprap placed to prevent erosion from wave action, especially on large lakes.

PLANNING CONSIDERATIONS

These projects may need State, federal or local permits, please check with the appropriate agencies for their requirements.

DESIGN CONSIDERATIONS

The design should be in accordance with USDA, NRCS, TR 2.

Riprap revetment is often the preferred method of shore protection. It is economical and suitable for all types of erosion problems when stone of sufficient size and quality is available. The key design considerations are the dimensions, foundation treatment and stone size. Construction is not complicated and no special equipment, other than a crane and tracks, is needed.

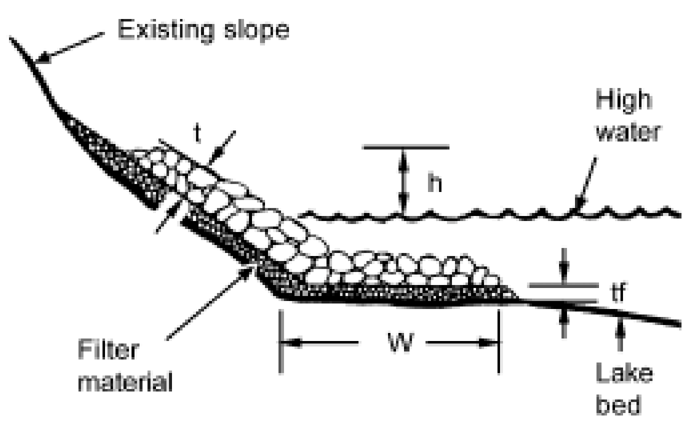


Figure 4.52-1 Riprap revetment

The slope should be compacted and graded to 1:1.5 or flatter. Place a gravel, small rock, filter blanket or nonwoven filter fabric on the prepared slope.

Place rock carefully with a crane. Rock should have a three-point bearing.
Ensure that rock sizes are well mixed. Larger and smaller rock should not be visibly segregated.

MAINTENANCE REQUIREMENTS

Shoreline riprap is subject to displacement. The effectiveness of the structure will be impaired by thinning of the protective layer or settling of the structure. Restoration of the rock slope protection to the designed top elevation, equivalent thickness and reduction of voids in the facing should be accomplished when and as needed.

4.53 Riprap Stabilization: OUTLET PROTECTION WITH RIPRAP

DESCRIPTION AND PURPOSE

Outlet protection is the use of protective measures to prevent erosion at the outlet of pipes or paved channels. These structures are intended to protect soil from turbulence and high velocities, which can cause scour erosion.

EFFECTIVENESS

Outlet protection can prevent scour erosion in channels, which will reduce the effects of turbidity and sedimentation downstream.

PLANNING CONSIDERATIONS

High-velocity flows from pipes or paved channels have the potential to cause considerable erosion. To prevent erosion, velocities must be reduced to allowable levels before the flow enters an unprotected area.

Outlet protection usually consists of a structural apron lining. Apron linings can be made of riprap, concrete, grouted riprap or other structural materials (see Figure 4.53-1). In some cases, flow velocities may be too high for economical use of an apron. In those cases, a stilling basin or impact basin may be more appropriate. The stilling basin is an excavated pool of water that is lined with riprap and used to dissipate energy from high-velocity flow (see Figure 4.53-2). An impact basin is a reinforced concrete structure that slows water velocities to an acceptable level before discharging the water to an outlet channel. For more information on energy dissipaters, refer to *Hydraulic Design of Stilling Basins and Energy Dissipaters*, Engineering Monograph No. 25, U.S. Department of the Interior, Bureau of Reclamation (see also Part 4.45).

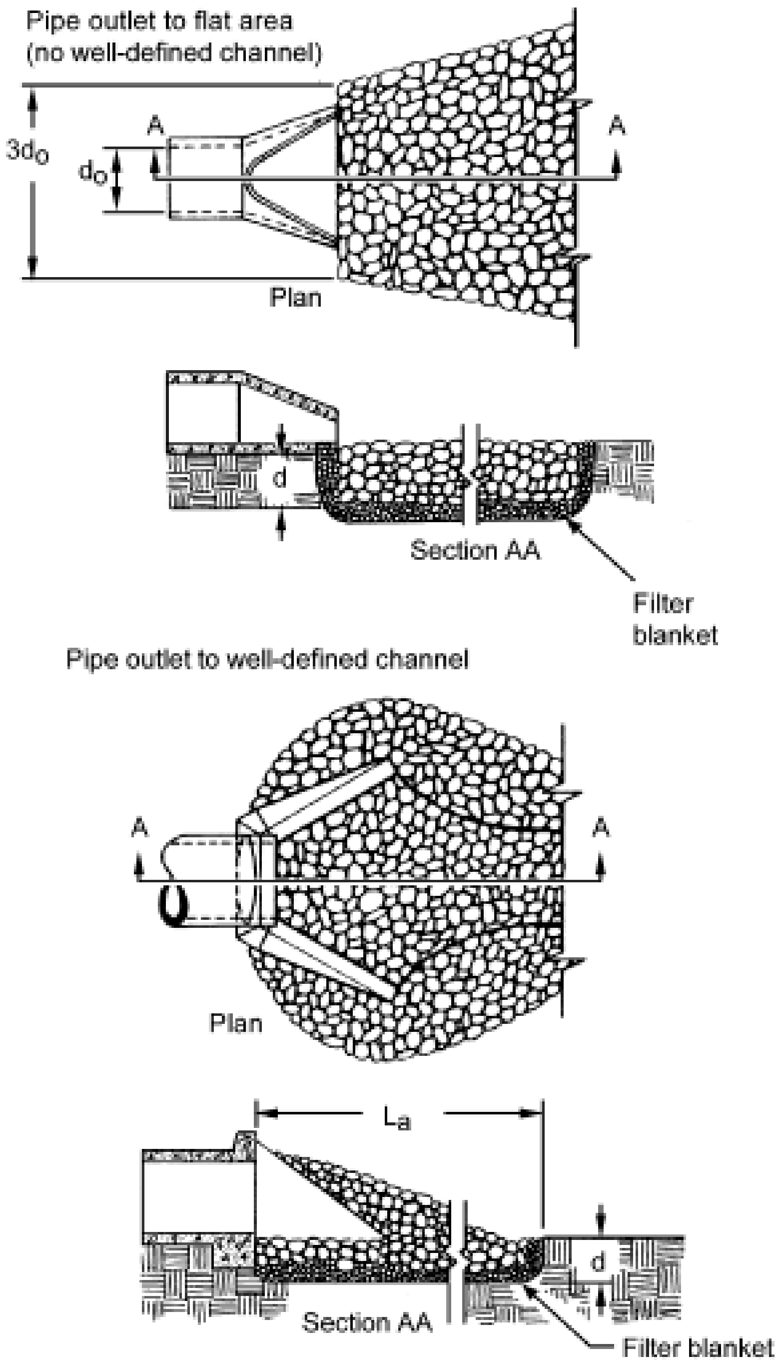
These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

DESIGN RECOMMENDATIONS

Outlet protection may or may not require a detailed design, depending upon the scope and complexity of the job. For outlets with very high velocities or very low tailwater conditions, outlet protection should be designed only by a qualified engineer. The following criteria are recommended for the design of structurally lined aprons below pipe outlets:

1. **Tailwater depth.** Determine the depth of tailwater immediately below the pipe outlet based on the design discharge plus other contributing flows. If the tailwater depth is less than half the diameter of the outlet pipe and the receiving stream is wide enough to accept the divergence of flow, it is classed as a **minimum tailwater condition**. If the tailwater depth is greater than half the pipe diameter, it is classed as a **maximum tailwater condition**. Pipes that discharge onto

broad, flat areas with no defined channel may be assumed to have a minimum tailwater condition unless site conditions indicate otherwise.



Note:

1. L_a is the length of the riprap apron.
2. d = 1.5 times the maximum stone diameter but not less than 6".
3. In a well-defined channel, extend the apron up the channel banks to an elevation of 6" above the maximum tailwater depth or to the top of the bank, whichever is less.
4. A filter blanket or filter fabric should be installed between the riprap and soil foundation.

Figure 4.53-1 Riprap outlet protection (modified from Virginia Department of Conservation and Recreation)

Figure 4.53-2 Outlet protection using riprap

2. **Apron size.** The apron length and width can be determined according to the tailwater condition. If the water-conveyance structure discharges directly into a well-defined channel, extend the apron across the channel bottom and up the channel banks to an elevation of six inches above the maximum tailwater depth or to the top of the bank, whichever is less.

   Determine the maximum allowable velocity for the receiving stream, and design the riprap apron to reduce flow to this velocity before flow leaves the apron. Calculate the apron length for velocity control or use the length required to meet stable conditions downstream, whichever is greater.

3. **Grade.** Ensure that the apron has zero grade. There should be no overfall at the end of the apron; that is, the elevation of the top of the riprap at the downstream end should be the same as the elevation of the bottom of the receiving channel or the adjacent ground if there is no channel.

4. **Alignment.** The apron should be straight throughout its entire length. If a curve is necessary to align the apron with the receiving stream, locate the curve in the upstream section of riprap.

5. **Materials.** Ensure that riprap consists of a well-graded mixture of stone. Larger stone should predominate, with sufficient smaller sizes to fill the voids between the stones. The diameter of the largest stone size should be no greater than one and one-half times the d_{50} size.

6. **Thickness.** Make the minimum thickness of riprap one and one-half times the maximum stone diameter.

7. **Stone quality.** Select stone for riprap from field stone or quarry stone. The stone should be hard, angular and highly weather resistant. The specific gravity of the individual stones should be at least 2.5.

8. **Filter.** Install a filter to prevent soil movement through the openings in the riprap. The filter should consist of a graded gravel layer or a synthetic filter cloth. Design filter blankets by the method described in section 4.50.

MAINTENANCE

Inspect riprap outlet structures after heavy rains to see whether any erosion around or below the riprap has taken place or whether stones have been dislodged. Immediately make all needed repairs to prevent further damage.

4.60 Filtration Practices: FILTRATION DEVICE WARNINGS

INTRODUCTION

The topic of infiltration can be divided into two categories: management practices and devices. Management practices in this context means reducing impervious surfaces, discharging impervious surfaces over pervious areas, disconnecting roof drains from the storm water system or other measures. These are encouraged and essentially noncontroversial practices. But as noted below, they may require special considerations in industrial areas or other unusual cases.

The other category of activity is called infiltration devices. This is everything from filter strips and swales to large infiltration ponds or infiltration trenches, tubes or other devices that conduct the runoff into the ground. In *most* cases the types of devices that are of most concern are devices that bypass the vados zone and conduct surface runoff directly into the ground. For example, swales and ditches are generally of less concern, while devices that conduct into deep aquifers are generally of greater concern. Note that these are generalizations that need to be evaluated on a site-specific basis. A site analysis should be conducted before implementing infiltration on your project or for your community.

Filtration devices -- especially infiltration devices, such as basins and trenches -- are controversial as BMPs for storm water management. Literature indicates that operation of infiltration devices is a concern for two reasons: (1) failure to operate, and (2) concerns for ground water contamination. These concerns are made greater or diminished depending on site circumstances, and must be compared to the benefits that infiltration can provide for reducing stormwater flows in surface waters and replenishing ground water through recharge. Therefore, infiltration devices should be used only after thorough, site-specific evaluation of these concerns and of the pros and cons of other stormwater management options. Infiltration should also be used in conjunction with other measures, such as avoidance and pretreatment practices to protect ground water quality and the function of the infiltration device. Sound judgment; good design, including a detailed site evaluation; and proper construction techniques should alleviate the operational problems with these systems.

RESTRICTIONS

Class 5 wells. Under federal laws, “Class 5 wells,” which are essentially any storm water infiltration device that is deeper than it is wide, are required to be inventoried by reporting to the EPA and the MPCA. There are no other regulations at the present time, but future regulation is anticipated.

Minn. R. ch. 7060. Minnesota State laws (M.R.7060) prohibit the direct discharge of untreated storm water to the saturated zone if the discharge threatens ground water from potential pollutants. There could be liability if it is determined that a discharge has introduced contaminants into ground water in violation of state law. Treatment before infiltration is a suggested means to discourage the possible introduction of pollutants into the ground water.

Wellhead Protection Plans. For stormwater systems located in defined wellhead-protection areas, the local unit of government must develop a “Wellhead Protection Plan” in accordance with state laws and requirements. Special attention should be given to injection wells or infiltration basins and trenches which may pose a high risk to the wellhead, especially for drinking water wells classified by the Minnesota Department of Health as vulnerable to contamination.

GOALS

The goal for stormwater-runoff systems should be “to maintain after development, as nearly as possible, the predevelopment runoff conditions.” “Maintain” means that the pre- and postdevelopment quantity, quality and rate of flows to surface and ground water should be kept the same. It also means that the beneficial uses of ground and surface water should be unchanged before and after development.

The *Maryland Storm Water Design Manual* (Schueler,1998) discusses recharge volume requirements to preserve the hydrology of streams and wetlands during dry weather. This approach is not adopted in this manual, but may be an approach that could be useful in specific jurisdictions. Recharge is an important factor that will need to be looked at more carefully in the future if urban natural resources are to be preserved.

We recommend that communities restrict peak and total flows to predevelopment levels or less. Peak control has often been done as part of the classic flood-control requirements, but we also recommend that the volume of runoff be controlled so that pre- and postdevelopment total flows are equal. For urban areas, the greatest volume of runoff over an average year comes from events under 1 inch in depth. Also, the increase in flow from urban development, as a percent of predevelopment flow, is greatest for the more frequent, smaller-storm events. At minimum, the two-, 10- and 100-year events should be evaluated. Here are some of the reasons we feel this is important:

Surface Flow Effects

- **Pollutant Loads.** Pollutant loads are more proportional to the total flow than the peak flows; therefore, increased flow volume increases the pollutant loading. For example, as the percent impervious surfaces within a watershed to a lake increases, so does the phosphorus loading to the lake. Phosphorus loading causes increases in algae production, which in turn decreases the clarity of the water, can deplete oxygen levels and cause other impacts.
- **Wetland Habitat.** We are also concerned about changes in stormwater discharges to wetlands. Wetland plant and animal communities are dependent on hydrologic conditions, such as the frequency and duration of inundation. They can be very sensitive to hydrologic changes, especially the more frequent events. Wetland bounce, or change in elevation from storm runoff events, criteria have been developed to provide suggested guidance in order to maintain the wetland vegetation in its current condition.
- **Erosive Stream Flows.** Flows that are reduced in peak but extended in length can be very erosive. We are especially concerned at the bankfull level, which is often about the one and one-half-year recurrence frequency in natural systems. But urbanization causes dramatic increases in frequency at which these flows occur or are exceeded. Ponds can reduce peaks, but without infiltration they extend the duration of flow in developed areas.
- **Ground Water Recharge.** One of the more important considerations is that ground water recharge must continue to be sustained for the various functions that ground water provides.

Infiltration and the Potential for Ground Water Pollution

The potential for ground water pollution is a concern when planning an infiltration device. The effects of infiltration basins on ground water have been studied as part of the Nationwide Urban Runoff Program (NURP). The NURP study was conducted on infiltration basins in the Fresno, California, area and on Long Island, New York. That study found that the soil beneath the basins was effectively trapping the pollutants studied and there was no significant contamination of ground water from the basins.

Because the NURP studies concluded that there was minimal evidence of ground water contamination from the basins, the NURP final report did not recommend any change in the use of those practices (USEPA, 1983). However, this does not mean that ground water cannot be adversely affected by infiltration basins. More recent studies conducted by Robert Pitt and others (Pitt *et al.*, 1994a) discuss the risk of ground water contamination being a function of a compound’s relative mobility, concentration and solubility. Pitt suggests guidelines on using infiltration practices along with using adequate pretreatment devices to support infiltration practices.

It is important to consider monitoring the ground water quality and capacity of the infiltration device its long-term operation.

Excluded Discharges

Discharges that should generally be excluded from infiltration devices include construction sites, spills, industrial discharges, and other discharges.

Construction Sites. Construction sites do not generally contain toxics that pose a threat to ground water, but high sediment levels will quickly clog infiltration facilities.

Spills. All reasonable measures should be taken to assure that spills do not enter infiltration areas. Pretreatment ponds with skimmers and shut-off measures are one method of dealing with potential spills.

Industrial Discharges. Untreated storm water from industrial and manufacturing areas has a high potential for elevated concentrations of metals and organic compounds. Industries under the storm water permit program are required, and other industries should be responsible enough, to:

- evaluate sources of potential contamination,
- prevent storm water contact with contaminated areas and where prevention is not possible, and
- treat runoff from their sites.

Other Discharges. Other discharges should be investigated for exclusion. These include potentially illegal discharges, such as dry-weather sewer flows, which could be illegal industrial discharges or combined sewer flows. Heavily salted runoff from streets and parking areas should also be evaluated carefully for potential impacts, since infiltration does not treat high concentrations of chlorides.

Site-sensitivity Analysis

Before an infiltration system can be designed, a site-sensitivity analysis should be performed. This evaluation may eliminate an infiltration practice from consideration or determine appropriate ways to avoid potential effects on ground water. 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.

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

- **Runoff water quality.** If runoff water will contain any significant concentration of soluble pollutants that could degrade ground water quality, such as runoff from industrial sites or even from heavily salted parking lots and roadways, a careful review of the pretreatment systems is necessary to assure that the pollutants of concern do not simply pass through.
- **Uses of the ground water** -- Is the ground water a sole-source aquifer, in a wellhead-protection area or a significant natural resource? If not, are there current or likely future drinking water supply wells tapping the receiving aquifer in the vicinity?
- **Geologic (ground water) sensitivity.** A site with a highly sensitive geology, such as those with carbonate or karst features, may eliminate these areas from consideration.
- **Depth to water table.** The water table must be far enough below the bottom of the structure to allow the structure to function hydraulically.
- **Soil permeability.** Soil permeability must be great enough to drain the system in a reasonable amount to time, generally 72 hours or less.
- **Soil characteristics.** Evaluate the soil's ability to trap or treat pollutants expected at the given site and also provide the required infiltration rate.

OBJECTIVES

Our objectives should be to avoid impacts, minimize impacts, and mitigate impacts.

MEASURES TO BE TAKEN

Avoid Impacts

Avoid sensitive areas, which *may* mean careful zoning or exclusions for development in highly sensitive geology, or wellhead protection areas. Preservation of forested urban areas is one of the best ways to avoid runoff increases.

Education for pollution prevention, should be a top priority for consideration, in order to avoid pollution problems related to infiltration.

Minimize Impacts

Reduced Impervious Surface. Development policies that reduce impervious surface area should be the first BMP for controlling the pre- and postdevelopment hydraulic conditions. Measures, such as cluster development, should be considered to reduce the volume of runoff. After the increase in runoff has been minimized, infiltration should be considered to reduce the volume of runoff to predevelopment rates.

Pretreatment. Dissolved materials, settleable solids, floating materials and grease and oil should be removed from runoff to the maximum extent feasible before it enters the infiltration device. If these materials enter the device, they can pass through to ground water, or clog the device, take up storage volume, and cause the system to fail. Detention ponds with skimmers, vegetative filters, sand filters, peat sand filters, grassed swales, biofilters, bioretention, filter strips or oil/grit separators are measures that can be used to remove these materials before they enter the infiltration device. It may be feasible to allow limited amounts of these materials to enter the device if their effects are considered during the design. One method of planning for this is to rely upon infiltration out of the sides of the device, or in extended-detention areas of the system, rather than the bottom.

Mitigate Impacts

A mitigation plan should be developed for all reasonably anticipated contingencies. A mitigation plan could involve ground water monitoring, and policies of preparedness for ground water cleanup.

INSTALLATION AND MAINTENANCE

System Design

Bypass. After considering runoff flow and concentration, and the nature of the aquifer, materials that are highly soluble and can impact ground water may need to be kept from being discharged to the infiltration system. The ability to direct contaminated flows so that they bypass infiltration devices may be an important of the system design.

Off-line Systems. Infiltration devices can be constructed as “off-line” systems where a regulated volume of flow is directed from treatment ponds to infiltration devices. High flow volumes would continue to be routed through the treatment ponds but the majority of high flow could be discharged downstream so the infiltration systems are not overloaded.

Professionals should do the hydrologic design of infiltration basins in accordance with accepted and appropriate procedures. Flood routing is recommended for all infiltration devices, and a system of bypasses or overflow devices should be considered.

Water Table and Bedrock Separation

We recommend ***a minimum 3-ft distance should be provided below the bottom of the system and bedrock or the water table***. Adequate depth to the water table, impeding layers or bedrock is required to prevent a water table mound from intersecting the bottom of the infiltration practice or affecting the hydraulic capacity of the practice. *We recommend that the distance be 10 ft to fractured bedrock because of higher hydraulic conductivity.*

INSTALLATION

Proper installation and maintenance of infiltration devices and their pretreatment measures is critical. Soils in the infiltration area should not be disturbed, or the infiltration capacity may need to be restored after construction.

MAINTENANCE

Infiltration devices and pretreatment measures should be maintained with a regular monitoring- and-inspection schedule and a regular maintenance schedule. Sediment accumulation is greatest with the most efficient of infiltration devices. Therefore, it is most important to regularly inspect and maintain these systems to maximize their efficiency and longevity. 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.

Vegetation should be maintained as needed. Devices with healthy vegetation tend not to clog. The use of low-maintenance varieties, which are flood and drought resistant, 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.

Be certain that the devices are cycled so that they are periodically dry over a season. This helps the soil re-establish its structure, as well as helping plants to become established.

DESIGN CRITERIA

Design for filtration devices is usually controlled by velocity of flow in the system for treatment and maximum flows. The design criteria for several devices are included in Table 4.60-1.

PLANNING CONSIDERATIONS

For all filtration devices, controlled flow volume, such as diversion of low flows to the system or bypass of higher flows, should be provided.

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Table 4.60-1 Bioretention and ponds

	Buffer Zone (not a treatment, but performs treatment functions)	Filter Strip	Swales and Enhanced Swales *	Infiltration Basins and Enhanced or Bioretention Basins	Infiltration Trenches	Ponds
Location	Usually adjacent to aquatic systems	Small-volume, low-velocity area	1-3 ft above water table	3 ft above water table, 10 ft above fractured bedrock	3 ft above water table, 10 ft above fractured bedrock	No specific requirements
Pretreatment	No concentrated flow	No concentrated flow	A sediment forebay is desirable	** Sediment and debris removal desired	** Sediment and debris removal desired	No specific requirements
Runoff from 1.25-inch event (water quality volume)	No specific requirement	0.5 ft/sec 0.5 inches Depth 10-minute flow time	Vel ≤ 1.0 ft/sec Depth ≤ 0.5 ft*	Discharge through soil in 24 hours or less	Discharge through soil in 24 hours or less	Outflow rate
Runoff from 1-yr. event ~ 2.4-inch event	No specific requirement	≤ 2 ft/sec	≤ 2 ft/sec $\tau \leq 1$ lb/ft^2	Discharge through soil in 48 hours or less	Provide bypass to other systems	Velocity ≤ 2 ft/sec
Runoff from 2-yr. event ~ 2.8-inch event	No specific requirement	≤ 3 ft/sec.	≤ 3 ft/sec $\tau \leq 1.5$ lb/ft^2	Discharge through soil in 72 hours or less	Provide bypass to other systems	Velocity ≤ 3 ft/sec. Discharge rate ≤ 50% of the predevelopment rate
Runoff from 10-yr. event ~ 4.0-inch event	No specific requirement	≤ 5 ft/sec	≤ 5 ft/sec $\tau \leq 2.5$ lb/ft^2	Provision for bypass at high flows	Provide bypass to other systems	Velocity ≤ 5 ft/sec and Discharge rate = predevelopment
Runoff from 100-yr. event ~ 6.0-inch event	No specific requirement	≤ 5 ft/sec	≤ 5 ft/sec $\tau \leq 2.5$ lb/ft^2	Provision for bypass at high flows	Provide bypass to other systems	Velocity ≤ 5 ft/sec and Discharge rate = predevelopment

* For enhanced swales, insert retaining dikes to retain water quality volume of runoff behind filter dikes.
** No industrial or highly contaminated sources without appropriate pretreatment.
τ = shear stress

4.61 Filtration Practices: FILTER STRIPS

DESCRIPTION

Filter strips are vegetated sections of land designed to accept runoff as overland sheet flow from upstream development. When conditions are appropriate, they may be adapted to natural vegetated forms, from grassy meadow to small forest. Dense vegetative cover facilitates pollutant removal. Filter strips cannot treat high-velocity flows. Therefore, they have generally been recommended for use in small drainage areas with a low percentage of impervious surface.

Filter strips can differ from natural buffers in that strips are often designed and constructed specifically for pollutant removal. Natural features may be incorporated into the treatment system; a filter strip can be an enhanced natural buffer where the pollutant-removal capability of the natural buffer is improved through engineering and maintenance activities, such as land grading, the installation of a level spreader or the enhancement of vegetation.

Filter strips also differ from grassed swales in that swales are concave, channelized, vegetated conveyance systems, whereas filter strips provide treatment by sheet flow over level-to-gently-sloped surfaces.

PURPOSES

Filter strips are one way to alleviate the impact of human activities, and should be an important part of comprehensive site planning. This practice may be applied as part of a resource management system to:

- reduce sediment and other pollutants from runoff.
- pretreat runoff before discharge to other treatment systems (*e.g.*, infiltration basins or trenches).
- reduce total volume of surface water runoff.
- reduce deposition of windborn pollutants into surface waters.
- enhance biological diversity by creating habitat between upland and surface waters.

PLANNING CONSIDERATIONS

Ordinarily, forests and other natural areas should not be destroyed to create a filter-strip system. They may already be functional or may only need to be enhanced to become properly functioning treatment systems. Upstream spreaders and flow-control measures, repair of eroded and bare spots and/or vegetative enhancements may often be all that is required to have a functional system. Figure 4.61-1 shows both a grassed and wooded filter strip.

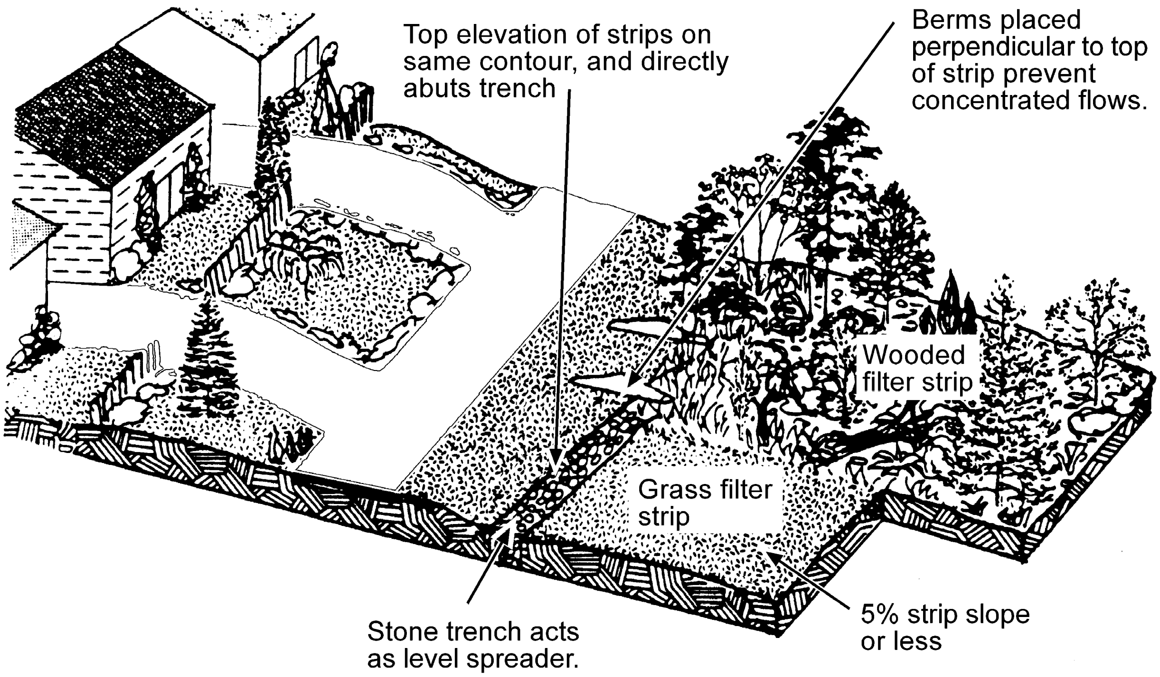


Figure 4.61-1 Schematic of a grassed-and-wooded filter strip (source: Schueler, 1987)

Existing perennial vegetation next to receiving waters may provide wildlife benefits but not significant pollutant-reduction benefits, depending on ground cover and runoff type. However, buffer areas provide valuable habitat and they should be maintained. Consideration should be given to buffer zone preservation as part of the design of the filter system.

Waterways should have filter strips on both sides to be effective as part of a filter system. An intermittent waterway itself may also provide filtering benefits if adequately vegetated (see part 4.62, Vegetated Swales).

DESIGN RECOMMENDATIONS

Measures to help prevent concentrated flows (Claytor, December 1996):

- The width of the filter should generally be measured perpendicular to the overland flow, and equal to the width of the treated drainage area
- The flow length through the filter system should be a minimum of 25 ft and at maximum no more than 300 ft. The slope of the filter should be limited to about 2 to 6%.
- The flow length of the drainage area to be treated is usually limited to 75 ft for impervious areas or 150 ft for pervious areas.

Filter strips should generally be on the contour and designed to pass the 1.25-inch, 24-hour water quality storm event at a flow depth of about 0.5 inch, and a velocity of 0.5 feet per second (fps).

Runoff water entering and moving through a filter strip must be kept shallow and uniform for effective filtering.

Shaping and grading of the area immediately upslope from the filter strip and the filter strip site itself may be necessary to insure shallow overland flow.

Velocity and depth for larger storm events should not exceed Table 4.60-1 in section 4.60, Filtration Devices.

In cases where a filter strip is planned, detention and storage will be needed to reduce peak flows to a practical level to allow for sheet flow conditions. Water carried by waterways and ditches must be converted into sheet flow conditions.

In those cases where concentrated flow is applied to a filter strip, a level lip weir or other “level spreader” measure should be included in the design to distribute flow uniformly across the top of the filter strip and maintain sheet flow across the entire strip.

Information on selecting and maintaining plant species suitable to site conditions can be found through the Natural Resources Conservation Service, the University of Minnesota Extension Service or from other professionals in this field.

Grass Filters

Tall, rigid, erect, perennial, sod-forming grasses are best suited for a filter medium. Desirable species include smooth bromegrass and creeping foxtail used alone or in combinations with fringed brome, cordgrass, intermediate wheatgrass, tall wheatgrass, tall fescue, or mixtures of big bluestem, switchgrass, little bluestem, Indiangrass, or side-oats grama.

Some species, such as reed canarygrass, function well but are highly invasive and are not recommended.

Species that have tendencies to mat down, such as Kentucky bluegrass, should generally not be used.

The effectiveness of filter strips should be maintained by cutting, usually twice each growing season. Cutting of the grass filter strips in the first few years of establishment is important to promote dense sod formation. It also helps maintain the vigor of most plant species. Cut high enough to promote rapid and adequate regrowth, usually 4 to 8 inches, depending on the species. Harvest and removal of vegetative growth may be important to projects where nutrient removal is critical. Time cutting to avoid potential adverse effects on wildlife nesting.

Seeding, sodding and other items related to establishing vegetation shall be in accordance with accepted erosion-control and planting practices. Apply needed lime and fertilizer based on a soil test and University of Minnesota or other professional recommendations.

Prepare and plant in a firm seedbed.

Forested Filter Strips

In urban areas, you can have trees and forests serve as filters and should not be destroyed to create filters or other water-quality-enhancing features. Some urban forests can be managed to more effectively act as a filter, or part of a filter system. Urban forest areas can be maintained as a buffer or as a filter without destroying the multiple benefits of habitat and water quality that forests provide.

Filter strips that include a forest component are intended to protect water quality by preserving the filtering capacity of the soil and surface vegetation. Forest leaf litter encourages infiltration, while the canopy protects the soil from impacts of direct rainfall. The forest also provides shade, which can prevent thermal effects of human activity, especially near streams and running water.

Forested filter strips are similar to, but not the same as, buffer zones. Forested filters are managed to perpetuate vegetation along aquatic areas, which helps to promote habitat and water-quality protection, especially for temperature. They are not natural areas, but they are managed for perpetuation of shade and habitat benefits. Management is allowed in these areas to promote continuous growth of shade-tolerant vegetation.

Mixed Filters

Filter strips can be planted to grasses or woody vegetation. Species selected for filter strips must be adapted to the soil and site conditions. Because of the multiple benefits to habitat, water, quality, and aesthetics, filter strips with a variety of vegetation types are often preferred.

Soils and ground cover in natural forest areas can provide effective treatment, but in disturbed areas, the ground vegetation, such as grasses, is critical to the treatment process. The vegetative ground cover can often be enhanced in forested areas to improve treatment rather than destroying the forest vegetation.

Native grasses are often best suited when biodiversity, upland habitat and pollutant filtering are objectives. Native grasses develop an extensive root system, but may take several years to become adequately established.

Cutting and harvesting forest and other native vegetation may not be beneficial or needed in most cases. However, cutting and harvest of vegetation for disease control or other management may be desirable.

INSTALLATION, OPERATION AND MAINTENANCE

Installation

Appropriate soil-stabilization methods, such as mulch, mats or blankets, 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.

Operation and Maintenance

- Avoid creation of furrows and channels immediately upslope from the filter strip to prevent flow concentration from occurring.
- Inspect annually for damage to vegetative cover, rilling or gullying in the filter strip, or sediment accumulations that block or impede sheet flow. Repair and reseed disturbed areas.
- Limit applications of fertilizer to maintain plant vigor based on soil test results and University of Minnesota recommendations.
- Avoid direct spray application and spray drift when applying pesticides on adjacent land.
- Avoid vehicle travel lanes or turn areas, in or immediately adjacent to the filter strip.
- Do not use vegetated filter strips for disposal of waste.
- Cut only when the soil is dry to prevent tracking damage to vegetation, soil compaction and development of flow concentrations.

Development of rills and small channels within filter areas must be minimized. Needed repairs must be made as soon as possible to re-establish sheet flow. For example, a shallow furrow on the contour across the filter can often be used to re-establish sheet flow.

All filter strips should be fenced as necessary to control destructive access by vehicles, pedestrians and animals.

Solids accumulations at the upstream edge of the filter may need periodic removal to maintain sheet flow and vigorous vegetation.

4.62 Filtration Practices: VEGETATED SWALES

DESCRIPTION AND PURPOSE

Definition

“Grassed swales” (see Figure 4.62-1) or “vegetated swales” (Figure 4.62-2) are earthen conveyance systems in which pollutants are removed from urban storm water by filtration through the grass and infiltration through the soil. The primary purpose of these structures is often conveyance, but they differ from conveyance channels because water-quality and quantity benefits are part of the design considerations.

Enhanced vegetated swales, or biofilters, utilize check dams and wide depressions and off- channel retention areas to increase runoff storage and promote greater settling of pollutants.

Purposes

Vegetated swales may be applied as part of a resource-management system to:

- convey water in properly protected channels.
- divert water around potential pollutant sources.
- provide infiltration to reduce total surface water runoff volumes.
- pretreat runoff prior to discharge to another treatment system (for example, an infiltration basin or trench).
- reduce sediment and other pollutants in runoff.
- enhance biological diversity by creating habitat between upland and surface waters.

PLANNING CONSIDERATIONS

Vegetated swales are most applicable in residential or institutional areas where the percentage of impervious cover is relatively small. Swales are usually located in a drainage easement at the back or side of a residential lot. They can also be used along roads in place of curb and gutter. In planning the drainage system for a development, the planner should consider the following characteristics of vegetated swales:

1. Vegetated swales are generally less expensive to install than curb and gutter.
2. Roadside swales keep flow away from the street surface during storms, thus reducing driving hazards.
3. Roadside swales become less feasible as the number of driveway entrances requiring culverts increases.
4. In areas with steep slopes, vegetated swales are best suited to locations where they can be parallel to the contours.

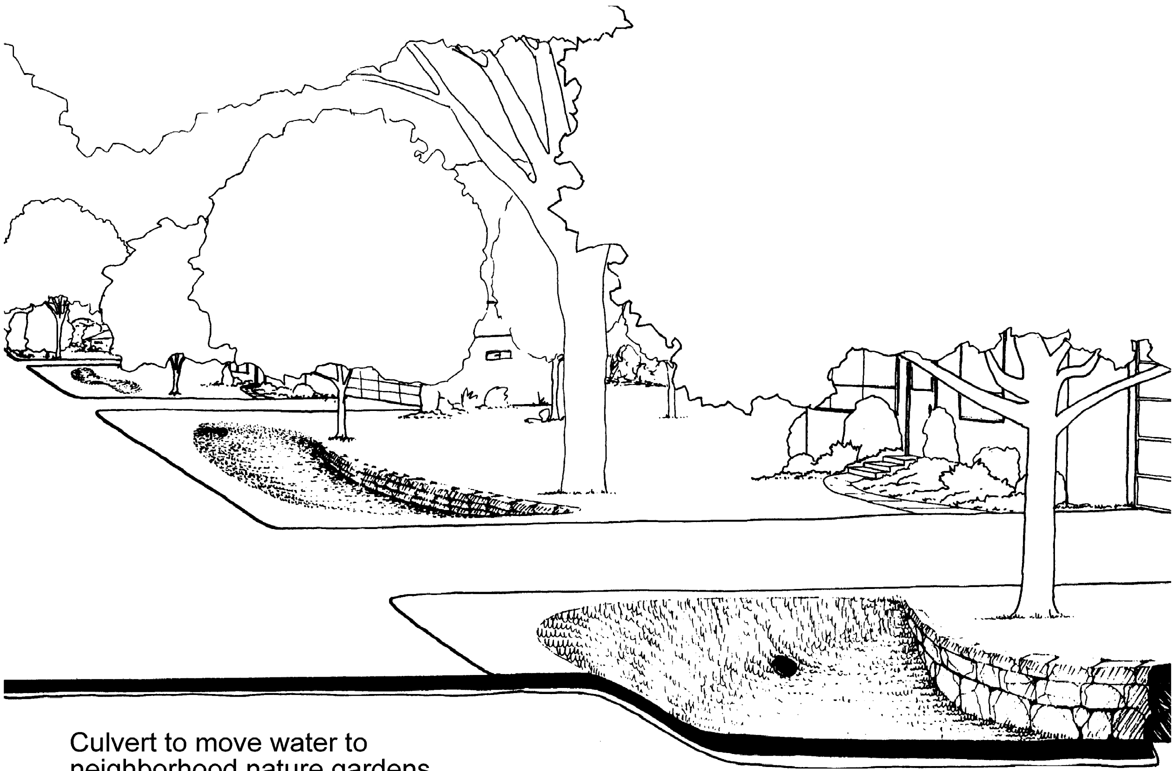


Figure 4.62-1 A turf swale can infiltrate storm water, but turf lacks the beauty and biodiversity of native plant gardens (Nassauer *et al.*, 1997).

Existing perennial vegetation adjacent to receiving waters of interest may provide wildlife benefits but not significant pollutant-reduction benefits, depending on ground cover and runoff type. However, preservation of natural areas should be considered in the swale design.

DESIGN CRITERIA

Vegetated swales are most effective when the flow depth is shallow and the velocities are low. These characteristics limit the application of grass swales as a BMP to locations where flows from the 1.25-inch, 24-hour water quality storm event can be discharged at less than 0.5 fps and 0.5 ft deep. The one-year and above event should be discharged in accordance with Table 4.60-1.

To be considered a treatment system, enhancements will generally be required. Flows from the 1.25-inch, 24-hour water-quality storm event must be stored in the facility. The storage volume can be increased by using check dams, or we recommend off channel bioretention areas to obtain the additional treatment volume and surface area (Claytor, December 1996). An overflow rate equivalent to pond design criteria (5.66 cfs/acre of surface area) may be obtainable in some cases.

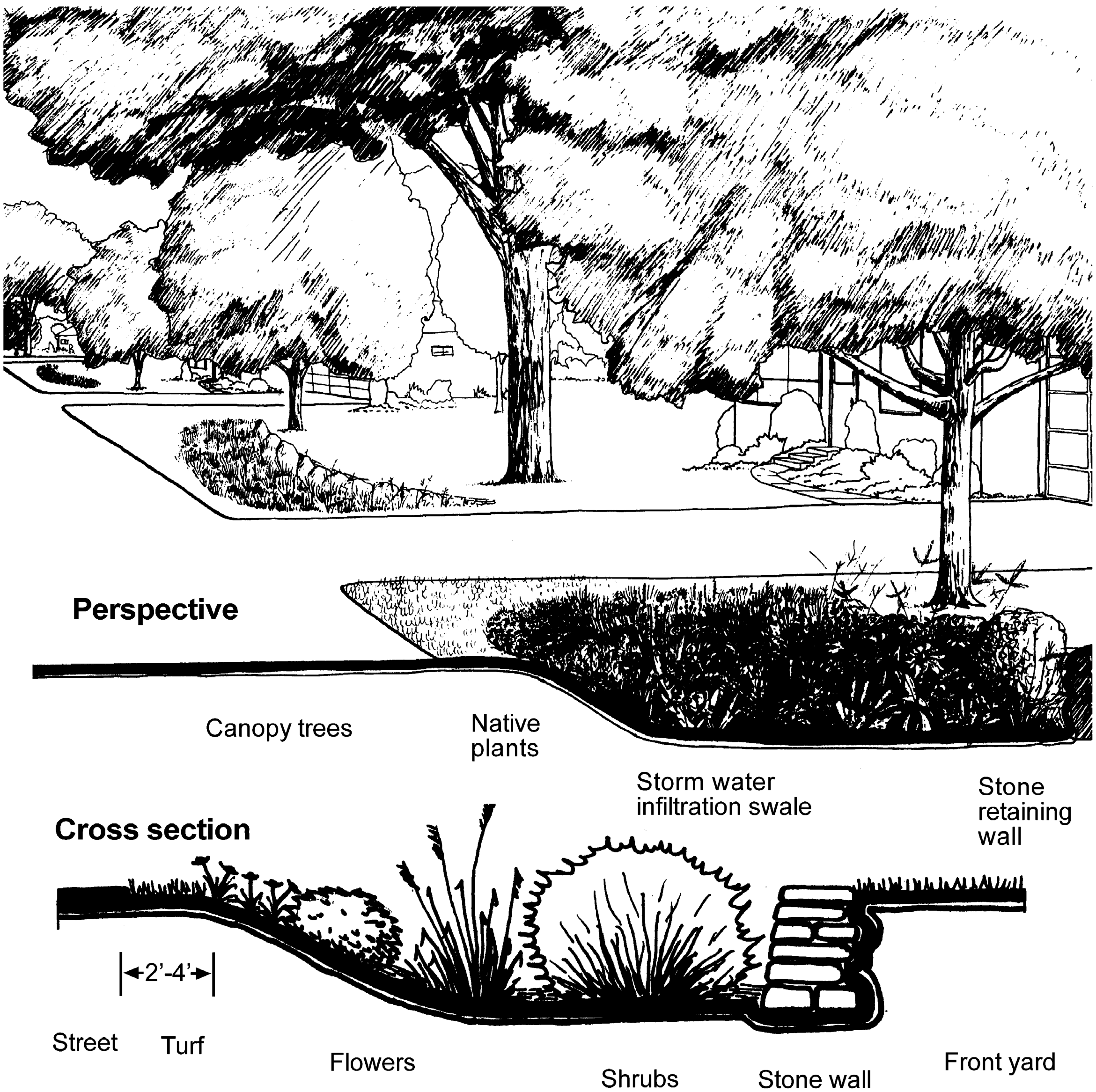


Figure 4.62-2 Asymmetrical high-volume swale with front yard defined by masonry wall (Nassauer *et al*., 1997)

Without enhancement, higher flows will not be treated to any significant extent. The use of enhancements, channel lining and conveyance channel design features should be included to convey and treat higher flows.

Provisions should be made for removing settled solids from the channel as necessary to maintain proper functioning. A sediment forebay is desirable to facilitate ease of maintenance.

Shaping and grading is required to assure controlled flow conditions. This is usually less than a 2% grade. The grade of the finished surface should be continuous and uniform. Maximum grades should be nonerosive for the soil and runoff factors anticipated. The outlet for the swale must be suitable with adequate capacity, such as a grassed waterway, a stable watercourse, an underground outlet, a vegetated or paved area, a grade-stabilization structure, or other suitable outlet.

Grass species and shape of channel should be such that grass stems will generally remain upright during design flow.

The soils should be suitable to establish a vigorous stand of vegetation. If dense vegetation cannot be maintained in the swale, its effectiveness will be severely reduced.

Both sides of the swales should generally have filter strips or vegetated buffer zones to protect the drainageways as part of a filter system.

INFILTRATION ENHANCEMENT

Check dams can be constructed in the waterway to temporarily store water, promote infiltration and increase the effectiveness of the grass swale. The check dam should be constructed of durable material so it will not erode. The area just downstream of the check dam should be protected from scouring with properly designed rock riprap or channel lining (see Figure 4.62-3).

On permeable soils, vegetated swales can be designed for infiltration as well as sedimentation. To enhance the infiltration characteristics, check dams can be used to store water in the swale or in off-line detention areas. These check dams should be designed so that the water ponded will infiltrate in 24 hours or less in order to protect the vegetation.

The seasonally high water table should be 1 to 3 ft below the bottom of the swale. Except in unusual situations, this will allow treatment of most pollutants before they reach the ground water. The designer should be aware of the warnings concerning the use of infiltration devices contained in the introduction to this section.

OPERATION & MAINTENANCE

Vegetative Cover

Information on selecting and maintaining plant species suitable to site conditions can be found through the Natural Resources Conservation Service, the University of Minnesota Extension Service, the MnDOT, and from other professionals in this field.

Tall, rigid, erect, perennial, sod-forming grasses are best suited for a filter medium. Desirable species include smooth bromegrass and creeping foxtail used alone or in combination with intermediate wheatgrass, western wheatgrass, tall wheatgrass, tall fescue, or mixtures of big bluestem, switchgrass, little bluestem, Indigograss, or side-oats grama. Some species, such as reed canarygrass, function well but are highly invasive and are not recommended.

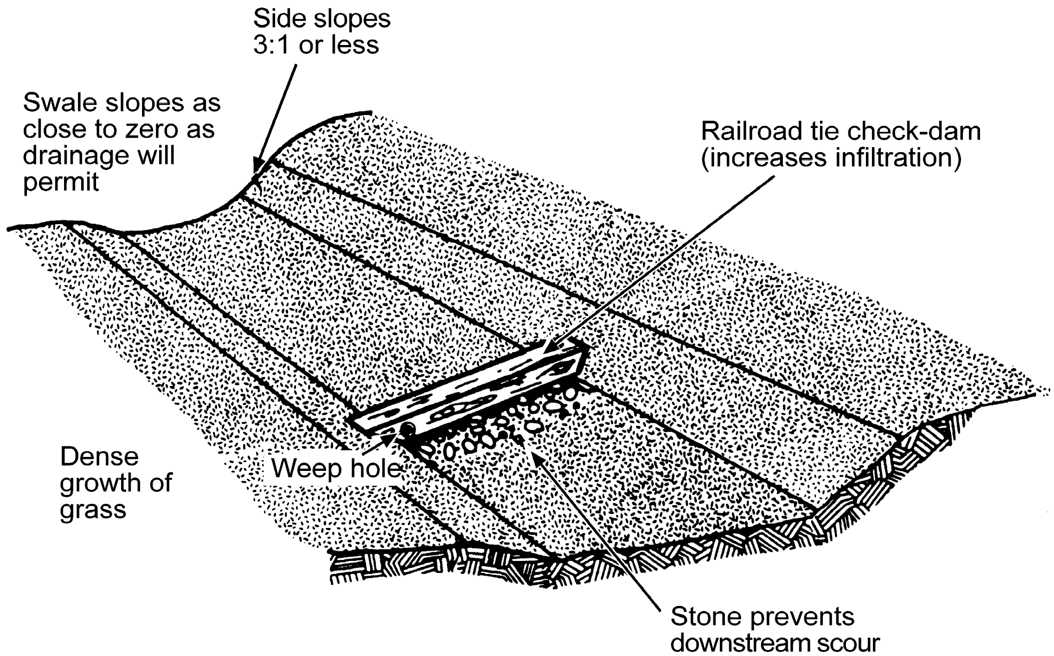


Figure 4.62-3 Schematic of an enhanced grassed swale (source: Schueler, 1987)

Native grasses, such as bluestem and brome, are best suited when biodiversity, upland habitat and pollutant filtering are objectives. Native grasses develop an extensive root system, but may take several years to become adequately established.

Appropriate soil-stabilization methods, such as mulch, mats or blankets, 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. 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.

Species selected for filter strips should be adapted to the soil and site conditions. Information on plant species suitability to site conditions is available from the Natural Resources Conservation Service and the University of Minnesota Extension Service.

Annual cutting of the swales in the first few years of establishment is important. This promotes dense sod formation and helps maintain vigor of most plant species. Stubble of 4 to 8 inches is usually high enough to promote rapid and adequate regrowth.

Depending on the vegetation, harvest and remove vegetative growth twice each growing season to maintain the effectiveness of the swale. Vegetation should be mowed to leave 6 to 8 inches of stubble, and the cuttings should be removed from the swale. Harvest only when the soil is dry to prevent tracking damage to vegetation, soil compaction and development of flow concentrations.

Apply needed lime and fertilizer based on a soil test and University of Minnesota or other professional recommendations. Consult standardized practices for optimum seeding times. Prepare and plant in a firm seedbed.

4.63 Filtration Practices: INFILTRATION BASINS

DESCRIPTION AND PURPOSE

An infiltration basin is a stormwater impoundment that does not contain a permanent pool of water because it has permeable soils. The inflow volume must be controlled so that the treatment volume can be discharged through the soil. 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. This infiltration removes many pollutants, provides ground water recharge, reduces the volume of runoff, and reduces peak discharges.

Target Pollutants

Infiltration basins are very effective for removing fine sediment, trace metals, nutrients, bacteria, and oxygen-demanding substances. Coarse sediment is effectively controlled, but should be removed from runoff before it enters an infiltration basin. Coarse sediment can clog the basin and take up storage volume. Dissolved pollutants are effectively controlled for storm events less than the design frequency, but these materials may not be removed from the runoff as it infiltrates, creating a potential ground-water problem.

Effectiveness

Infiltration basins have been designed to infiltrate a design runoff volume. For storms larger than the design storm, effectiveness will be reduced, but will be similar to those reported for detention ponds of similar size. Although infiltration basins are very effective for controlling pollutants in surface water, using infiltration as primary treatment can reduce the infiltration rate by clogging, and some soluble substances can be expected to move to the ground water. Chloride from road salt is an example of a soluble material that will not be removed during the infiltration process.

PLANNING CONSIDERATIONS

Note the caveats and warnings about infiltration devices in section 4.60.

Infiltration basins are best suited for sites with drainage areas of two to 15 acres. A typical basin will have a depth of 3 to 12 ft. The maximum depth of a basin is limited by the infiltration rate of the soil and maximum detention time. Figure 4.63-1 depicts a typical infiltration basin.

The soils on a prospective site are an important consideration when determining the suitability for infiltration. The soils should generally have an infiltration rate of between 1.0 inch and 6.0 inches per hour to be considered for an infiltration basin. Although any site can be designed to provide some infiltration by limiting the loading rate beyond these infiltration rates, special consideration may be required. Soil surveys are useful for preliminary screening of a site for soil infiltration rate. However, a geologic investigation of the specific site is required for design of an infiltration basin. The borings or trenches used for the geologic investigation should extend at least 5 ft below the bottom of the proposed basin.

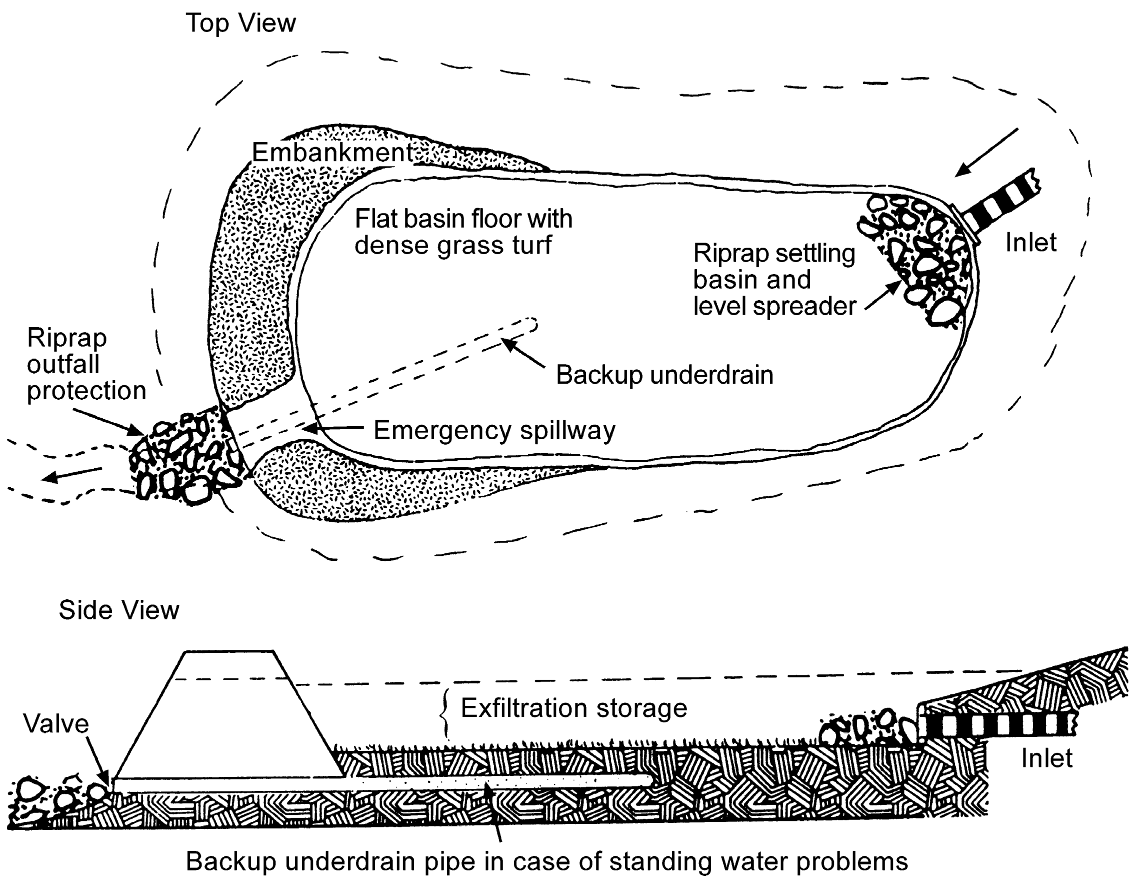


Figure 4.63-1 Schematic of an infiltration basin (source: Schueler, 1987)

DESIGN RECOMMENDATIONS

The design recommendation provided here were derived from *Standards and Specifications for Infiltration Practices,* which was prepared by the Maryland Department of Natural Resources (MdDNR, 1984). See also Table 4.60-1 in section 4.60.

Ponding Time

The maximum ponding time recommended is 24 hours. This maximum ponding time combined with the infiltration rate of the soil will determine the maximum design depth of the basin. The maximum design depth can be related by:

$d\ max = (f)(Tp)$

Where: $d\ max$ = maximum design depth (inches),
f = soil infiltration rate (in/hr), and
Tp = design ponding time (hours).

Water Table and Bedrock Separation

A minimum 3-ft distance should be provided below the bottom of the system and bedrock or the water table (For fractured bedrock, separations up to 10 ft may be required, or denial of the infiltration option may be the only reasonable alternative). This minimum separation distance is required to trap or treat pollutants before they reach ground water or bedrock and to maintain vegetation in the basin. In addition to removing pollutants, the separation to water table is required for basin hydrologic operation.

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 potential effects on ground water. 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.

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

- **Runoff water quality.** If runoff water will contain significant concentration of soluble pollutants that can contaminate ground water, an infiltration basin should not be used.
- **Degree of detail.** Determine how much detail will be required for the study. For instance, a small structure receiving runoff from a residential roof top will not require as much detail as a structure serving a larger area and having a higher potential pollutant load.
- **Geologic (ground water) 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.** The water table must be far enough below the bottom of the infiltration basin to allow the structure to function hydraulically and to allow trapping and treatment of pollutants by the soil.
- **Soil permeability.** Permability of the soil must be great enough to drain the structure in a reasonable amount to time, generally 24 hours or less.
- **Soil characteristics.** Evaluate the soil's ability to trap or treat pollutants expected at the given site and also provide the required infiltration rate.

These are a few of the major consideration involved in a site sensitivity analysis. For a more detailed discussion, the reader is directed to "Evaluation Techniques for Large Drainfield/Mound Systems Under Varying Geologic Settings," by J. A. Magner, in *Proceedings of the Fourth National Symposium on Individual and Small Community Sewage Systems* (Magner, 1985).

OPERATION AND MAINTENANCE

Runoff Filtering

Settleable solids, floating materials and grease should be removed from runoff to the maximum extent possible before it enters the infiltration basin. If these materials enter the basin, they can clog the bottom of the basin, take up storage volume and cause the system to fail. Devices, such as detention ponds, vegetative filters, sand filters, peat sand/compost filter, grassed swale, biofilters, bioretention, urban filter strip or oil/grit separator, can be used to remove these materials before they enter the infiltration basin. It may be feasible to allow these materials to enter the basin if their effects are considered during the design. One method of planning for this is to rely upon infiltration out of the sides of the basin rather than through the bottom.

Embankment Design

Embankments should be constructed in conformance with the USDA *Soil Conservation Service, Minnesota Field Office Technical Guide*, *Standard 378*, *Ponds.* Any structure using an embankment to impound water should have an emergency spillway to safely bypass flows from large rainfalls.

Principal Spillway for Combination Structure

If a combination detention pond/infiltration basin is being used, the elevation of the principal spillway crest should not be higher that the three-day infiltration capacity of the basin. All other aspects of the basin design, such as flood routing, should meet the requirements of an extended-detention pond.

Hydrologic Design

The hydrologic design of infiltration basins should be in accordance with the recommended procedures included in the hydrology section of this manual or other appropriate procedures. For combination basins, where flood routing is required, the short-cut routing procedures in the hydrology section of this manual can be used (see chapter 8). This procedure will result in conservative designs. A more refined flood-routing procedure may reduce the temporary storage requirement and thus the construction cost of the basin.

Infiltration Capacity Protection

Initial excavation of the basin should be carried out to within 1 ft 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. The final phase of 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. 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.

The bottom of infiltration basins may be lined with a layer of filter material, such as filter fabric or 6- to 12-inch coarse sand, to help prevent the buildup of impervious deposits. The filter layer can be replaced or cleaned if it becomes clogged. The slopes of infiltration basins usually need little maintenance to maintain their infiltration capacity.

Establishing dense vegetation on basin floors and slopes is recommended. Vegetation will not only prevent erosion, but will also provide a natural means of maintaining infiltration rates. Vegetation should be selected and established in accordance with the permanent vegetation practices of this manual. For Minnesota, wet-weather and drought-tolerant species are recommended.

Maintenance

Proper maintenance of infiltration basins and their pretreatment devices is critical. Basins and pretreatment devices should be maintained with a regular inspection schedule and a regular maintenance schedule. Sediment accumulation is greatest with the most efficient of infiltration devices. Therefore, it is most important to regularly inspect and maintain these systems to maximize their efficiency and longevity. 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.

Vegetation should be maintained as needed to control weed growth and maintain the health of the grass. Maintenance includes mowing and fertilization. The use of low-maintenance and drought-resistant varieties will minimize maintenance needs. When fertilizer is needed to maintain the vegetation, proper application methods should be used to minimize the potential for leaching. Split applications and use of slow-release fertilizers will help to minimize the chance of leaching.

RELATED ISSUES

Peat-sand filters are a variation of infiltration basins that show promise for treating urban runoff. A peat-sand filter consists of a bed of a peat-sand mixture, which is constructed over a drainage system. The drainage system collects treated runoff and discharges it back to surface waters. This type of filter is very effective for removal of suspended solids and associated pollutants. Preliminary studies have also found that peat-sand filters remove about 70% of phosphorus from runoff (Farnham and Noonan, 1988). These systems are still in the experimental stage at this time. For new approaches to sand and peat-sand filtration designs, refer to Schueler (1994a).

4.64 Filtration Practices: INFILTRATION TRENCHES

DESCRIPTION AND PURPOSE

An infiltration trench is a shallow excavated trench, usually 2 to 10 ft backfilled with a coarse stone aggregate, which allows temporary storage of runoff in the void between stones. Stored runoff then infiltrates into the surrounding soil. Figure 4.64-1 shows a typical infiltration trench.

TARGET POLLUTANTS

Infiltration trenches effectively control the pollutants in the surface runoff that enters them. They are not intended for control of coarse sediment or heavy concentrations of fine sediment because these materials can clog infiltration trenches. This practice should not be used to control soluble pollutants that can affect ground water quality.

EFFECTIVENESS

The effectiveness of infiltration trenches depends upon their design. When runoff enters the trench, 100% of the pollutants are prevented from entering surface water. Water that bypasses the trench will not be treated. When runoff enters infiltration trenches, many pollutants will be trapped or treated as they pass through the soil. However, some soluble substances, such as chloride from road salt, will not be treated during infiltration and will end up in ground water. This practice can be very effective for reducing the volume of runoff from a site of limited size.

PLANNING CONSIDERATIONS

Infiltration trenches are most applicable on sites with a relatively small drainage area. They can be used to control runoff from parking lots, rooftops and residential lots. An infiltration trench can also be used under a vegetated swale to increase its effectiveness for infiltration.

Soil permeability is a major consideration in determining whether an infiltration trench is feasible. Soils with an infiltration rate of 0.27 inches per hour or greater are suitable. This rate generally corresponds to sandy or silty soils in an A or B hydrologic soil group. The seasonally high water table should be at least 2 ft below the bottom of the trench. The 2-ft depth allows treatment of runoff before it reaches ground water and ensures that water will drain from the trench. As with any infiltration practice, care must be taken to prevent ground water contamination. The discussion in part 4.63, Infiltration Basins, and the general observations in section 4.60 about impacts on ground water apply to this practice, also.

Infiltration trenches should not be used in locations that will be receiving sediment loads that could clog the trench. In most cases, a vegetative filter or some other means of removing coarse sediment should be used to treat runoff before it reaches an infiltration trench.

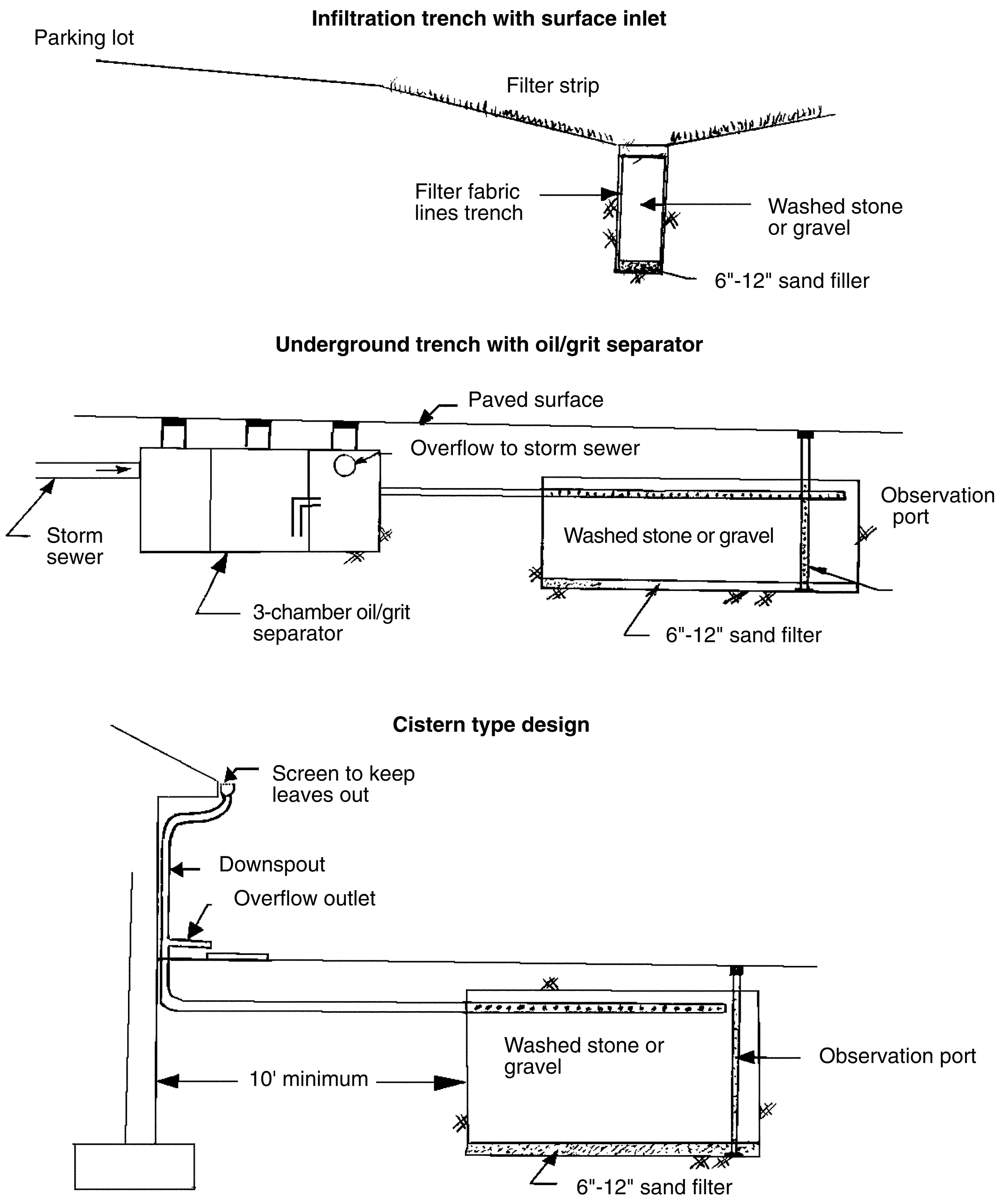


Figure 4.64-1 Schematic designs for infiltration trenches

DESIGN RECOMMENDATIONS

Storage volume

A storage volume equal to the runoff from a 1-inch rainfall is recommended. If greater control of runoff volume or peak discharge is desired, additional storage capacity can be used to meet these needs. The design storage volume of the infiltration trench is provided in the void space between the aggregate used for backfill. The aggregate backfill should be a clean, washed rock with a minimum diameter of 1.5 inches and a maximum diameter of 3 inches. For this size of rock, a void ratio of 30 to 40% can be assumed. The void ratio is the ratio of the volume of void space between the stones to the total volume. Therefore, the storage volume available is a product of the trench volume and void ratio.

Storage time

The maximum storage time that should be used is 24 hours. This storage time, along with the void ratio of the rock backfill and infiltration rate of the soil, can be related to determine the maximum trench depth that can be used. Trenches deeper than the maximum depth would take longer than 72 hours to evacuate.

Depth to water table and bedrock

A separation distance is required between infiltration trenches and ground water and bedrock. This distance is required to provide treatment of runoff before it reaches ground water and to protect against flooding of the structure from a high water table, which would render the trench ineffective. The Minnesota state rules for septic systems (Minn. R. 7080) requires a separation distance of 2 to 4 ft between on-site wastewater systems and the seasonally high water table or bedrock. Since urban runoff can contain many of the same pollutants as on-site wastewater-treatment systems, a 2 to 3-ft separation is recommended for filtration practices. A site sensitivity analysis as outlined in Practice 4.53, Infiltration Basins, should also be a part of infiltration trench planning.

Adjacent structures

The effects of seepage from the trench should be evaluated with respect to near-by or adjacent structures, such as foundations, basements, roads or sloping areas. The use of infiltration trenches on sites with steep slopes is not recommended. In some cases, slopes down gradient of an infiltration trench could become saturated and subject to failure. In residential areas, special care should be taken to prevent seepage from the trenches, which can cause wet basements. Infiltration trenches more than 3 ft deep should be located at least 10 ft down gradient from foundation walls. Infiltration trenches should also be located at least 100 ft away from any water supply well.

Runoff filtering

Oil, grease, floating organic matter and settleable solids should be removed from runoff water before it enters an infiltration trench. Runoff filtering devices, such as vegetated filter strips or oil/grit separators, can be used to remove these materials. All trenches with surface inlets should be designed to capture sediment before the flow enters an infiltration trench. Vegetative filter strips or oil/grit separators should be designed in accordance with the recommended criteria for those practices.

Trench construction

Construction of infiltration trenches should be delayed until the entire site is stabilized. This will prevent clogging of the trench from high sediment loads during construction.

After the trench has been excavated, its sides and bottom should be lined with filter fabric to prevent intrusion of soil into the stone. Clean, washed 1- to 3-inch stones should be placed in the trench in lifts and lightly compacted with plate compactors.

It is recommended that an observation port be installed in each trench. In addition to monitoring the performance of the trench, a port helps mark the trench location. Trench performance can be monitored by inserting a dipstick in the port immediately after a storm and then each 24 hours until the trench is empty.

After the trench is constructed, surface inlets to the trench should be protected from sediment until the site is stabilized and vegetative filtering practices are fully established.

MAINTENANCE

Proper maintenance of infiltration trenches and their pretreatment devices is critical to the success and longevity of the infiltration device. A regular inspection schedule and a regular maintenance schedule should be implemented. Routine maintenance for infiltration trenches involves activities intended to prevent clogging of the trench. Grass clippings and leaves must be removed from surface trenches to prevent clogging also. The trench should be inspected after the first few runoff events and then at least annually thereafter. It should also be inspected after major storms to check for ponding, which may indicate a clogged trench. Water levels in the observation port can be recorded over a several-day period to check for clogging.

If an infiltration trench becomes clogged, rehabilitation can be very expensive. Clogging in trenches open to the surface occurs most often at the top of the trench. This problem can be corrected by replacing the filter material and filter fabric at the top of the trench.

4.65 Filtration Practices: FILTERS

INTRODUCTION

Stormwater-filtering systems refer to a diverse group of techniques for treating the quality of storm water runoff. The commonality is that each utilizes some kind of filtering media, such as sand, soil, gravel, peat or compost, to filter pollutants from stormwater runoff. In addition, most filtering systems are typically applied to small drainage areas (five acres or less). Third, filtering systems are designed solely for pollutant removal. Flows greater than the water quality treatment volumes are bypassed around the filter to a downstream stormwater management facility. Lastly, filtering systems incorporate four basic design components in every application: inflow, pretreatment, filter and outflow.

The information in this section is based on the Center for Watershed Protection's "Design of Stormwater Filtering Systems" (Claytor *et al.*, 1996).

DESCRIPTION

Filter designs are grouped into three broad categories: (1) surface and underground sand filters, (2) organic/sand filters, and (3) artificial media filters. These differ in size, method of construction, location and type of filter media used, but the operation and principles of filtration are similar (see Figure 4.65-1).

DESIGN

The various kinds of storm water filters have several common design components. The four basic design components of a filtering system are: (a) inflow regulation that diverts a defined flow volume into the system, (b) a pretreatment technique to capture coarse sediments, (c) the filter bed surface and unique filter media, and (d) an outflow mechanism to return treated flows to the conveyance system and/or safely handle storm events that exceed the capacity of the filter. Each of the design components is described in greater detail below.

Inflow Volume Control

The inflow regulator is used to divert runoff from a pipe, open channel or impervious surface into the filtering system or to divert excess flow away from the system. The inflow regulator is designed to divert the desired water quality volume into the filter and to allow large-flow volumes to continue through the conveyance channel. With a few exceptions, most filtering systems are constructed off line (*i.e.*, runoff is diverted from the main conveyance system; see left-hand side of Figure 4.65-2). A few filtering systems, such as the swale system depicted in the right-hand side of Figure 4.65-2, are constructed on-line. On-line filters are located within the conveyance system, and are exposed to the full range of flow events, from the smallest storm up to and including the 100-year event.

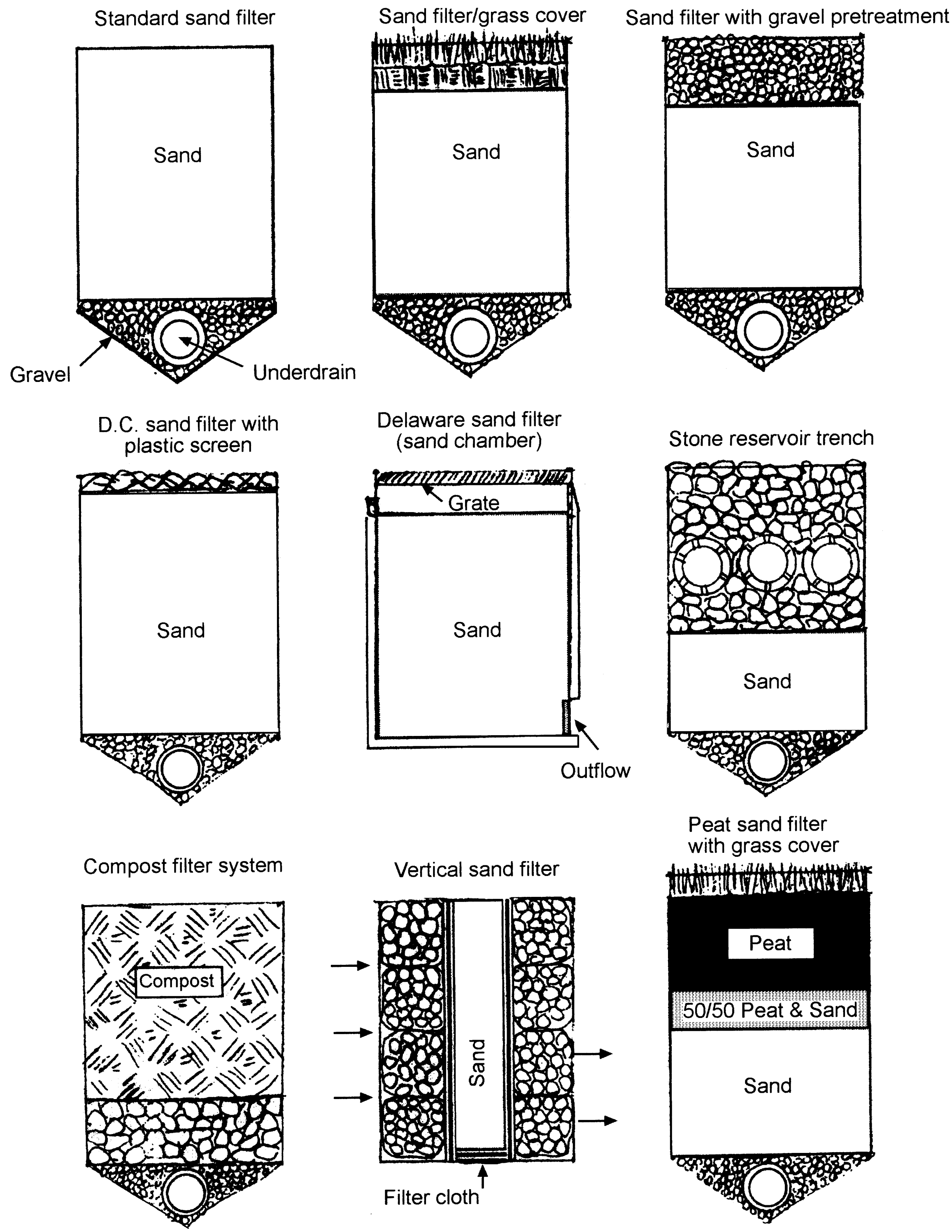


Figure 4.65-1 Cross section of sand filter design variations (source: Schueler, 1994a)

Pretreatment

The second key component of any filtering system is pretreatment. Pretreatment is needed in every design to trap coarse sediments before they reach the filter bed.

Without pretreatment, the filter will quickly clog, and lose its pollutant-removal capability. Each filter design differs with respect to the type and volume of pretreatment afforded. The most common technique of pretreatment is a wet or dry settling chamber. Geotextile screens, pea gravel diaphragms and grass filter strips may also be used as a secondary form of protection. Sediments deposited in the pretreatment chamber must be periodically removed to maintain the system.

Filter Bed and Filter Media

Each filtering system utilizes some kind of media, such as sand, gravel, peat, grass, soil or compost, to filter pollutants from urban storm water, and some designs utilize more than one. The selection of the right media is important, as each has different hydraulic, pollutant-removal and clogging characteristics.

The filter media is incorporated into the filter bed. The three key properties of the bed are its surface area, depth and profile. The required surface area for a filter is usually based as a percentage of impervious area treated and the media itself, and may vary due to regional rainfall patterns and local criteria for water quality treatment volumes. The depth of most filtering systems ranges from 18 inches to 4 ft. A relatively shallow filter bed is used for hydraulic and cost reasons, and because most pollutants are trapped in the top few inches of the bed. Each design also utilizes a slightly different profile through the bed. An example of the variation in sand filter profiles is shown in Figure 4.65-1. As can be seen, each design has slightly different surface protection and layering through the bed.

Outflow Mechanism

The final component of any stormwater filter design is the method(s) used to collect or exfiltrate the filtered runoff that leaves the filter bed and bypass the larger storm flows. The two primary methods for handling filtered runoff are to collect it in the perforated pipes and return it to the conveyance system, or to allow it to exfiltrate into the underlying soil where it may ultimately reach ground water. Each method has its pros and cons.

In the collection method, the bottom of the filter bed may be sealed with an impermeable liner, which allows the filtered runoff to be captured in pipes and returned to the conveyance system. Filtered collection is desirable if the contributing land use is considered a pollutant hotspot or if ground water contamination is a concern.

In the exfiltration method, the bottom of the filter bed is fully or partly permeable, and the filtered runoff continues downward, through the soil, and into the ground water. The uncollected runoff volume and pollutant mass drain into underlying soils and the water table. The advantage of exfiltration is that it provides ground water recharge and takes advantage of the natural filtering capacity of soil to remove additional pollutants.

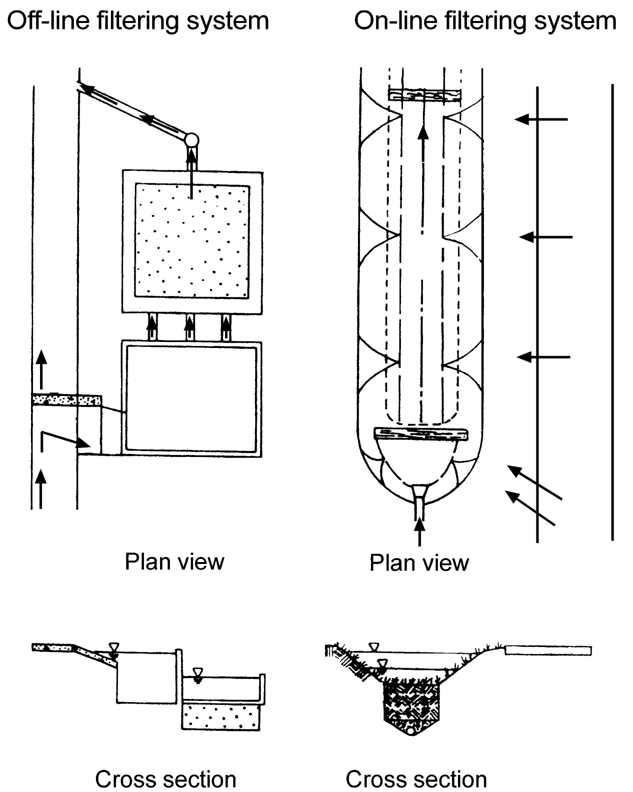


Figure 4.65-2 Schematic: on-line vs. off-line design

CHAPTER 5

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5.00 STORMWATER-DETENTION PONDS

DESCRIPTION

This chapter focuses on the application of stormwater ponds as a best management practice (BMP) for improving the quality of urban runoff and reducing peak discharges. Stormwater ponds have become the most common "structural" method of regulating and treating stormwater runoff. A significant body of technical literature documents the favorable performance of stormwater ponds. Many municipalities and watershed districts require stormwater ponds to mitigate the adverse impacts of urbanization.

PURPOSE

This chapter recommends design features for stormwater wet detention basins and wetlands designed for urban stormwater treatment. Information contained herein does not replace the need to understand the site-specific design needs, nor does it supersede other requirements, such as applicable regulatory requirements.

TREATMENT MECHANISMS

Published stormwater-treatment literature indicates that ponds treat primarily by dynamic and quiescent settling of sediment particles. In addition to settling, treatment may also be accomplished by biological and chemical action, plant uptake, evapotranspiration, infiltration and, in some cases, physical diversion to other systems (USEPA, December 1983).

TARGET POLLUTANTS

If well designed, wet ponds and constructed wetland treatment systems are effective for removing sediment and associated pollutants, such as trace metals, nutrients and hydrocarbons. They also remove or treat oxygen-demanding substances, bacteria and dissolved nutrients.

EFFECTIVENESS

The Nationwide Urban Runoff Program (NURP) research projects determined that 90% removal of total suspended solids (TSS) appears to be an attainable goal in stormwater-treatment ponds. Significant removal of other pollutants, such as phosphorus, was also predicted to be achievable (USEPA, December 1983). Actual removal will vary due to site-specific conditions (see Figure 5.01-1).

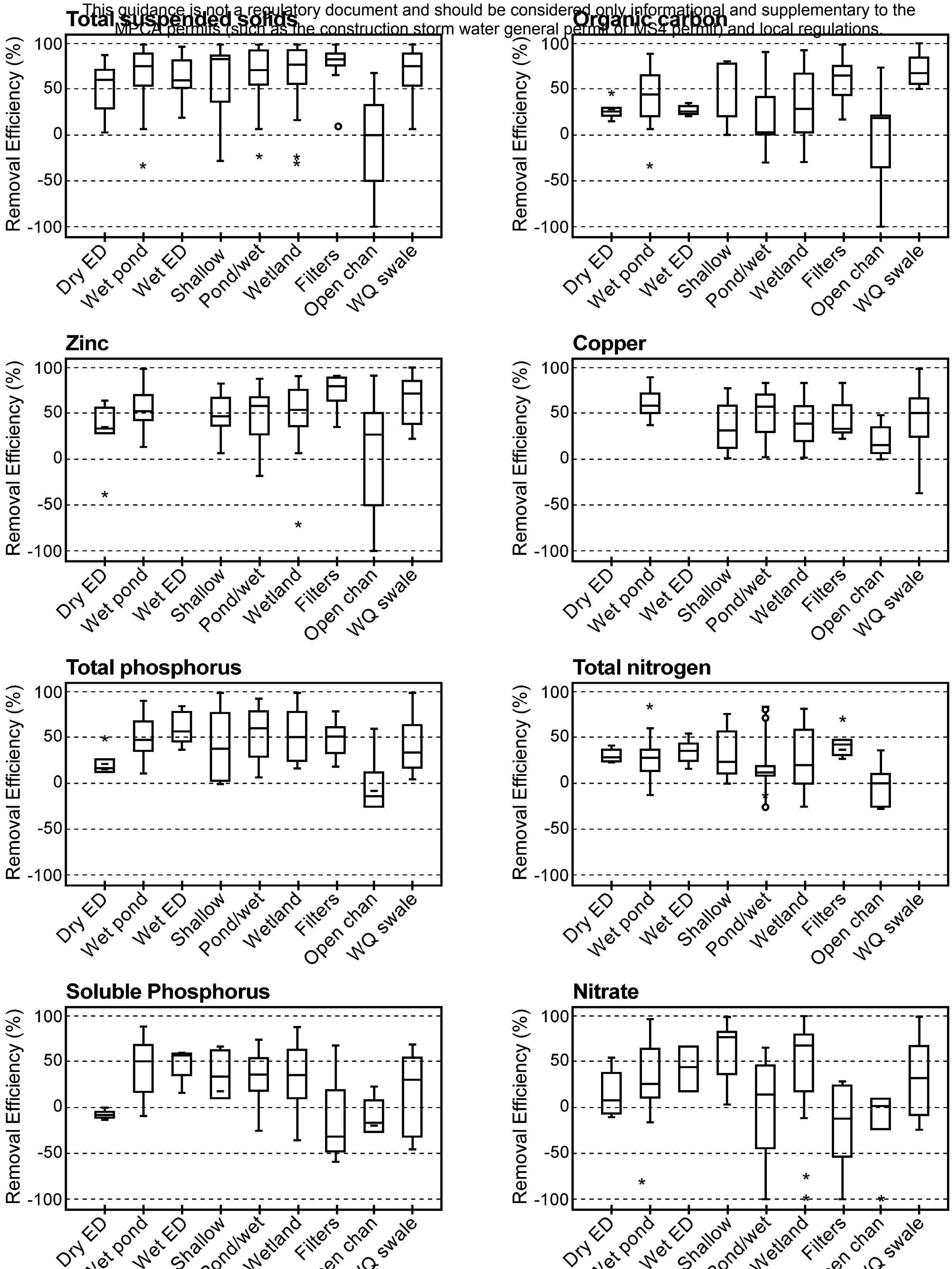
5.01 Pond Design Criteria: SYSTEM DESIGN

Many issues cut across the distinction between the planning and design phase of a project. Many tradeoffs must be assessed in the development of pond policy. Pond location, pond design type, pond ownership and pond policy flexibility are some of these issues.

Selecting the appropriate system design depends on many considerations. The project goals and objectives must be considered with the site physical limitations along with financial implications and political considerations. These issues are discussed in chapters 1, 2 and 3. Design factors to consider include the type of facility desired, variability of the rainfall and runoff, soil and cover types (see chapter notes 5.01-1 and 5.01-2).

Ponds can be built in a wide variety of designs and with a wide variety of features. Of course, different designs will have variable treatment effectiveness at different sites (see Figure 5.01-1). Good design must anticipate maintenance issues and should include community desires for aesthetics or recreation by incorporating desirable features into the pond design. However, there is a range of variability that should be understood within each type of pond. Even the expected performance of a particular design may be highly variable (see Figure 5.01-2). There is no single solution or design for all situations.

It should also be evident that given the number and type of variables involved, even well-designed ponds will not always perform as designed. Your plans should take this variability into account, since the best performance you can expect will be for the pond to meet the design criteria on an average annual basis. The standards presented here are an attempt to present reasonably implementable goals, which will provide an adequate level of water-quality protection. For critical situations and outstanding resources, additional or more stringent requirements may be necessary.



Dry ED = Dry extended detention
Pond/wet = Pond/wetland
Open chan = Open channel swale
WQ swale = Water quality swale

Figure 5.01-1 Pollutant removal by type of facility

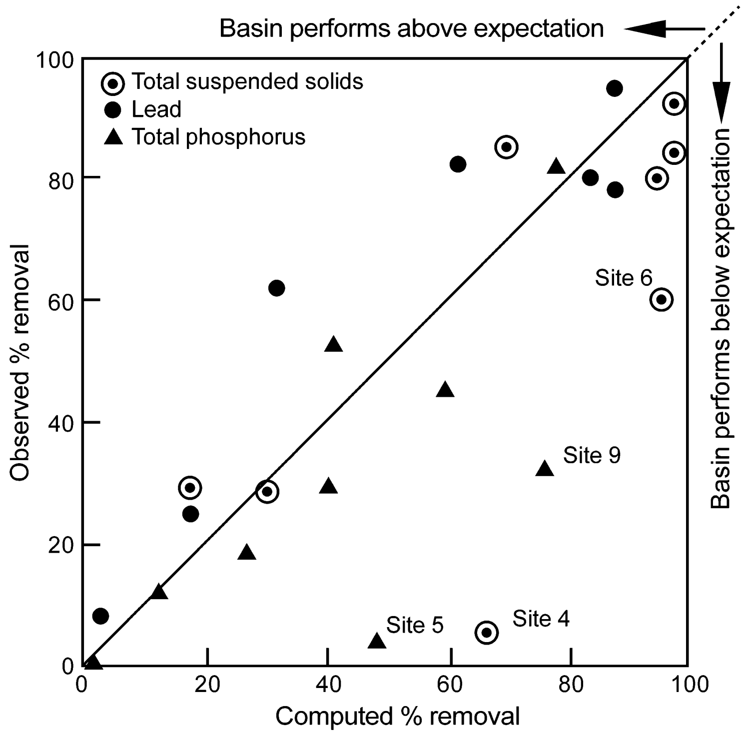


Figure 5.01-2 Comparison of observed vs. computed removal efficiencies (percent removal of pollutants during monitored storms)

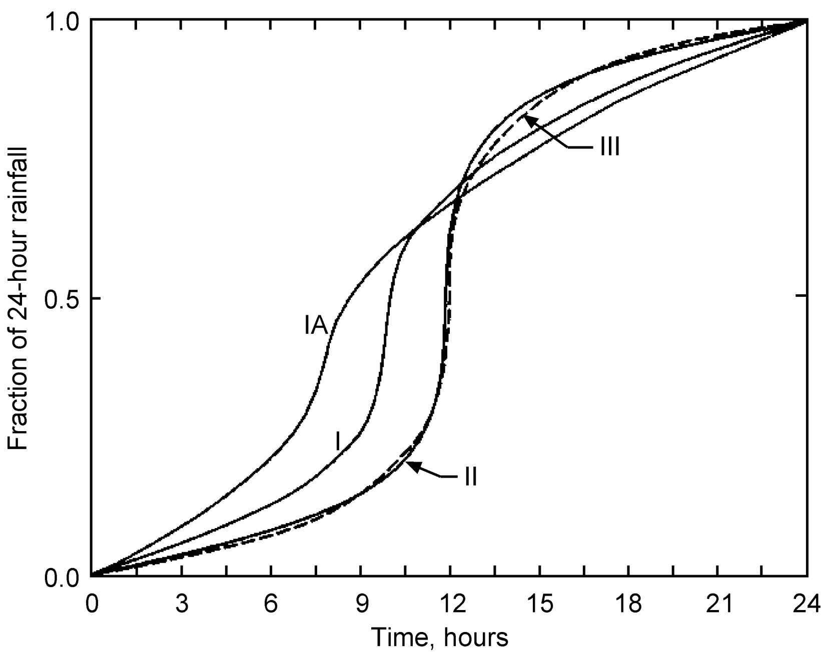


Figure 5.01-3 Synthetic 24-hour rainfall distributions

Note 5.01-1 Describing a Design Storm Event

It is not enough to specify a rainfall amount in inches to describe a rainfall event. Before we can begin to talk about the runoff from an event, the nature of the storm event must be carefully considered. When talking about a storm event, we mean a storm with a certain amount of rainfall, such as a 1.25- or 2.5-inch event. But this alone is not all of the storm information needed for design purposes. For the purpose of designing ponds or other devices, it is important to understand the assumptions that are implied in the adoption of the design storm. The factors that need to be defined to describe a storm include volume, duration, intensity and distribution, and frequency.

Volume: This is the volume of rain that occurs for the given storm. The volume of the event is often the only information given, but it is not enough to describe the storm for design purposes.

Duration: Duration of a storm is the time over which it occurs. This manual assumes the event occurs over a 24-hour period. However, an infinite variety of storms can occur over a 24-hour period, even those that have the same amount of total rain. This is due to differences in the intensity and distribution of the rainfall.

Intensity and Distribution: Intensity is the rainfall stated in inches per hour. However, rainfall intensities vary from storm to storm and in most events are not constant during the storm. Constant rain may be an acceptable assumption over four hours, but it is probably not good over a 24-hour period. Therefore, we also need to describe the distribution of the storm, which is how the intensity of the storm changes through the storm's duration. This manual assumes the Natural Resource Conservation Service (NRCS) storm types, which for Minnesota is the Type II storm distribution (see Figure 5.01-3). This is one of the more commonly used distribution assumptions. The assumptions built into any distribution should be fully understood in order to properly apply hydrologic principles to your project.

Frequency: Frequency is the recurrence interval or the reciprocal of the probability. The size of storm we can expect to occur at any given frequency changes across Minnesota from northwest to southeast from about 1.8 to 2.6 inches for a one-year, 24-hour storm. This means that an annual event is much smaller in northwest than in southeast Minnesota. When frequency of recurrence is important, this must be taken into account. The recurrence interval in this manual is usually assumed to be for rainfall events with a distribution for events measured at the Minneapolis-St. Paul airport.

We refer to specific storm events to establish a common ground of design. This can only be effective if the assumptions are understood and properly applied in a given design situation. Determining whether these events or assumptions are appropriate for your project must be done on a site-specific basis. Remember, a design storm does not reflect actual events, but should reflect the typical assumed conditions for which the design is intended.

Note 5.01-2 Particle size assumptions

There is a wide range of particle sizes and composition, and hence, settling velocities, in any sample of stormwater runoff. This range can be described by a probability distribution of pollutant settling velocities and determined by an appropriate analysis of the data obtained from standard settling column tests. When the settling velocity distributions obtained from the NURP studies were analyzed, differences were found between storms at a site and between storms at different sites. Site-to-site differences were of the same order as storm-to-storm variations at a particular site, justifying the combination of all data. The result of such an analysis, illustrated by Figure 5.01-4, indicated that it is reasonable to make estimates of "typical" urban runoff settling characteristics and expect that, in an appropriate analysis, short-term variations will average out. This assumption and the relationship shown, proved to work out quite well in the analysis of the performance of nine detention basins in different parts of the country that differed radically in size.

While the "typical" values provided here are considered to be satisfactory for initial estimates and for screening analyses, additional site-specific settling column studies are encouraged to expand that database and improve site-specific estimates.

(From: U.S. Environmental Protection Agency, 1986)

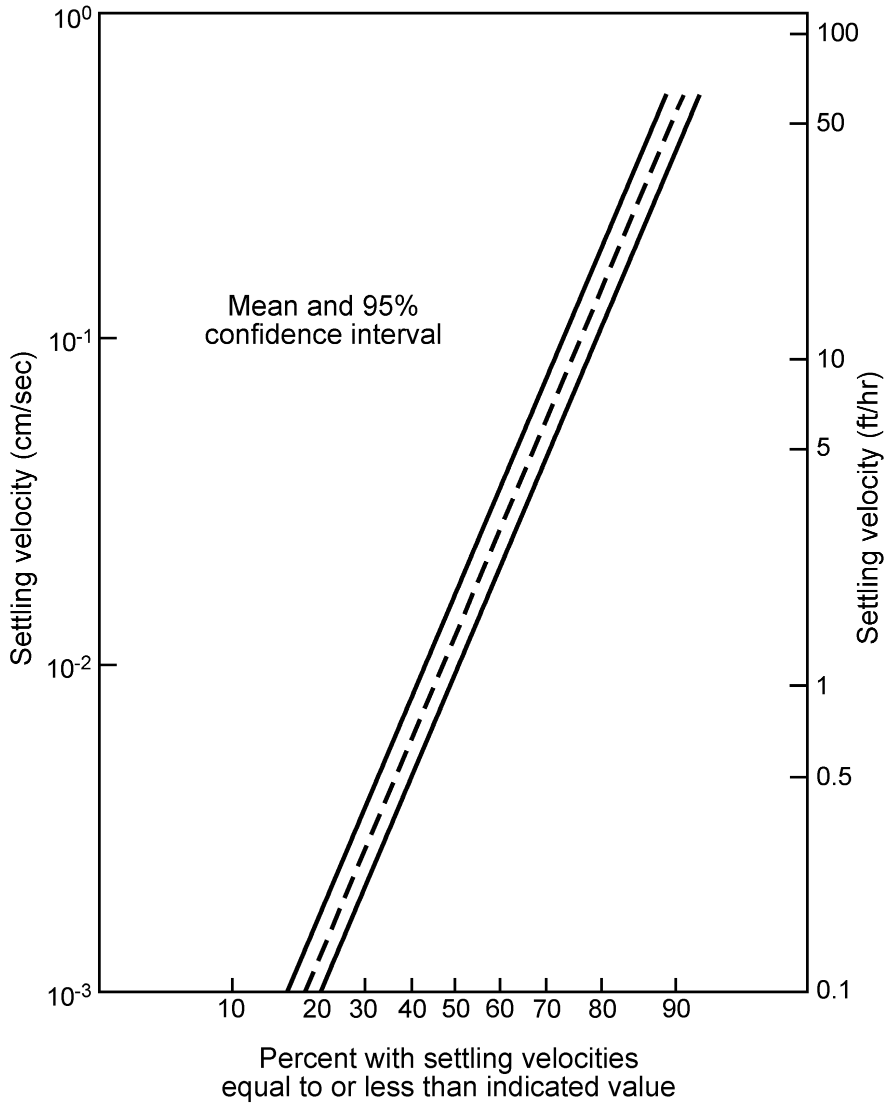


Figure 5.01-4 Particle size settling velocity probability distribution

5.02 Pond Design Criteria: POND LAYOUT AND SIZE

Often, the pond is divided into three zones: (1) an inlet, which can have a deep pool or other design for flow dispersal; (2) the main, or primary, treatment area; and (3) an outlet zone, which can be deep to prevent resuspension or be designed for final “polishing.” The main treatment area of a pond is typically located between its inlet and outlet areas. Multiple ponds or pond wetland systems can also provide these design features, but the function of the zones remains essentially the same.

INLET DESIGN

Pond design normally includes an inlet area with a permanent sediment storage area 3 to 8 feet (ft) deep. This storage starts below the inlet spillway elevation and extends downward to what can be the deepest point in the pond. In general, this area should have a design that provides energy dissipation, sediment storage and some quiescent settling.

Inlet Sediment Storage

An inlet area 3 to 8 ft deep (with an area 10-20% of the total area of the pond) is recommended. The inlet is the zone where the largest sediments will settle out and, therefore, will need to be removed periodically. Access to the inlet areas should be provided to facilitate maintenance and repairs.

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.

OUTLET DESIGN

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. Pitt (1994a and April 29-30, 1998) found that a ratio of approximately 5.66 cubic feet per second (cfs) of outflow for each acre of pond surface area resulted in a predicted sediment trapping efficiency of approximately 90%. This conclusion is based on urban storm water with particle size distribution found in Madison, Wisconsin, runoff. Outlets with this design can be expected to meet the stated NURP goals (USEPA, 1983) on an average annual basis.

MAIN TREATMENT AREA

Field studies of wet stormwater ponds in the NURP program reveal that 90% removal of TSS is attainable with a pond surface area that is about 1% of the watershed area. Pitt (1994a and 1998) studied the pond-surface-area-to-watershed-area ratios and found that open-space watersheds with highly permeable soils require less pond surface area, down to about 0.6% of the watershed area.* He also found that ratios varied, with requirements of 0.8% for residential land use areas and 1.7% for commercial areas, up to 3% for totally paved areas (see Table 5.02-1). An estimate of 1% is often used for watersheds with mixed land use, but this must be analyzed on a site-specific basis.

Table 5.02-1 Wet pond surface area required as a percent of drainage area , for a given land use and goal of 90% sediment removal (Pitt, 1998)

Land Use	Percent of Watershed
Totally paved areas	3.0
Freeways	2.8
Industrial areas	2.0
Commercial areas	1.7
Institutional areas	1.7
Construction sites	1.5
Residential areas	0.8
Open spaces	0.6

Shape and Appearance

Flow length and path through the pond affects settling performance. Conventional design dictates that, when the pond is considerably longer than wide (*e.g.*, three times as long as wide), it will likely provide additional detention time for settling and biological treatment of runoff. However, an oblong or rectangular shape does not guarantee that short-circuiting will not occur. Excessive inlet velocities, wind or thermal currents can cause sediment movement, resulting in short circuiting in the pond and inefficient use of the entire pond volume.

Landscaping of upland areas adjacent to stormwater ponds is frequently incorporated into final design plans. In many cases, parkland or recreational trails exist alongside stormwater-treatment and storage ponds. Cities and watershed districts often play a major role in determining landscape features. They should develop policies that encourage functional and aesthetic landscaping practices.

Flow Patterns

Baffles and curved flow paths are often used to increase settling efficiency. Schueler (October 1992) uses the natural-looking variation in bottom contours to enhance flow characteristics in his wetland designs (see Figure 5.02-1). The actual dynamics of flow and sedimentation in stormwater ponds relative to the pond shape are not well described in available literature. Design of stormwater-treatment ponds remains a developing technology.

* The Ramsey-Washington Metro Watershed District finds that a 0.5% ratio is often acceptable. Note: these numbers may need to be adjusted upward for small watersheds (see Special Considerations).

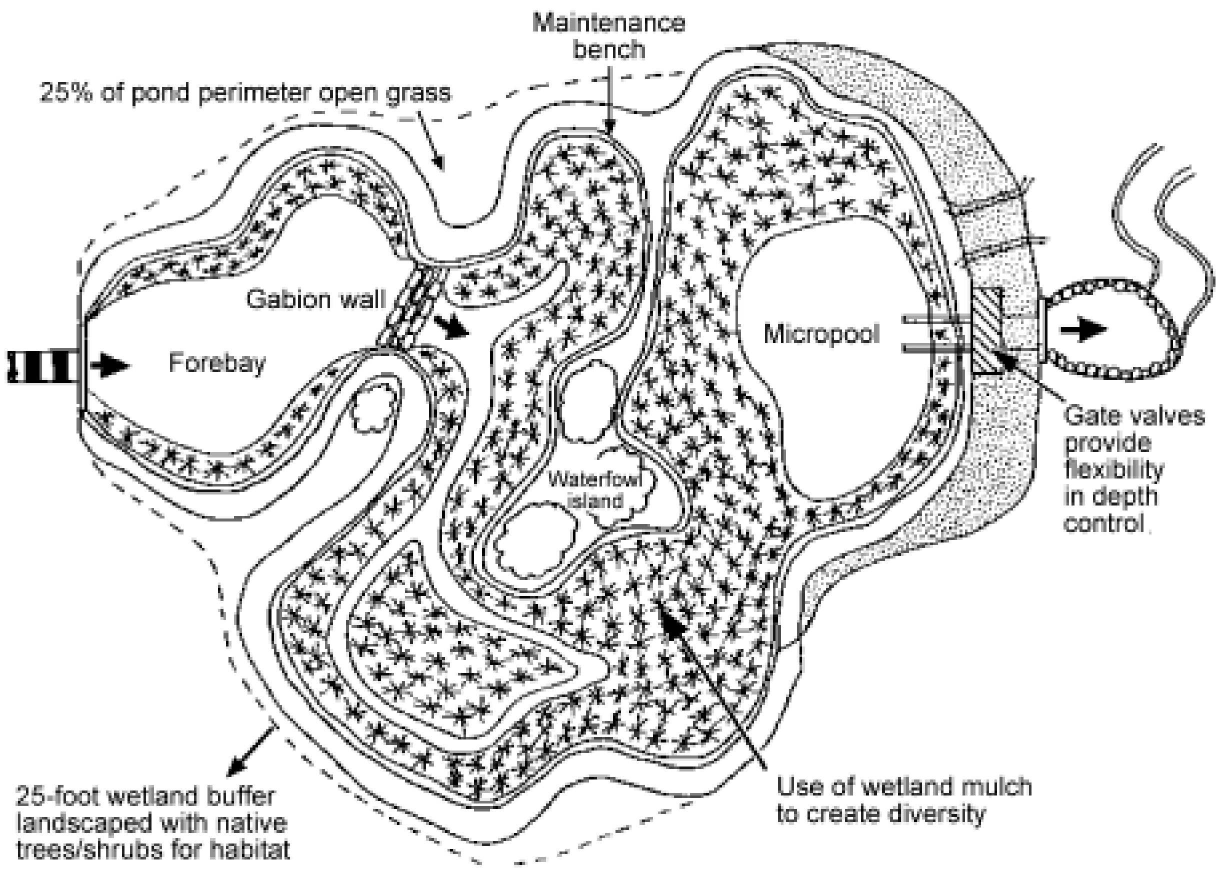


Figure 5.02-1 Baffles and contours in a pond system (Schueler, 1992)

5.03 Pond Design Criteria: MAIN TREATMENT CONCEPTS

DESCRIPTION AND PURPOSE

The main treatment area may be a wetland, deep pond or any combination that meets the design criteria for the project. In general, the main treatment area is designed to provide an area for settling of the fine to medium-size particles (*i.e.*, 5 to 100 microns in diameter) in urban runoff. It typically constitutes 30-80% of the total volume of the stormwater pond. The main treatment area may be designed to provide a suitable habitat for various types of wetland plants and associated wildlife species. In some instances, open water may be desired for sediment storage or aesthetic reasons.

Water Quality Volume

The water quality volume is defined in terms of the effectiveness of the treatment on an average annual basis. If the removal goal for the water quality volume is 90%, then the removal for lower flows will be higher, but higher flows will have less removal. We cannot design for 90% removal from all storms, so we calculate a design storm that will give us 90% removal on an average annual basis. The assumptions and variability required to estimate this type calculation are discussed in *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality* (USEPA, 1986).

Properly conducted, the design water quality volume would give the equivalent of the "flow weighted mean removal rate," for a given particle size, rainfall and runoff distribution characteristics of the site. It could reasonably be expected that 20 years of data for each site would be required to get statistically significant data that could be applied to this type of calculation. By making reasonable assumptions and by using data and practical applications from across the country, Pitt (1994a), Walker (1987a and 1987b) and others have come up with suggested design parameters.

Sizing for Treatment (Pitt Method)

The Maryland Department of Natural Resources (Barfield *et al.*, 1986) indicates that the ratio of pond surface area to peak discharge is a practical criteria for design of sedimentation ponds. Our evaluation indicates that this ratio is also easier to compute and apply as a practical design tool than detention time, and it can be more readily field checked for compliance.

Pitt found that a ratio of approximately 5.66 cfs of outflow for each acre of pond surface area resulted in a predicted sediment trapping efficiency of approximately 90% in urban storm water with particle size and rainfall distribution found in Madison, Wisconsin, runoff (Pitt, April 29-30, 1998). Thus, the treatment goal for wet ponds is to remove about 90% of the suspended solids by using a design ratio of 5.66 cfs of pond outflow per acre of pond surface area.

When Wisconsin Department of Natural Resources staff analyzed the water quality volume using Pitt and Walker models for local conditions, they found that the assumptions, such as particle size distribution, were critical to the calculations (Personal communications). Although their goals, assumptions and analysis methods differed somewhat from those used in this manual, they concluded that a water quality volume based on 1.25- to 1.5-inch events would provide a reasonable average annual removal rate of 80%. The design recommendations of this manual are more conservative than the assumptions used in their modeling; therefore, their conclusions support this manual's 90% goal.

Pitt provides an explanation and reasonable estimate of the return frequency event for 90% overall removal of suspended solids in urban areas of the Upper Midwest. He proposes the 1.25-inch event (Pitt, 1998). This is about the 0.3-year return frequency, or the event occurring about three times per year.

Using the Pitt method, the stage and discharge for the pond spillway are designed so that the maximum flow out should be less than or equal to 5.66 cfs per acre of pond surface area. The maximum discharge should occur when the elevation of the pond has the entire water quality volume. Using the entire water quality volume and specific outflow rate as the design criteria also makes it relatively easy to field check the as-built structure to see whether it complies with the criteria.

Sizing for Treatment (Walker Method)

Another estimate of the water quality design is provided by Walker in his report to the Vadnais Lakes Area Management organization (see Walker, 1987b). Walker proposed storage with a permanent volume equal to the 2.5-inch event. This is twice as big an event and more than twice the water quality volume recommended by Pitt. The differences between Pitt and Walker are large, but you need to consider the basis of their design and assumed removal mechanisms. Pitt design methods are primarily directed at suspended solids. Pitt methods may require a smaller initial volume but also require carefully controlled release and bounce in the pool. Walker-design ponds are primarily directed at phosphorus removal. They require a large storage for inter-event treatment, but do not require controlled release. Therefore, bounce in the pool is not part of Walker design calculations.

This manual has attempted to resolve the differences in these widely accepted design recommendations by allowing both options. Using either design option can be reasonably expected to meet water-quality goals, provided that control of velocity in the pond to prevent resuspension of sediments, and other specific conditions of design are complied with.

Calculating Water Quality Volume

The volume of runoff from the water quality event is best predicted by a combination of monitoring existing conditions and modeling future conditions. For design purposes, the water quality volume should be considered an instant flow to the pond, not an inflow-outflow calculation. Both Walker and Pitt use this assumption (Walker, 1987a and b, and Pitt, 1994a). The assumption of instant runoff is conservative, but it accounts for a great deal of the variability that occurs in storm events and runoff conditions.

Bench Areas

Stormwater-treatment ponds should be designed with shelves or benches that slope gradually into the open-water area and form a transition between the open-water area of the pond and the surrounding property. A 3- to 10-foot bench should be constructed. Slopes of 10:1 (10 ft horizontal to 1 ft vertical) to 6:1 are recommended. When enough area is available, a 10-ft bench with a 10:1

slope is recommended. Bench areas may comprise 10-20% of the total pond area. Emergent vegetation, such as cattails and grasses, should be encouraged, but often they will grow voluntarily on bench areas (see Figure 5.03-1).

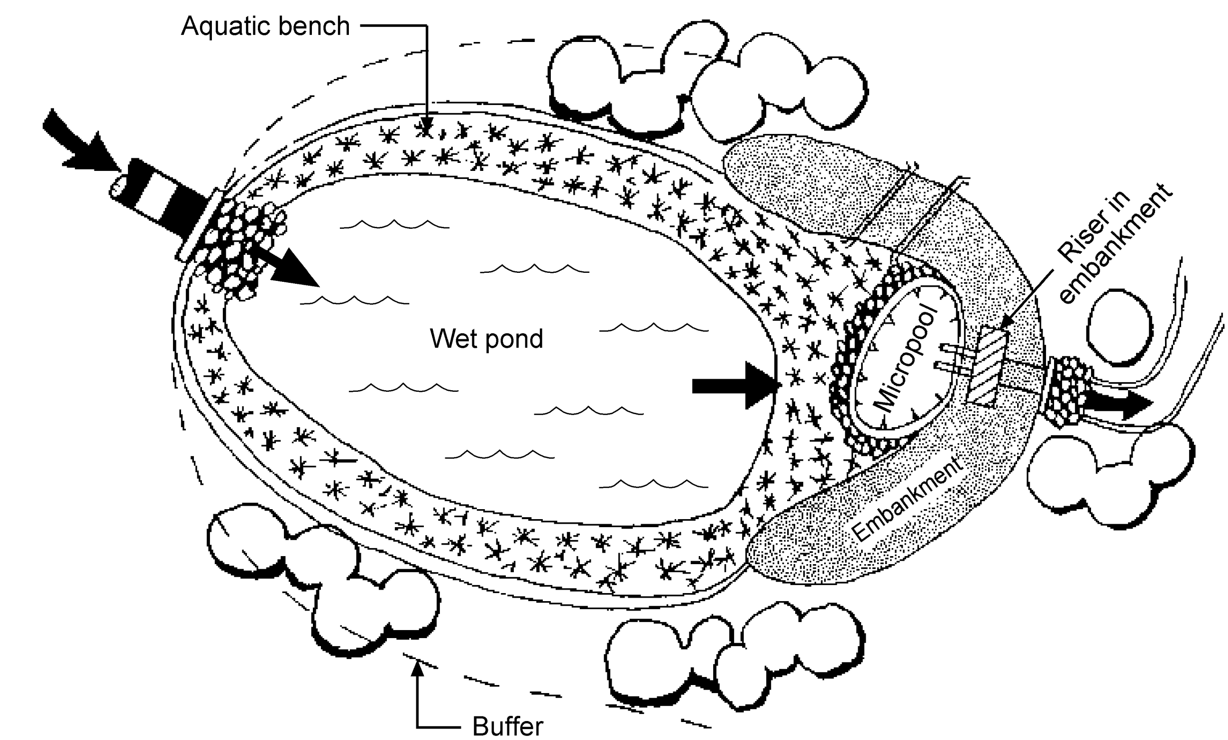


Figure 5.03-1 Aquatic bench

Wetland Vegetation

Aquatic vegetation provides some aquatic nutrient uptake, prevents erosion and provides an aesthetically more pleasing and perhaps more effective way of removing nutrients than other measures. Walker (1990), in documentation for his P8 model, also indicates that there is evidence that vegetation in a pond or wetland may provide increased settling effectiveness by laminar settling. In these cases, vegetation slows flow and acts like settling plates to remove suspended particles.

Vegetated bench areas also provide wildlife habitat and help prevent children from entering open-water areas. In addition, vegetated bench areas discourage the use of adjacent grassed areas by geese. Geese prefer open, grassy areas and tend to overpopulate mowed park areas that are immediately next to open water.

Wetland Designs

Wetlands treatment systems should be designed using the surface outflow rate method discussed in this manual as the main water quality treatment design mechanism. We encourage the use of wetlands for treatment, but detailed designs of wetland treatment systems are beyond the scope of this manual. Wetlands may reduce dead storage, but can provide added benefits that make up for the dead-storage loss. Wetland systems must be designed in consultation with professionals who are knowledgeable in the field of wetland design, construction or restoration. Refer to the section on "Special Considerations" below and refer to experts, such as Schueler, Dindorf, Eggers and others in the references for further information.

Unless carefully designed, discharges to wetlands may disrupt the wetland systems to such an extent that they destroy the wetland vegetation and habitat values. Therefore, discharges to natural wetland systems should generally not be allowed or given treatment credit, or allowed unless there are no other available options. Allowing discharges to natural wetlands without pretreatment and rate controls should be avoided wherever possible.

5.04 Pond Design Criteria: DEAD STORAGE VOLUME

DESCRIPTION AND PURPOSE

There are three distinct storage areas in a pond: (1) the stormwater drainage control volume, (2) the water quality volume and (3) the storage volume below the pond outlet, often called "dead storage" (see Figure 5.04-1). The purpose of dead storage is to help diminish velocities, reduce scour, encourage quiescent settling of sediment and provide sediment storage volume. However, there are potential problems with any large permanent storage volume.

Potential Problems with Dead Storage in Ponds

Large dead-storage volumes in urban stormwater ponds can be related to elevated temperatures. Deep pools may turn anoxic and release pollutants, such as nutrients and metals. Depths over 8 ft are not encouraged, but this effect can occur in shallower pools as well. The Minnesota Pollution Control Agency (MPCA) has observed this effect in wastewater-treatment ponds less than 4 ft deep (Helgen, 1992).

Benefits of Dead Storage

Dead storage provides additional settling and potential biological treatment between rainfall events. Methods (USEPA, 1983) based on DiToro and Small (USEPA, 1986) assume a settling velocity and multiply it by the pond treatment area to determine the volume of treated water between events. When considering inter-event treatment, a volume limitation (no more treatment credit than the volume of the pond) and an efficiency factor should be applied because wind and thermal currents significantly reduce the theoretical removal rates for fine particles (Fair and Geyer, 1954).

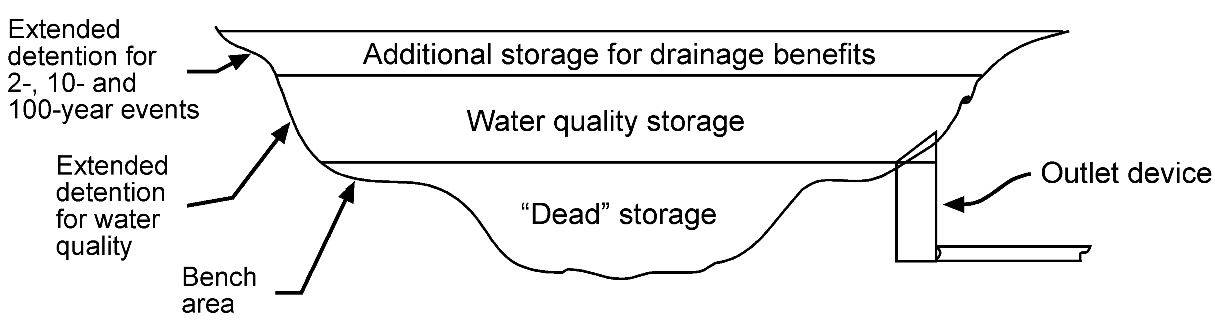


Figure 5.04-1 Cross section of pond showing dead storage volume, water quality storage volume and stormwater control volume (from *Wet Detention Ponds,* Robert E. Pitt, April 29-30, 1998)

In ponds designed to use the dead storage as the primary treatment, the pond storage volume is often large to allow possible biochemical treatment and quiescent settling to occur. Dissolved phosphorus (P) and other substances with dissolved fractions are some of the parameters where additional pond retention time may allow biological or chemical treatment to occur. Pond volume is increased to lengthen residence time, and potentially provide biological and chemical removal. The use of pond design storms from 2.0-inch (Brach, 1989) to 2.5-inch rainfall events (Walker, 1987b) reflects this concern for additional volume.

If the dead storage volume is designed to incorporate the water quality treatment volume, that means that the design does not rely on treatment by extended detention above the outlet. The dead storage volume provides sediment storage, flow diffusion and other purposes in addition to settling. Therefore, the volume below the outlet needs to exceed the water quality volume to provide equivalent treatment. This manual recommends that the dead storage volume be capable of holding an instant runoff volume from an event twice the water quality event; in other words, it should hold the runoff from a 2.5-inch event. This volume is adapted from the Walker pond design, which is accepted by many jurisdictions in Minnesota (Walker, 1987b).

Ponds with large dead storage volumes can provide adequate treatment if the displaced water quality volume is the quiescently treated water in the pond. When sufficient extra volume is provided, the design outflow rate of 5.66 cfs per acre of surface area for the water quality volume is usually met, but need not be strictly complied with.

Whether dead-storage pond designs meet the outflow rate criteria or not, they should provide velocity and scour reduction and meet other design criteria described in this manual, or be modified to do so. To prevent resuspension of sediments, ponds with large dead storage volumes must meet the velocity requirements in the pond for the 0.3-year (water quality event) event, and the one-, two-, 10- and 100-year events (Table 5.10-1). Generally, this can be checked by routing the various storms through the pond and calculating the discharge divided by the critical cross section. The high-flow events (two-, 10- and 100-year events) should also have peak discharge rates less than the predevelopment discharge.

Sediment Storage

Sediment volume should at least conform to applicable MPCA permit requirements. If the pond uses dead storage instead of extended detention as its treatment system design, keeping adequate storage is an important consideration. We recommend that when possible the pond should be built with capacity for about 25 years of storage. As a practical matter, larger particles in the sediment will tend to accumulate near the entrance to the pond. Therefore, more frequent maintenance will probably be needed at the entrance area no matter what the total pond sediment capacity may be. Properly designed inflow areas with easy access can reduce total maintenance costs over the life of the system.

A detailed analysis of pond sediment storage volume may be helpful to determine cost-effective sediment-control plans. Methods, such as the NRCS and universal soil loss equation, can be used to estimate sediment volume from a watershed and, therefore, can be used for sediment storage sizing. To be properly applied, they should be evaluated by professionals on a site-specific basis.

Here is one method of calculating the basic sediment equation and design considerations:

$$\text{Volume} = \frac{E \times DR \times TE \times A \times Y}{217{,}800 \times G}$$

where: *Vol* = design sediment storage capacity,
E = average rate of erosion in the watershed in tons per acre per 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.

Table 5.04-1 compares some benefits and potential problems of using pond designs which use permanent volume below the inlet verses those that use extended detention storage.

Table 5.04-1

Permanent Volume Below the Outlet	Benefits	Potential Problems
Shallow water (<3' deep)	Settling, vegetative filtering and biochemical treatment. Habitat creation can be aesthetically pleasing.	Needs careful design to prevent scour and vegetation die-off. Fall die-off may release trapped nutrients.
Deep Water (3-8' deep)	Reduces scour, provides sediment storage volume, provides retention time for quiescent settling and biochemical removal.	Elevated temperatures may cause depleted oxygen and release of nutrients and metals, potential aesthetics problems.
Extended Detention Volume		
Water quality volume and flow attenuation volume (0 to 3' above normal pool)	Maximizes settling removal. Provides flood control, multiple uses in semi-wet areas. Less permanent loss of upland.	Can be habitat trap due to bounce. Needs plantings adapted to fluctuating levels.

5.05 Pond Design Criteria: EXTENDED DETENTION

DESCRIPTION AND PURPOSE

The extended detention volume of wet detention basins is the volume above the outlet or normal pool elevation, commonly called the bounce. It uses the semi-wet areas above the permanent pool for treatment and includes the water quality treatment volume and flood storage volume (see Figures 5.04-1 and 5.05-1). It is intended to accommodate inflow from small to much larger storms. For storms with a recurrence interval of about one year, the maximum bounce (water elevation increase) above normal pool usually should not exceed 3 ft. The extended detention 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.

Water Quality Treatment Volume

To provide 90% overall removal, a design criterion needs to be established which will provide reasonable treatment given the assumptions about storm events, particle size distribution and settling velocities. To standardize design methods, we have selected an outflow ratio of 5.66 cfs per surface acre of treatment pond. This outflow rate has been selected to provide 90% removal 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 metropolitan area. Note that, in accord with the discussion in part 5.03, the water quality treatment volume is calculated as an instantaneous volume, not an inflow outflow calculation.

The water quality volume required must be at least as large as the applicable MPCA permit requirements, which is 0.5 inch of runoff over the impervious surface (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. However, it is often best to perform a hydrologic analysis of the watershed and design using the greater of these volumes.

Controlling the Two-, 10- and 100-year Events

Urbanization will increase the runoff volume that occurs from each storm event, overloading the natural drainage systems that had adapted themselves to the pre-existing conditions. The frequency of bankfull and over-bank events usually increases with urbanization of the watershed. The stream attempts to enlarge its cross section to reach a new equilibrium with the increased runoff volumes and discharge rates. The erosive force of the increased channel flows can significantly upset the sediment-load equilibrium that has established itself over time, and may result in the stream meandering or forming new channels (Rosgen, 1994). Therefore, stormwater system design needs to consider both rate and volume control.

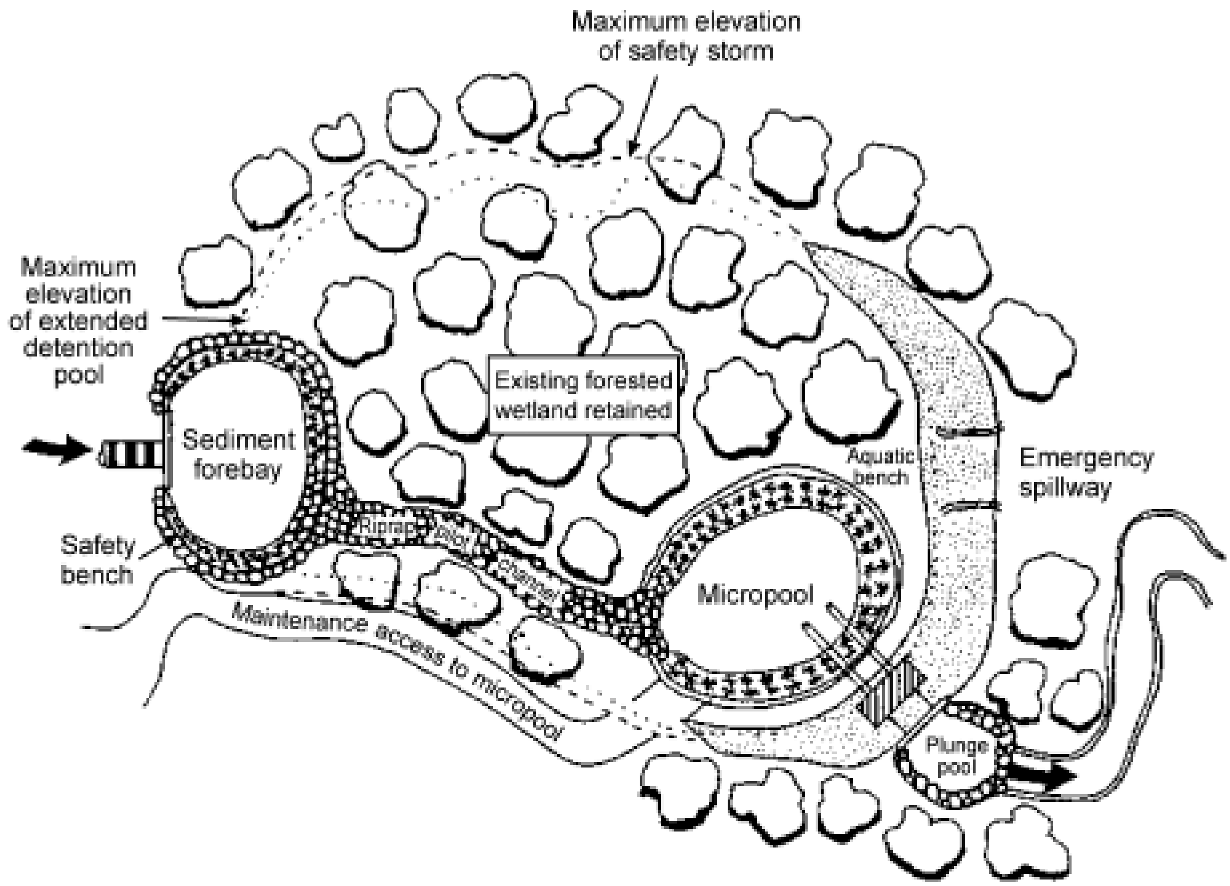


Figure 5.05-1 Extended detention (Schueler, October 1992)

Two-year Event Control

By reading the output from models such as TR20, we see that ponds can reduce peak discharges to less than the predevelopment rate. But ponds do not usually decrease the total volume of runoff. Analysis at most sites clearly shows an increase in runoff volume from predevelopment conditions, even when the peak discharge from developed conditions is held to predevelopment peak discharge rates or less. This is because the duration of discharge is extended proportionately. Since 1.3- to two-year events are approximately bankfull, and bankfull events are usually the most erosive per unit of flow, this increase in duration can significantly increase erosion problems for the downstream watershed, even for small storm events.

As a result of postdevelopment erosion problems, many states, including Maryland and Washington, and some watershed districts have proposed or developed policies on erosive flow controls. Washington has pond rate control policies that restrict postdevelopment flow to one-half the predevelopment flow for the two-year event. Maryland (Schueler, 1998) has proposed recharge volume requirements as well as retention for new development.

The significance of the large flood events should not be underestimated, and needs to be incorporated in the design. But in addition, the cumulative effects of the smaller but more frequent and cumulatively significant events need to be given sufficient consideration for protection of water quality, property and habitat.

Flood Control Goal

Many watersheds require that postdevelopment runoff must equal the runoff from the 10- and 100-year predevelopment events. In addition, low floor elevations of structures are typically required to be at least 0.5 to 3.0 ft 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.

Addition Flow Reductions

Watershed analysis may lead designers to conclude that the downstream system will be better served if we can reduce outflows more than the general guidelines contained here. Discharges to wetlands should be restricted in accordance with the guidance developed by the Storm Water Advisory Group (Minnesota, State of, Storm Water Advisory Group, June 1997). This guidance recommends limiting the change in the hydrologic character of a downstream wetland based on its vegetation types. Total volume reduction should be the preferred option, but adding a relatively small volume of additional storm event storage in upstream basins may be a cost-effective measure to minimize downstream impacts when there is limited capacity in the downstream system.

5.06 Pond Design Criteria: POND OUTLET STRUCTURES

DESCRIPTION AND PURPOSE

Outlet structures control the outflow from the pond, which determines the flow in the pond and determines the treatment capabilities of the facility. They can also provide options for unusual operating conditions, such as drawdown of the structure for maintenance.

Outlet Area

In addition to the inlet and main treatment area, a stilling pool, 3 to 8 ft deep, is recommended as part of the wet pond design. This pool is usually located at the outlet and is sized to reduce outflow velocities to levels that prevent scour and resuspension. The outlet structure should be designed to work in conjunction with the stilling pool.

Outlet Design Options

Outlet or spillway design is crucial for effective stormwater treatment and for controlling flood discharges to downstream drainageways and receiving waters. It also affects the velocities in the pond. The design must allow treatment (90% removal) of the water quality volume, (0.3-year return events) while controlling the two-, 10-, and 100-year event discharges, described in the design summary in Table 5.10-1. The features to be addressed are access, maintenance and flow control.

There are many ways to provide water quality treatment and manage larger flows through the pond and outlet structure(s). Most stormwater-treatment ponds will require multiple outlet spillways to handle the water quality treatment as well as provide conveyance of larger flood flows. Weirs can be designed to provide the required low-flow characteristics and can be combined with overflow channels and overflow weir sections and/or culverts if needed for larger events. Some examples of weir outlet structures are shown below. One can use V-notch weirs, multiple orifices or pipe outlets to accomplish the same objectives. The optimum design should meet both the flood-control and water-quality-treatment objectives.

Outlet Control Structures

Outlet control designs consisting of V-notch weirs, multiple orifices and multiple-stage weirs are described by Pitt (1994a), USDA, SCS, (1988) and others. More information concerning outlet-design methodology can be obtained from the Minnesota Department of Transportation (MnDOT) or consulting engineers familiar with multiple flow-control issues.

Outlet Features

Outlets are usually built into a dike or berm with easy access for maintenance and where structure access is available. A box or manhole outlet structure can accommodate a variety of outlet control mechanisms. A skimming device to remove floatable materials and liquids is a desirable outlet feature. Skimmers should extend about 6 inches below the ordinary pool level, and flow velocity at the skimmer should be reduced to about 1 fps. Outlet trash racks may be needed as final outlet protection and as a safety device. Trash racks should be designed so that debris will be lifted by higher flows. In addition, periodic maintenance will be necessary to remove trash and repair damage caused by natural forces or vandalism.

Box drop structures or manhole access control mechanisms often have accessible control gates equipped with locks. Interior weir control structures, including removable aluminum plates, stop logs and orifice outlets, are also recommended. Drawdown valves can be included if they are used and maintained. If not regularly operated and maintained, these valves often become virtually impossible to operate. Stand pipe outlets are not recommended unless accessible and heavily reinforced to prevent the damage from ice movement (see Figures 5.06-1 through 5.06-3).

Final Design

Once the pond area and outflow rates have been established, the outlet needs to be designed and sized. The sizing of outlet structures is typically a process where iteration refines the design details. A stage discharge curve is usually established for a given outlet design, then a model is run to determine whether the peak outflow for the water quality volume and the two-, 10- and 100-year events is at or below the applicable criteria.

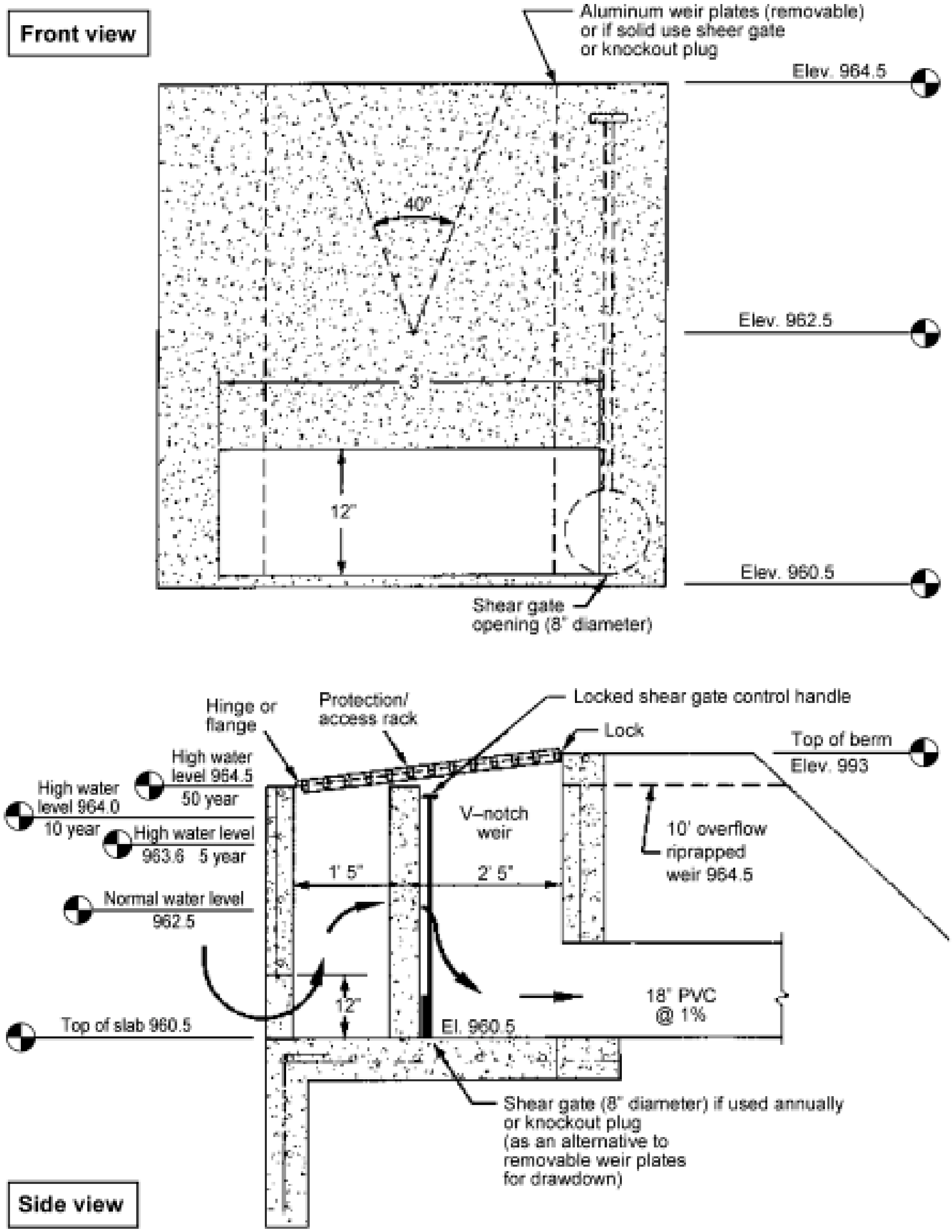


Figure 5.06-1 Schematic of generalized outlet (from Bonestroo, Rosene, Anderlik & Associates)

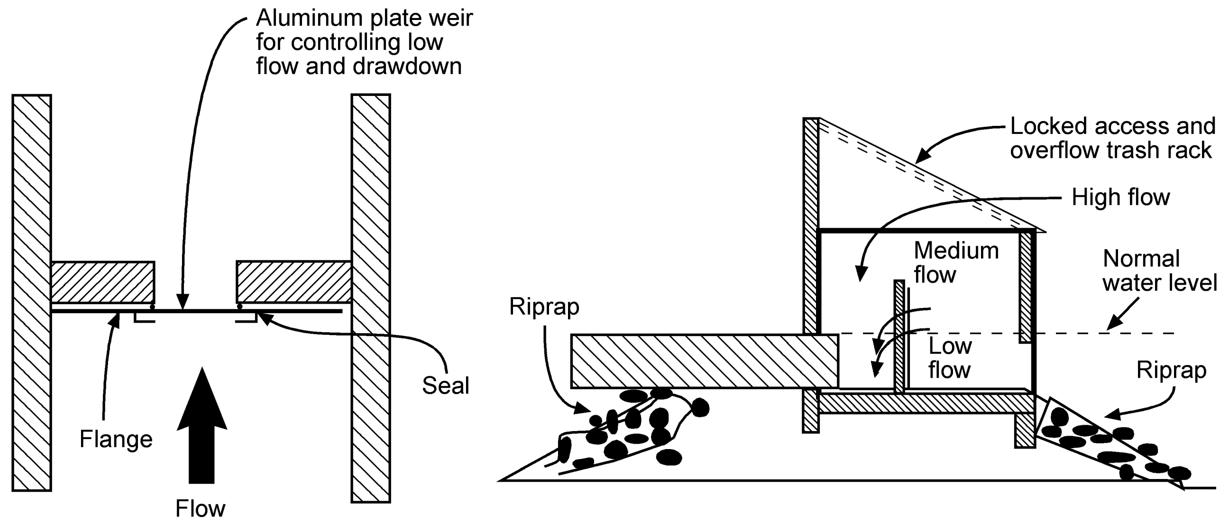


Figure 5.06-2 Cross section and plan of an outlet

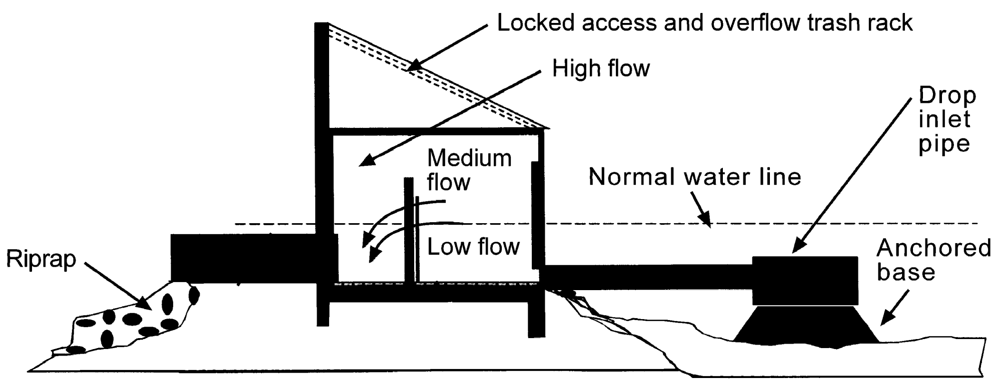


Figure 5.06-3 Cross section of an outlet with a drop inlet pipe

5.07 Pond Design Criteria: OPERATION AND MAINTENANCE

DESIGN AND CONSTRUCTION OF STRUCTURES

All embankments, spillways and other structures for ponds should be constructed in accordance with accepted engineering practice, such as the NRCS Field Office Technical Guide, Standard 378, *Ponds,* (USDA, NRCS, February 1995), whenever applicable. Construction should be in accordance with appropriate construction and material specifications. Dam safety requirements should always be incorporated in the structural design. See section 5.70 for more information.

Fences

Most stormwater ponds do not require fencing and typically pose a safety hazard that is no greater than that of existing lakes and wetlands. This may not be the case when slopes are too steep, pond inlet flow velocities are large, or where an unexpectedly deep pond exists. Most natural water bodies in Minnesota are not fenced, even though they can pose a hazard. Similarly, most constructed ponds are not fenced. In fact, a fence can be a detriment because it may impede escape or rescue efforts. Typical regulatory requirements for ponds include four horizontal feet to one vertical foot (4:1) side slopes, or less, and vegetated benches. Ultimately, liability and decision-making rests with the local government, and decisions must be made on a site-specific basis.

Sediment

Sediment accumulation is usually the primary long-term-maintenance concern. Sediment accumulation may result in loss of pond volume or creation of channels that may cause short-circuiting of flow through the pond. Therefore, access to primary settling areas should be an integral part of any design.

Erosion Control

Permanent and temporary erosion-control measures are typically incorporated into the plans and specifications for a stormwater-treatment pond. Permanent erosion-control features include provision for a vegetative buffer strip around the pond, design of grassed waterways as overflow channels, armoring of spillways and banks, and any other permanent features needed to prevent erosion for the life of the facility.

Temporary erosion controls include items, such as straw bales, silt fence and mulch, that are applied or installed to prevent erosion until vegetation is again established in and adjacent to the new pond. Information regarding erosion control and landscaping is available from the NRCS and MnDOT and from consulting engineers.

If erosion should persist following construction, remedy the situation as soon as possible. Many new and standard treatments are available for this purpose, including application of erosion-control blankets and turf reinforcement mats. (See chapter 6).

Erosion-protection Areas

Pond benches and adjacent upland areas may need to be stabilized following construction of the basin. Typically, a combination of permanent and temporary erosion-control measures are necessary. The desired erosion control, seeding work and other construction-site restoration are typically incorporated in the plans and specifications for the stormwater-treatment pond.

Erosion of banks, spillways, outfalls and channels should be the most immediate concern. These areas should be inspected frequently after construction and on a regular schedule thereafter. If erosion occurs, the eroded areas should be restored as quickly as possible. If erosion persists, the area should be protected with appropriate permanent measures, such as bioengineering measures, turf reinforcement mats, vegetated-concrete-block-armoring or properly sized riprap and filter materials.

Vegetated buffer strips (of about 25 ft) that surround a pond will help to prevent erosion and treat runoff entering the pond from the pond's immediate tributary area. The buffer may also serve as diverse habitat for wildlife, which, incidentally, helps to avoid undesirable monocultures, such as flocks of geese.

Information about landscaping pond sites and erosion control is available from the NRCS, from the Minnesota Department of Natural Resources (MDNR), the MnDOT and other professionals.

Vegetation

Establishment of vegetation on site is a permanent erosion-control feature that helps to maintain the integrity of the pond and its appearance. Any vegetation to be established should be suitable for conditions that exist on site. Literature regarding this subject includes Eggers and Reed, 1997; Dindorf, 1993; Schueler, October 1992; and Henderson *et al.,* 1999. Establishment of a vegetative buffer strip around the pond is strongly encouraged to prevent erosion, provide wildlife habitat, impede human encroachment, and to provide a more aesthetically pleasing facility.

High marsh and **low marsh** vegetation around and in the pond is generally encouraged. It prevents erosion, stabilizes the bottom sediments, and provides physical and biological treatment. Establish appropriate vegetation, chosen to thrive based on frequency and duration of inundation within the treatment system. Use the guidance of Schueler (October 1992) for general design, and information in local literature (Eggers and Reed, 1997; Dindorf, 1993; and Henderson *et al.,* 1999) or other professionals for appropriate local modifications.

Any vegetation to be established on site should be suitable for natural conditions. In many cases, the existing plant species will inhabit the bench area from natural seedbeds and it will be unnecessary to provide other plant material. However, in some cases, landscaping measures, such as wetland soils, plantings and additional contouring, may be desirable or necessary additions to the project.

Vegetative harvesting may be considered for stormwater-treatment ponds to remove nutrients contained in the vegetation. Such ponds should be designed to allow access for harvesting. Proper disposal of cuttings should be required.

5.08 Pond Design Criteria: SPECIAL CONSIDERATIONS

Water-quality Standards

Water-quality standards must be maintained for all waters, even if no specific permit is required for a particular action. The primary requirements are that waters not be degraded by human activity in such a way that the existing beneficial uses of the water are lost.

The generation of new surface-water runoff is not prohibited. The question that needs to be addressed is, does the human activity (usually development of land in urban areas) change the uses or degrade the receiving waters? If water-quality standards are violated, an individual permit or enforcement action may be required to remedy the violation. If unique resources, such as trout streams, ground-water-recharge areas or wetlands exist, they must be adequately addressed in the plan.

Ground-water Pollution

Whereas infiltration through 3 ft of natural soil is usually sufficient to treat most storm water, ground-water contamination is a potential problem where there is a direct path for infiltration, such as highly permeable soils or karst topography. In addition, site-specific sources, such as potential spills or industrial contaminants, having potential for discharging pollutants to ground water, may require additional considerations or involve certain prohibitions. Local governmental units should impose restrictions on wellhead-protection areas. Stormwater discharge to ground water, without adequate treatment, is prohibited by state laws.

Pollutants in Sediments

In addition to the physical sedimentation process, pollutants associated with urban runoff, such as trace metals, will accumulate in sediments. For example, when U.S. Fish and Wildlife Service sampled bottom sediments in the Minnesota Valley Wildlife Refuge below a major stormwater discharge point in the Twin-Cities area, it found lead levels in the sediment exceeded 300 parts per million (ppm). Tissue analysis of bottom-feeding fish showed whole-body lead levels in excess of 3 ppm (U.S. Fish and Wildlife Service, 1988). This indicates probable biological uptake of the metals in fish. The effects of trace metals on waterfowl and plant tissue have also been shown to be harmful at higher levels. Therefore, there is always a concern wherever there is a potential for concentration or bioaccumulation.

Sediment Removal

Pond sediments must be removed and disposed of in accordance with the sediment-disposal guidance (see chapter 7, part 7.28). To date, sediments in stormwater ponds have not been found to exceed hazardous-waste criteria. However, if a stormwater pond is affected by spills, hazardous waste or runoff from industrial areas, then source separation and/or controls, monitoring and other special precautions may be needed.

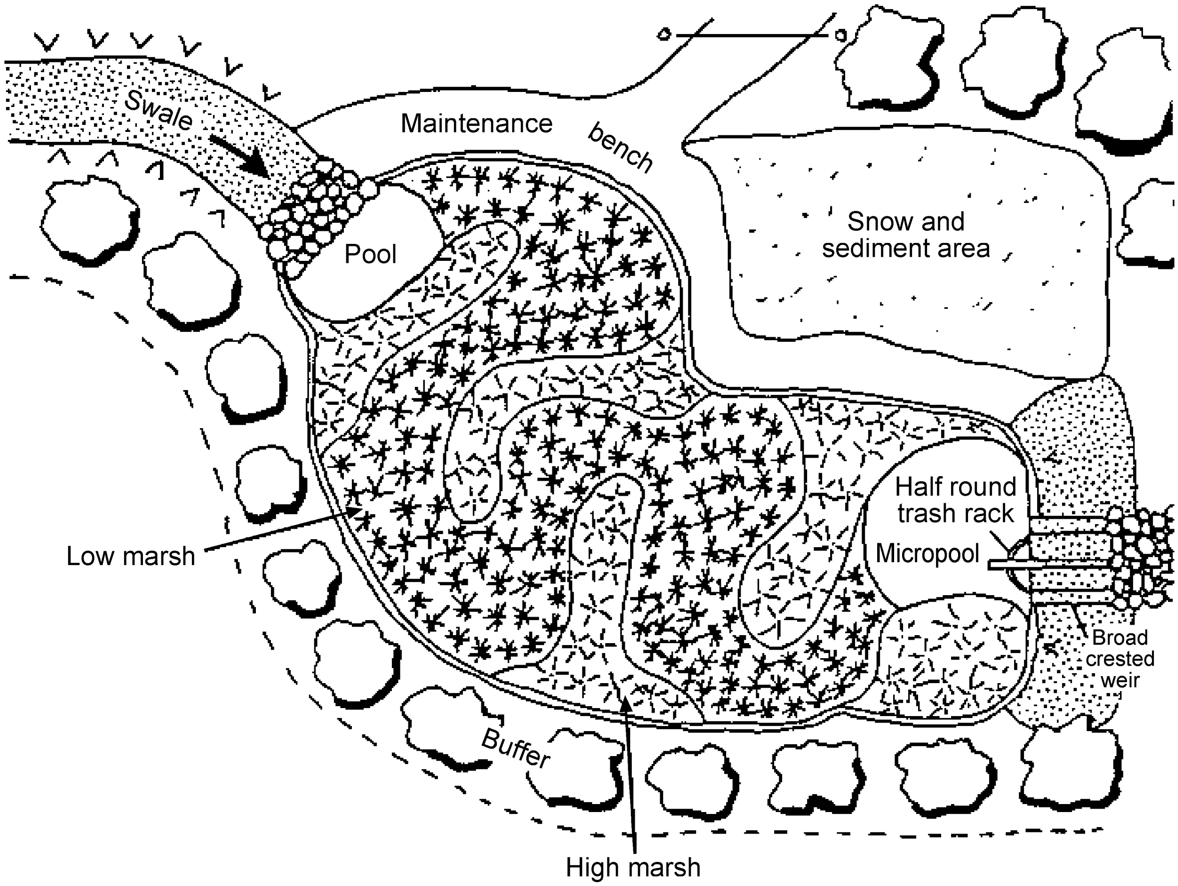


Figure 5.08-1 Examples of desirable pond design features (from Schueler, October 1992)

Permitting Requirements

The design team must investigate the nature and scope of local, state and federal permits and approvals that must be secured. These may include:

- Clean Water Act, Section 402 storm water National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit for significant point source, construction activity or industrial sites (from the MPCA).
- Clean Water Act, Section 404 permit if the treatment system involves the placement of dredged or fill material in waters of the United States, including wetlands, lakes or streams (from the U.S. Army Corps of Engineers).
- Clean Water Act, Section 401 water-quality certification if any federal permit is required (from the MPCA).

- Local or state permits for such things as wetlands, storm water, sediment control, dam safety, waterway disturbance, and forest clearing (from the MDNR, MPCA and local governments).

The design team should objectively assess the "permitability" of the project, and strive to involve key members of the regulatory community early in the planning process.

Dam Safety Requirements

In accordance with state rules, a permit from the Minnesota Department of Natural Resources (MDNR) is required for the construction of any dam or artificial barrier that is over 6 ft high and has a maximum storage capacity over 15 acre ft. The height is measured from the top of the dike or overflow (not the spillway structure) to the downstream toe of the dike. Structures up to 25 ft high and with a storage capacity up to 50 acre ft may be exempt from this permit requirement if it is proven that there is no potential for loss of life due to failure or misoperation.

Wetland Impacts

Wetlands may be impacted by the diversion or discharge of storm water as well as the discharge of fill. The regulatory agencies involved include the MPCA, MDNR, the Corps and local governmental units (LGUs), including those that implement the Wetland Conservation Act. To determine whether a project will impact a wetland, the appropriate regulatory body should be contacted. In addition the guidance, such as *Storm Water and Wetlands: Planning and Evaluation Guidelines for Addressing Potential Impacts of Urban Storm Water and Snow-Melt Runoff on Wetlands* (Minnesota, State of, Storm Water Advisory Group, June 1997), should be consulted.

The wetland vegetation types as well as the hydrologic changes, such as the discharge to the wetland, should be considered. *Storm Water and Wetlands* (Minnesota, State of, June 1997) indicates that sensitive wetlands, such as calcareous fens, should retain their hydrologic regime to avoid impacting the wetland. On the other hand, less-sensitive wetlands can accommodate moderate-to-substantial changes of hydraulic and pollutant loading. At the heart of the planning considerations should be avoiding, minimizing, and mitigating the destruction or changes in wetland values from hydraulic alterations.

Natural Wetlands

Natural wetlands are not recommended for use as treatment systems without pretreatment of urban runoff. Wetlands can be very effective for trapping and treating urban pollutants. However, excessive urban runoff can overload and degrade a natural wetland. The solids in urban runoff are deposited in the wetland, where they may be difficult to remove at a later date. Hydrologic changes in the frequency and duration of inundation can affect any wetland vegetation and wildlife habitat, but some types can be affected significantly more than others. Because of these factors, and the potential damage to wetlands from increased urban runoff, it is strongly recommended that appropriate pretreatment be used. Ponding to remove sediments and nutrients, or ponding, flow splitting and other flow controls to prevent destructive hydrologic changes are some of the recommended measures.

Natural wetlands can serve to "polish" runoff after it has been treated by a BMP, such as a treatment pond. The wetland can provide some additional removal of fine sediment and allow nutrient uptake by plants. Care should be taken to limit the frequency and duration of inundation to levels appropriate to the sensitivity of the vegetation.

Wetland Conversion

The decision-maker should compare the effectiveness of the pond to the effectiveness of the existing wetland system for the treatment of urban runoff. In order to compare these two, the wetland can be monitored to evaluate the removal efficiencies that are currently being obtained. But, several years of monitoring may be required to obtain representative data. An alternative to monitoring involves utilizing available literature and models to provide a range of probable values. If the pond system is modeled, the variability of the model should be recognized. Expected ranges of pond and wetland performance should be analyzed as part of the project-development process.

The variability of flow rate and pollutant loading should also be discussed. The treatment efficiency of natural and constructed treatment systems will vary greatly no matter how well a system is designed.

Generally, it is better to build a treatment pond in an upland area than to alter a natural wetland. Unless unavoidable circumstances can be demonstrated, significant alteration of natural wetlands should be avoided.

Further compensatory mitigation may be required to offset the loss of wetland area values or functions that can be attributed to the conversion of existing wetland to a wetland altered to provide additional treatment for storm water.

Constructed Wetlands

The design of constructed wetlands for treatment is described in Schueler (October 1992). Seven basic design criteria related to volume, area, depth allocation, volume allocation, length, dry- and wet-weather water balance, and extended detention volume are listed. The establishment of proper vegetation is essentially determined by these basic parameters. Care should be taken to adapt the vegetation to local conditions rather than using guidance directly. For example, Schueler's vegetation lists are developed for the Mid-Atlantic Region. Minnesota's vegetation design parameters vary considerably across the state from north to south and from east to west because of climatic differences, such as temperature and hydrology. There are also significant geologic and soil differences from place to place throughout Minnesota; which can significantly affect the acceptability of a particular wetland design.

Local professional sources of information on vegetation and plantings should be consulted for all projects. Helpful sources include the MDNR and MnDOT Environmental Services as well as some of the cited literature, such as Eggers and Reed, 1997; Dindorf, 1994; and Henderson *et al.*, 1999.

Wetland Replacement

Replacement of lost wetlands is necessary to satisfy the federal and state laws, rules and policies of no net loss of wetlands. Created stormwater-management basins are generally not considered to be wetland mitigation. Constructed wetlands, stormwater ponds, and water-quality-treatment ponds may be eligible for water quality replacement credit, provided appropriate design criteria are met. The eligibility and design criteria should be determined by the jurisdictional regulatory agencies, which may vary depending on the location and nature of the project. Be careful that the values of the area to be used as mitigation are not greater than the pond they are suppose to mitigate, which may be the case if a forest or woodland is used to create a wetland-replacement area.

Other Regulations

Any work within, or manipulation of, natural wetlands may be subject to state and/or federal regulations. Contact the MDNR for protected waters permit requirements, or the Board of Water and Soil Resources (BWSR) for the local unit of government delegated to implement the Wetland Conservation Act in a particular area. Contact the U.S. Army Corps of Engineers Regulatory Functions Branch for information on federal regulations and permits.

Design for Small Watersheds

Watersheds under 100 acres in size may require special considerations. The flow from these small watersheds will be less consistent and more variable than that from large watersheds of the same type due to multiple hydrologic inputs and longer times of concentration in the large watersheds. Schueler (October 1992) states that wetland designs require an upland drainage area of at least 25 acres to be fully effective. Some local consultants (Klein, 1996) feel that wet ponds above the ground-water table should not generally be attempted for watershed areas of less than five acres since these ponds may tend to dry down to mud flats during dry periods.

Watershed areas of less than 20 acres may not produce enough runoff annually to maintain a wet pond unless the pond is deep enough to extend beneath the water table. If preliminary hydrologic design computations indicate that the watershed is unable to provide enough runoff to support a wet pond, then other BMPs, such as swales (Claytor, 1996) or modified dry ponds (Klein, 1996), should be evaluated. If the MPCA permit requirements cannot be met, contact the MPCA.

On any small watershed, a careful design process should be undertaken considering the following factors:

- rainfall frequency distribution;
- surface flow volume and other hydrologic conditions;
- ground-water levels and flow patterns;
- regulatory requirements and
- feasible alternatives.

Design for Winter-runoff Conditions

Snowmelt runoff events in Minnesota may convey high concentrations of urban runoff pollutants to stormwater ponds and other receiving waters (Oberts, 1991). Recommendations to manage this potential influx of contaminated snow and ice melt include incorporating extended detention 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 often flows 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 expand the extended-detention capability of the pond. You 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.

Following the recommendations of this chapter, by providing deep inlet and outlet zones or multiple pools, will usually result in designs that are generally robust enough to handle the winter and spring conditions without special considerations. However, runoff volume from 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.

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, plan snow-storage areas that minimize surface-water impacts.

Dry-weather Flows

Dry-weather flows should be sufficient to maintain the nature of the pond. Some considerations include having a watershed which should be large enough (at least 25 acres depending on soil type and rainfall) to sustain a wet, open-water pond. Maintaining permeable surface in the watershed to preserve ground water interflow should also be a priority.

When a wet detention pond is desired, soils on the proposed pond site should have an infiltration rate low enough so that base flow or stormwater runoff can maintain a permanent pool. Many natural soils contain hydrophytic plant propagules, which can be expected to grow in the new system. If these soils are not available, most other soils will allow the establishment of wetland vegetation as long as there is sufficient hydrologic conditions. Contact experts in this field for site-specific evaluation.

5.10 STORMWATER POND SYSTEMS

Table 5.10-1 Treatment system summary design matrix: recommended criteria

Design Parameter	Design Basis	Planning Basis	Design Calculations
Total pond area	Overflow rate and water quality and quantity control volume	0.5-3.0% of watershed, based on ultimate land use runoff	0.5 to 3.0% of watershed, depending on land use
Benches around edge of pond	Vegetated area for erosion and access control	10:1 slope around pond edge (10-ft width desirable)	Bench area = pond perimeter x 10 ft
Pond inlet zone (3- to 8-ft-deep pool)	Prevent scour and control mixing in treatment areas	10-20% of area and volume	Reduce velocities from inlet zone to <1 fps
Pond outlet zone (3- to 8-ft-deep pool)	Prevent scour	Outlet 10-20% of area and volume	Maximum velocity in pond <2 fps (1-yr. storm)
Main treatment zone			
Deep water: (3 to 8 ft) depth treatment area	Maximum quiescent settling and minimize resuspension velocities	20-40% of area 20-70% of volume	Area and volume calculation (for treating 2.5 in runoff volume)
Low marsh (6-18 inch) treatment zone	Emergent vegetation for settling and biological treatment	25-40% of area 30-55% of volume	Area and volume calculation
High marsh (0-6 inch) treatment zone	20% reserved for pond bench; remainder for biotreatment areas	30-80% of area 10-25% of volume	Area and volume calculation
Semi-wet or extended detention (0-3 ft above the outlet) treatment	All in pond fringe and around high areas for multipurpose design	0-50% of area 0-50% of volume	Stage discharge relation, <5.66 cfs per acre of pond for water quality volume
0.3-yr., 1.25-inch event* (instant runoff volume)	Water quality volume	Quantity out ÷ pond surface area in acres < 5.66 cfs	Outflow rate
1-yr., 2.4-inch event*	Scour prevention	Maximum velocity in treatment area ≤ 1 fps	Q out/area of critical cross section
2-yr., 2.8-inch event*	Scour prevention	” ≤ 3 fps	”
10-yr., 4.0-inch event*	Scour prevention	” ≤ 5 fps	”
100-yr, 6.0-inch event*	Scour prevention	” ≤ 5 fps	”
Discharges to erodible channels or streams (postdevelopment)	Erosion and flood control	One-half the 2-yr. and same as the 10- and 100-yr. predevelopment rates	Pre-existing runoff vs. pond discharge at full development
Discharges to wetlands	Wetland vegetation type	Bounce and duration for vegetation type	Follow wetland guidance
* 24-hour NRCS distribution events.			

5.11 Pond Systems: ON-SITE VERSUS REGIONAL PONDS

On-site detention uses structures to detain runoff on the development site. These types of structures often integrate parking lot, rooftop and cistern storage; dry or wet detention ponds; infiltration basins and infiltration trenches.

On-site structures are generally satisfactory for reducing peak discharges for a certain distance downstream of the site. Infiltration structures are also capable of reducing runoff volumes. However, random placement of on-site detention facilities for stormwater detention can actually increase flooding downstream (Pitt, 1998). When this is a potential problem, a peak-flow timing analysis of the watershed should be performed as part of the pond design planning process.

From a water-quality standpoint, the benefit of these structures can vary widely. As previously mentioned, the effectiveness of dry or wet detention areas depends upon their design. Infiltration basins or trenches can be very effective for reducing pollutant loadings to surface water from a site. However, these must be carefully designed and maintained to prevent contamination of ground water and to ensure that they continue to function.

Maintenance is a major drawback to the use of on-site facilities for trapping pollutants. Regular maintenance is critical to the continued performance of most structures for pollutant removal. The large-scale use of on-site facilities can result in hundreds of these structures in an area, with individual landowners responsible for maintenance. This results in a maintenance workload that can be difficult to manage.

Regional detention ponds with larger drainage areas are generally more cost effective than on-site basins. Regional detention ponds have several other advantages. One is that regional detention ponds can sometimes provide cost-effective control for already developed areas as well as for new development. This is an important consideration when nonpoint-source pollution from previously developed areas must be controlled to meet water-quality goals. In many cases, on-site detention in previously developed areas would be prohibitively expensive. Studies have concluded that random placement of detention facilities in a watershed may have little effect on overall peak flows and can actually increase downstream problems (Pitt, 1998). Because of this, on-site basins may not reduce peak flows enough to control flooding and streambank erosion.

Regional ponds have some disadvantages. One is that regional ponds may leave some areas unprotected if treatment is not provided between the development and the waterway. The drainage area of regional ponds should be small enough to minimize unprotected areas, but large enough to allow cost savings and meet overall stormwater-management goals.

Another disadvantage to regional ponds is that site constraints may limit the area available to construct a properly sized pond. Available land area may be limited or there may be wetlands or other resources at the site that would be impacted. Often in developed or rapidly developing areas, the only remaining undeveloped areas that have possible sites for effective water-quality treatment are the low areas, such as wetlands, or areas adjacent to them.

5.12 Pond Systems: ON-LINE VERSUS OFF-LINE PONDS

On-line (On-channel) Storage

On-line or on-channel storage involves constructing an embankment, widening the channel or other means to hold water in a swale, valley or similar area. This allows a detention facility to control runoff from an entire drainage area. When properly designed, these structures can be some of the more effective practices available for trapping pollutants from urban areas as well as for flood control.

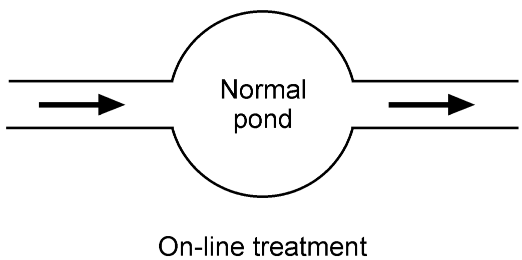


Figure 5.12-1 A normal pond in a drainage system

The primary process involved in pollutant removal with on-channel storage is settling of solid particles. However, detention ponds can also be designed to take advantage of biological uptake to remove dissolved nutrients. The design considerations and effectiveness of on-channel detention for pollutant removal is discussed in the extended-detention basin and detention pond practices.

On-channel storage can also be effective for flood control. In many areas, flood control is subject to regulation of the local watershed district or water-management organization. Local needs for flood control can vary widely, depending upon drainage conditions. In many cases, regional detention facilities are most effective for overall flood control and are also the most economical form of detention for water-quality treatment. To minimize the amount of unprotected area and maximize the economies of scale, the drainage area of a regional facility should be on the order of several hundred acres (Hartigan, 1986). Larger structures may require a dam safety permit, but all structures should be designed with safety in mind since they can create downstream hazards because of the impounded water. This is especially important in a densely populated urban area.

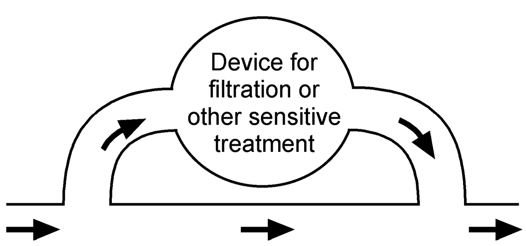


Figure 5.12-2 Off-line treatment with return flow

Stormwater-detention areas that receive flow that is diverted into them are referred to as “off-channel storage.” These structures can only treat flows that are diverted to them; flows that are bypassed typically receive minimal water-quality treatment. Off-line treatment can also be used to reduce peak discharges to downstream areas.

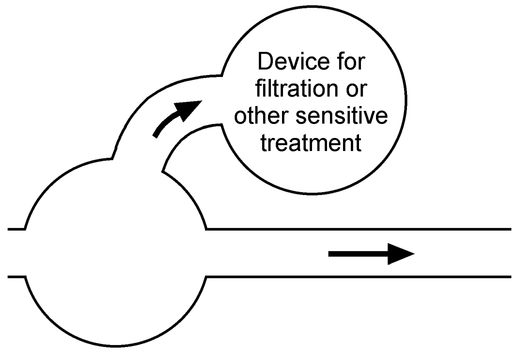


Figure 5.12-3 Off-line treatment without return flow

Although off-channel storage can reduce peak flows and trap pollutants, the two uses are not totally compatible. For pollutant removal, the best use of the storage is to treat all flow from small, frequent runoff events. However, treating small events may use up all or much of the off-channel storage volume before peak discharges from a large storm arrive.

To maximize peak-flow reductions, an off-channel storage facility is often designed to bypass low flows. During high flows, a portion of the discharge is diverted into the storage area, thus reducing peak flows. The problem with this is that runoff from small events is not treated. Unfortunately, these small runoff events deliver a majority of the annual runoff volume (Pitt, 1998).

Figure 5.12-3 provides one solution for the water-quality aspects of this problem. An on-line pond can provide pretreatment and divert low-flow events for further treatment, such as infiltration. This can be highly effective for low flows, while treating high flows to a lesser degree.

5.13 Pond Systems: OTHER POND SYSTEMS

Other pond systems can be used, but each has advantages and disadvantages for a given purpose and situation.

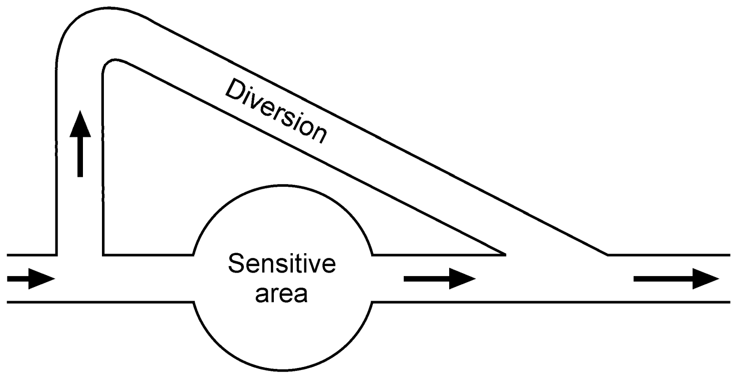


Figure 5.13-1 Use a diversion around a wetland or other sensitive area.

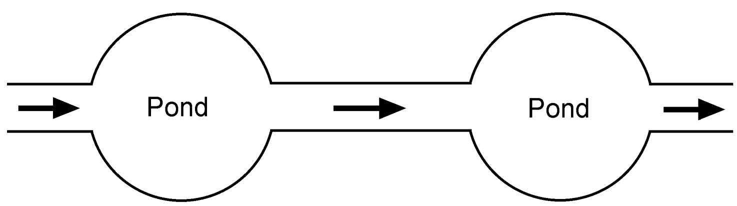


Figure 5.13-2 A series of ponds can provide more efficient treatment of storm water.

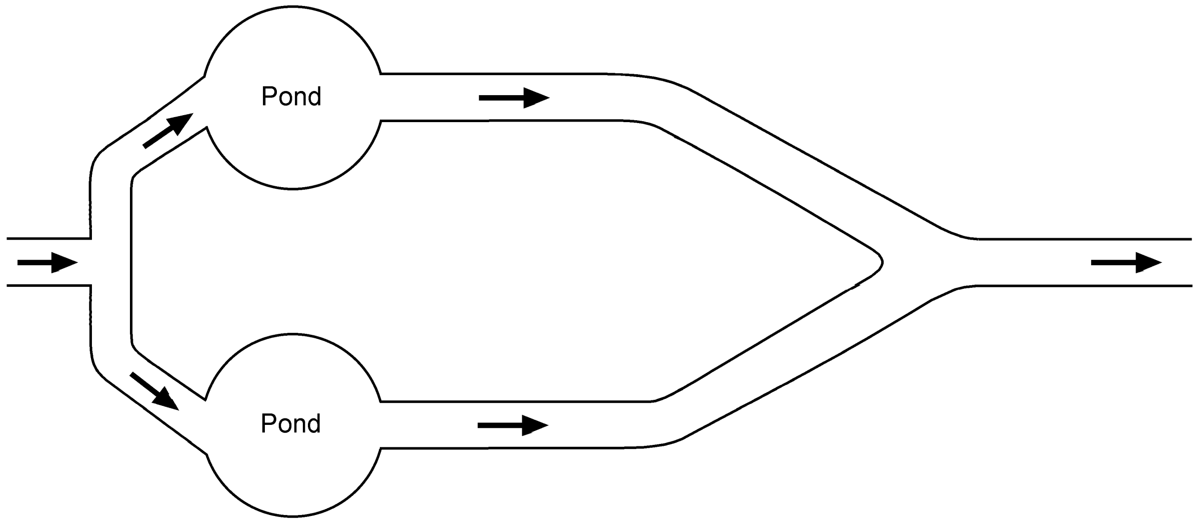


Figure 5.13-3 Parallel ponds allow continued treatment of storm water during pond maintenance.

5.20 Ponds: EXTENDED-DETENTION PONDS

DESCRIPTION AND PURPOSE

Across the country, terms such as "retention" and "detention" have variable and inconsistent meanings (Walesh, 1989). In this manual, extended-detention basins are stormwater basins that are designed to temporarily hold storm water for an extended time, which varies with the stormwater-runoff volume. Extended detention 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. Figures 5.05-1 and 5.20-2 show how the features of extended detention can be incorporated in very different types of ponds.

All ponds have some aspects of detention, but in this manual, "extended detention" describes ponds that are not just flood-control measures, but are designed to use this detention time as their primary method to allow the physical settling of pollutants.

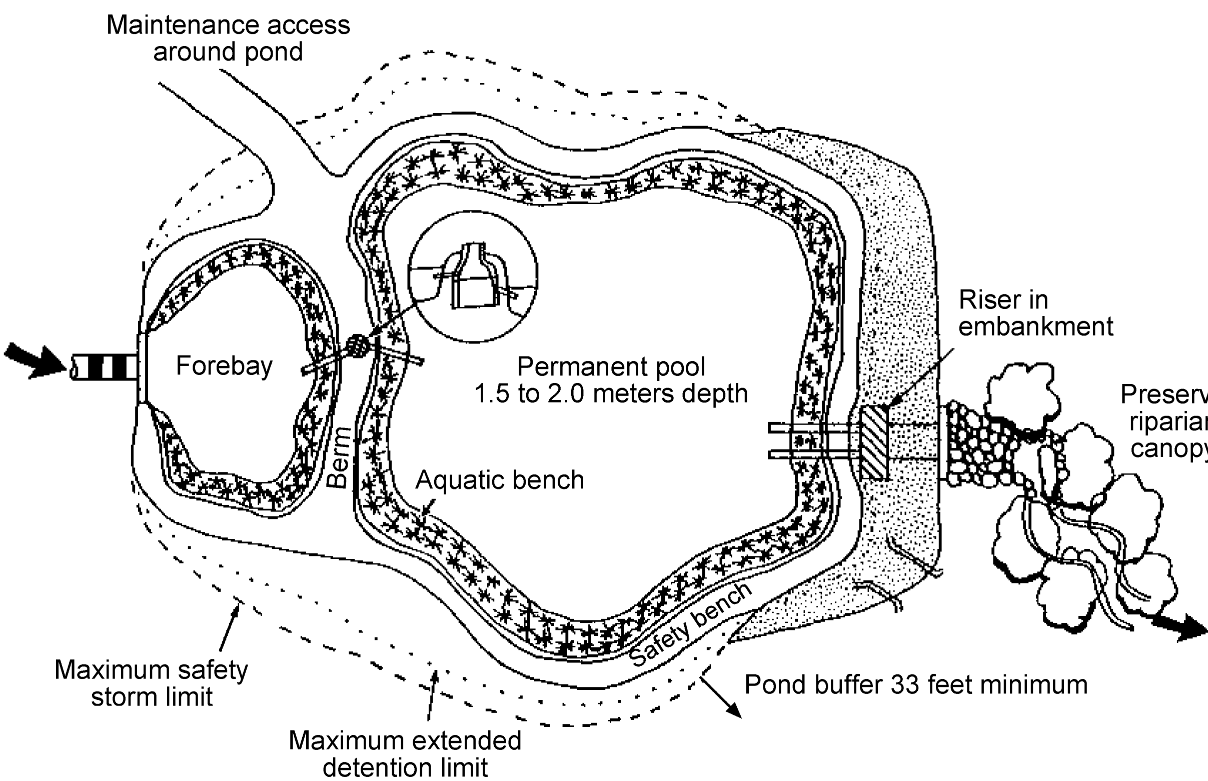


Figure 5.20-1 Schematic of an enhanced wet extended-detention pond (source: Schueler, October 1992)

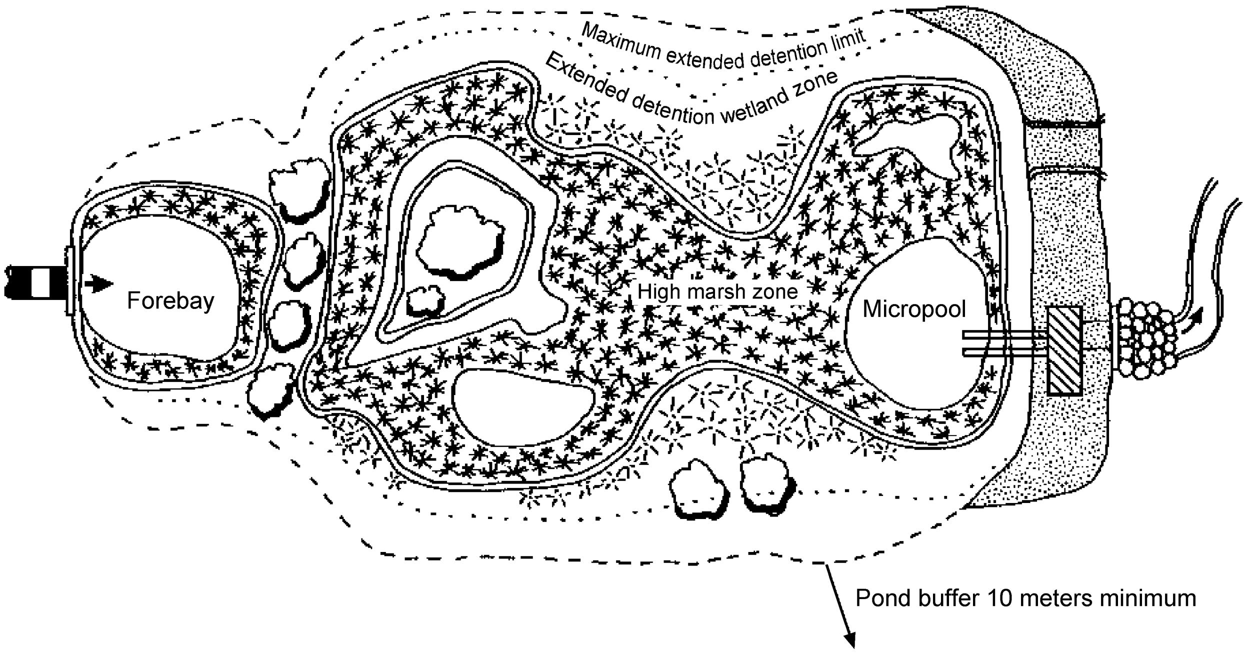


Figure 5.20-2 An extended-detention wetland (source: Schueler, October 1992)

Extended-detention ponds are effective for removing particulate pollutants from urban runoff as well as reducing peak discharges. In many instances, dry ponds designed as flood-control structures can be modified to meet the criteria of an extended-detention pond for a relatively low initial cost but generally increased maintenance costs.

TARGET POLLUTANTS

Sediment and the associated pollutants, such as trace metals and nutrients, are the pollutants most effectively controlled by extended-detention basins. If the 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. Extended-detention basins are also some of the best facilities for treating spring and winter runoff, because of how ice conditions effect the flows. Ponds without extended detention have minimal storage above the ice surface; therefore, treatment is often bypassed. In addition, extended-detention basins are very effective for controlling peak discharges, an important factor in reducing downstream streambank erosion and sediment loads.

EFFECTIVENESS

Extended-detention basins can be fairly effective for removing particulate pollutants from urban runoff. The efficiency of an extended-detention basin depends largely upon the surface overflow rate (Barfield *et al.*, 1986).

The primary treatment process for most basins is that of settling. Pollutants attached to sediment particles exhibit settling characteristics similar to those of sediment. Lead, for example, has a strong affinity for sediment and its removal curve is very similar to that of sediment. Zinc, on the other hand, has a substantial portion of its load in the soluble form. Almost all of the zinc that is removed by extended detention is the portion that is attached to sediment.

Phosphorus acts similarly to zinc in that slightly less than half of the phosphorus is dissolved and is not removed through sedimentation. Nitrogen has an even lower removal rate because of the high percentage that is typically in a soluble form. If additional removal of nutrients is desired, several alternative designs can be used. For example, the permanent pool of the extended-detention pond can be designed and managed as a wetland treatment system or deep pond. Biological and chemical transformations in the pool and wetland can provide some removal of soluble nutrients between events. The permanent pool of water in the marsh will also provide a much higher removal efficiency of suspended solids for very small runoff events by providing a relatively long residence time between storms for settling.

PLANNING CONSIDERATIONS

Extended detention is a practical way to derive water-quality benefits from dry stormwater-detention basins that were originally designed and constructed for flood control only. In many cases, the outlet structures of these dry basins can be modified to detain runoff from small storms long enough to remove many pollutants.

When designing new facilities, extended detention is a possible alternative when a limited permanent pool of water is desired because of site constraints or because of concerns, such as the warming of sensitive trout streams. The temporarily flooded areas of extended-detention basins may be suitable for some recreational activities if they are maintained in a normally dry condition.

The lower stage of extended-detention ponds can be designed to be managed in one of several ways. The lower stage can either be normally dry (Figure 5.05-1), have a permanent pool of water (Figure 5.20-1) or have a shallow marsh established in it (Figure 5.20-2). Those with a shallow marsh or permanent pool of water typically will be more effective for pollutant removal than those that are normally dry. This is because they will provide sediment storage and allow quiescent settling to occur.

Detention time is widely used, but problems are encountered in defining detention time in the case of intermittent stormwater flows. It is essentially impossible to define a detention time for stormwater flows (USEPA, 1983, NURP, Vol. II, 1982). Overflow rate which is equivalent to outflow rate, is the design parameter recommended for extended-detention-pond design (Barfield *et al.*, 1986).

When designing an extended-detention 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.

DESIGN CONSIDERATIONS

The minimum recommended water quality volume for extended detention 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. Other regulatory programs often require treatment of the “first flush” runoff volume. First flush treatment is an often-used concept for water quality volume. In some urban areas, the water quality volume is often considered as 0.5 inch of runoff for all impervious areas in the watershed. If you are required to meet other regulatory requirements, we recommend calculating both the 1.25-inch and other regulatory volumes, then using the larger measure for the water quality volume in your design.

Outflow Rate

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. The outlet device can then be designed to provide the desired outflow rate of 5.66 cfs per acre of pond surface area for the water quality volume (Pitt, 1994a and 1998) and appropriate rates for the two-, 10- and 100-year events.

For extended-detention basins, a multiple-stage outlet design is usually needed to provide extended detention of small (less than two-year event) storms while allowing a higher discharge rate for larger storms passing through the basin. This keeps the storage volume down to a reasonable level.

Outlet Device

The outlet device of an extended detention pond must be effective at controlling the outflow rate while also being protected from clogging.

The type of outlet device used will depend upon factors, such as the type of principal spillway, pond configuration and extended detention outflow rate. For very low outflow rates, internal orifices or subsurface drains may provide adequate control of the outflow rate. However, on structures with larger drainage areas, orifices that can pass a substantial flow may be required.

Sediment Storage

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 frequent basis, the sediment storage volume in the basin may be reduced. A common maintenance cycle would be about five years.

Pond Shape

The pond shape should be selected keeping several considerations in mind. First of all, the pond should be designed in such a way that turbulence in the main treatment area is minimized. Forebays are the most commonly recommended method of turbulence reduction. 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.

Second, the inlet and outlet should be positioned in such a way that short-circuiting in the basin is minimized. Pond geometry that reduces short-circuiting is discussed part 5.02, *Pond Layout and Size*.

Third, the slopes in the basin should be flat enough that they are relatively easy to maintain. Slopes of 4:1 (horizontal:vertical) or flatter are recommended. In some cases, slopes flatter than 4:1 may be required because of soil-mechanics considerations. Accessible slopes leading into the basin should not be steeper than 3:1.

Low-flow Channels

Low-flow channels provide additional detention and longer travel time to the outlet. The channel should not be extended near the outlet device. If the low-flow channel is allowed to extend to the outlet device, pollutants will be delivered directly to the outlet, and previously settled material then can be resuspended. A micropool is recommended at all outlets (Schueler, 1992).

STRUCTURAL DESIGN AND CONSTRUCTION

Any embankment, principal spillway or emergency spillway constructed in conjunction with an extended-detention basin should meet the criteria of NRCS Standard 378, *Ponds*, (NRCS, February 1995), wherever applicable. MDNR Dam safety program requirements must be complied with.

MAINTENANCE

There are considerations that can be used in extended-detention-basin design that will help reduce operation and maintenance costs. Some of these may not increase construction costs significantly, but can make maintenance easier.

1. Keep all slopes 4:1 or flatter whenever possible for safety and so that vegetation can be maintained easily.
2. All extended-detention outlet devices should be protected from clogging. All devices should have above-ground access for cleanout, should this be necessary.
3. Vehicle access to the pond at least 10 ft wide and no steeper than 15% should be provided. The planned maintenance access should never include travel on an emergency spillway unless the spillway has been designed for vehicles.
4. On-site sediment-disposal sites should be provided whenever possible. The cost of sediment cleanout increases drastically when sediment must be disposed of off site.

5.30 Ponds: DEAD STORAGE OR QUIESCENT PONDS

Most ponds have some dead storage. In this manual, dead storage, or quiescent, ponds are ponds designed to primarily treat runoff in the storage area between events by inter-event settling and biological and chemical activity. They provide control of dissolved contaminants, such as phosphorus, as well as treatment of suspended particulates.

PLANNING CONSIDERATIONS

One of the main contaminants of concern for discharge to lakes is phosphorus. Suspended solids are highly correlated with other contaminants, but phosphorus usually has a sediment-related component and a dissolved component. Although most pond designs remove some phosphorus when they remove total suspended solids, the quiescent settling pond has been designed with additional phosphorus removal as its primary objective.

Dead storage or quiescent treatment ponds are often the largest pond designs. They have often been constructed with little consideration of temperature and aesthetics problems.

This type of pond often appears to be an easy fix because once treatment volume is selected, there is no need for additional calculation of outflow rate and bounce. However, failure to address these issues may lead to loss of vegetation or downstream flow-control problems. Dead storage ponds can be adapted to serve multiple purposes quite well, but this often requires additional design information.

DESIGN RECOMMENDATIONS

The size of this pond design can vary considerably, depending on the watershed size, soil types, amount of impervious surface and other factors.

Pool Volume

Quiescent ponds require a design ponding capacity, based on the characteristics of the local storm events and the variability of the period between storms. The most frequently used treatment volume is the watershed runoff from the one-year storm event (2.0- to 2.4-inch event in 24 hours), plus a volume for sediment control. Treatment is assumed to be accomplished by settling and biochemical activity during quiescent settling periods. Plug flow is desirable but less important to this design consideration.

For the one-year, 24-hour event, the permanent pool should be equal to or greater than the design runoff for fully developed watershed conditions. Use accepted hydrologic analysis methods to determine the volume of runoff. The volume used to size the pond is a total runoff volume, not an inflow outflow analysis. In most of Minnesota, this volume will provide an average hydraulic

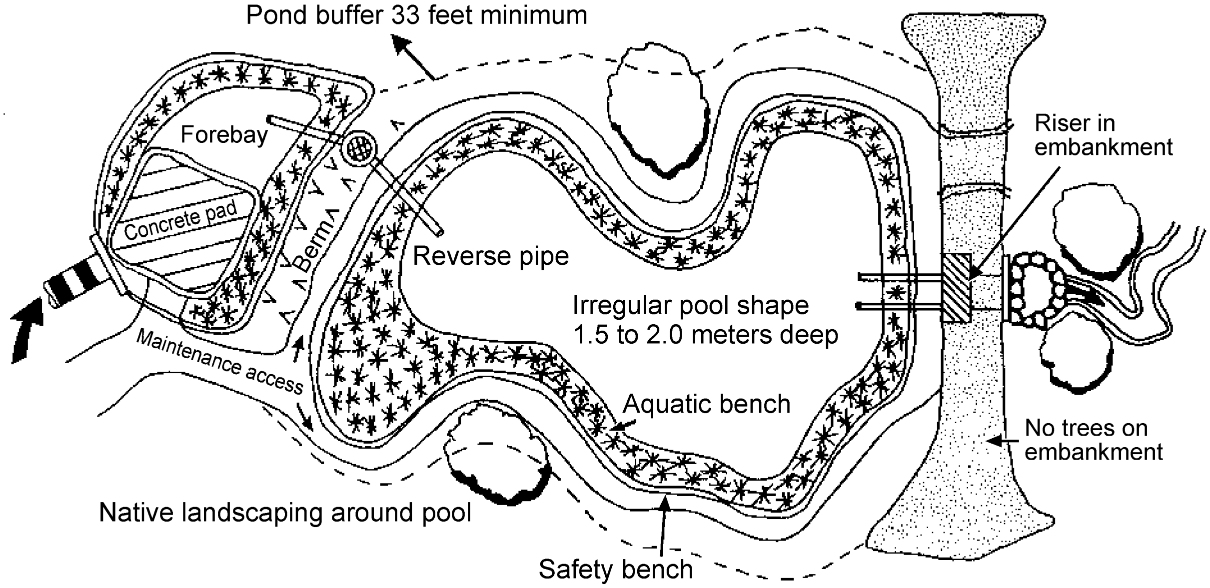


Figure 5.30-1 Schematic of a dead-storage or quiescent pond (source: Schueler, October 1992)

residence time in the pond of approximately 15 days for summer months. Sediment storage must be added to this volume to compute the total pond volume.

Pond Depth

Once the treatment volume has been determined, the size of the pond is calculated by restricting the depth or surface area and then calculating other dimensions. The depth of the pond is usually restricted to 3 to 8 ft. Settling during events is not a design consideration, but resuspension is still a major concern. Flow dissipation and pond configuration should be carefully designed, especially for high-flow events, to prevent short-circuiting and resuspension.

The maximum depth should usually be 3 to 8 ft. If shallower depths are used, and little or no flow dissipation is used in the basin, fine sediments may be resuspended by flow or wind-generated currents. If depths of greater than 8 ft are used, the pond may be subject to temporary thermal stratification. This may result in releases of phosphorus from the anoxic or nearly anoxic bottom sediments. The phosphorus quantities may then be mixed back into the upper layer of the pond by flow or wind-generated currents. This mixing is referred to as “internal loading.”

Pond Shape

“Plug flow” conditions are desirable in a wet pond to enhance water-quality benefits. In an ideal plug-flow situation, the pond volume would be totally displaced before new runoff is discharged from the basin. This ideal condition will not occur, but the pond should be designed to encourage it as much as possible.

The most common shape of pond to promote plug flow is one that has a length-to-width ratio of 3:1 or more. This ratio may not be practical in some situations where site restrictions determine the pond shape. In some cases, energy dissipaters, inlet flow diffusers, baffles or flow directional berms can be used to prevent short-circuiting in ponds with small length-to-width ratios as described in "Minnesota Technical Release 8 (TR8)," (USDA, NRCS, 1988). Other ways to increase plug-flow characteristics are to construct variable bottom depths (Schueler, October 1992) or use two or more ponds in series that have a total volume equal to or more than the required treatment volumes and areas.

Outlet Controls

The quiescent pond design does not specify the outfall structure to be utilized nor does it control the rate of discharge. The design engineers can utilize other applicable criteria, including particle size, average time between events, or flood routing and erosion control for the outlet design criteria.

5.40 Ponds: WETLAND TREATMENT

DESCRIPTION AND PURPOSE

Wetland ponds are simply extended detention treatment ponds with vegetation-enhanced features. These ponds usually utilize active settling and other design concepts described above, but they require additional measures to protect vegetation (Schueler, 1992). They may also be designed to provide mitigation of impacts as described in the Minnesota Wetland Conservation Act.

Wetland treatment involves passing a carefully controlled volume of runoff through a natural or constructed wetland to remove or treat pollutants. Wetlands provide favorable conditions for removal of pollutants from urban runoff. Sedimentation and an intense pool of biological activity may help to remove nutrients during the growing season. Although wetlands are effective for removing pollutants, care must be taken in the design and operation of wetland treatment systems (see Figure 5.40-1).

TARGET POLLUTANTS

Wetland treatment can be very effective for removing sediment and pollutants associated with it (such as trace metals, nutrients and hydrocarbons), oxygen-demanding substances and bacteria from urban runoff. Wetlands can also be effective during the growing season for removal of dissolved nutrients as well as those adsorbed to sediment.

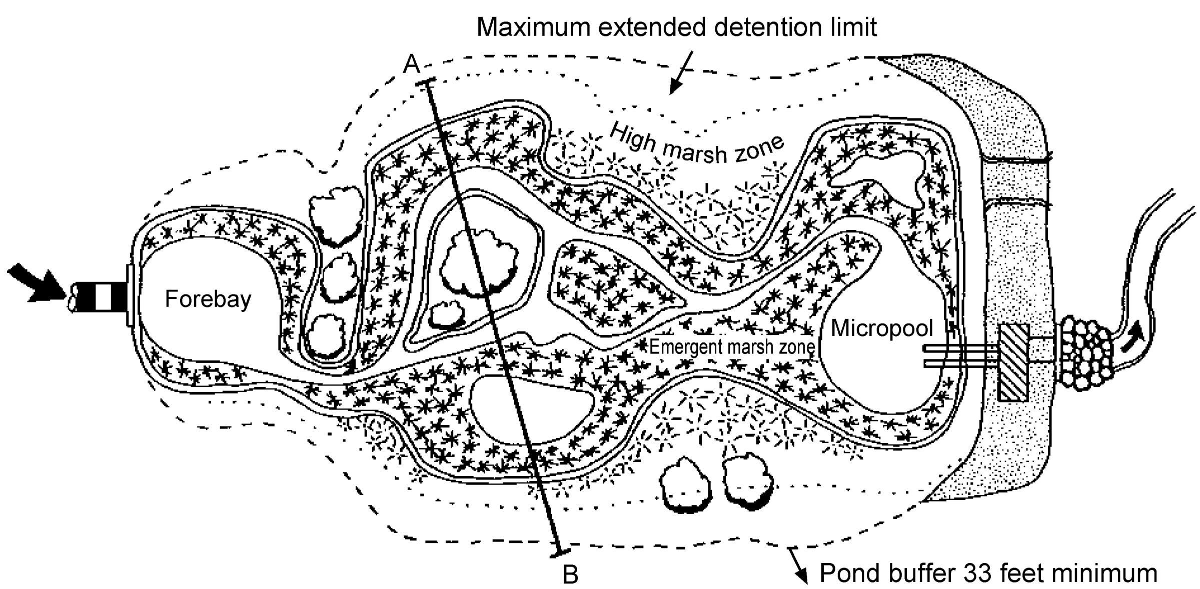


Figure 5.40-1 Schematic of a shallow marsh system (source: Schueler, October 1992)

EFFECTIVENESS

The effectiveness of wetland treatment systems for the removal of urban pollutants will depend upon 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. Natural wetlands have often been altered by increased sediment and hydraulic loading. These wetlands often establish distinct channels and provide very little treatment. Outlet controls and flow-dispersion measures can reestablish treatment, but it must be done carefully so that the nature of the wetland is not destroyed.

Hickok *et al.* (1977) studied a wetland in Wayzata, Minnesota, with a drainage area of 72 acres and wetland area of 7.5 acres. The wetland in that study retained 78% of all phosphorus and 94% of all suspended solids entering it during the evaluation period. The effectiveness of wetlands for removing nutrients depends heavily upon the season. During the summer, when biological activity is maximized, nutrient uptake will be the greatest (Nichols, 1983; Brown, A.G.,1985). Phosphorus may release in fall die-off of vegetation.

PLANNING CONSIDERATIONS

Although wetlands are effective for removing pollutants, some drawbacks limit their use as a BMP. In response to the physical sedimentation process, pollutants associated with urban runoff, such as trace metals, will accumulate in the wetland sediment. Biological uptake of bioaccumulative materials by bottom-dwelling and -feeding organisms is a concern.

Any work within, or manipulation of, natural wetlands may be subject to state and/or federal regulations. Contact the MDNR or BWSR for the local unit of government delegated to regulate the Wetland Conservation Act in your area. Contact the Corps of Engineers Regulatory Branch at (651) 220-0375 for information on federal regulations and permits.

DESIGN RECOMMENDATIONS

Wetlands should have standard design features that take into consideration wetland size, bed and shoreline diversity, soils, wetland vegetation, wetland treatment and outlet designs.

Wetland Size

The Metropolitan Council of Governments (Schueler, October 1992) has developed guidelines for constructing wetland stormwater basins. Those guidelines recommend a wetland surface area of 1 to 2% of the watershed area, depending on the nature of the watershed and the design of the facility. Pitt's (1996) pond-design recommendations of 0.6 to 3.0% of the watershed can also be used as a guide for wetland design.

It is often difficult to create a wetland with a drainage area less than 25 acres, unless the wetland is near the natural water table. For watersheds of less than 25 acres, there is simply not enough runoff to support hydric soil and vegetation.

Bed and Shoreline Diversity

Aquatic benches for safety and erosion control should be about 3 to 10 ft wide with 10:1 slopes. When area is available, 10 ft is the recommended width.

Sediment forebay at the inlet just upstream to the wetland should be 4 to 8 ft deep, with access for cleaning.

Establish habitat for a variety of plant types. Bed and shoreline diversity establishes a more robust system of plants, able to adapt to variable hydrologic conditions. A healthy wetland may have dozens of wetland plant types.

A micropool should be established at the outlet to prevent resuspension of fine sediments and clogging.

Wetland outlets should be designed according to recommended design practices for ponds, with special measures to allow drawdown for wetland management.

Soils

Soils at the proposed wetland site should have an infiltration rate low enough so that base flow or stormwater runoff can maintain a saturated soil or, if desired, a permanent pond. If readily available, natural wetland soils should be used for the bottom of the constructed wetland. Wetland soils usually contain hydrophytic plant propagules, which can be expected to grow in the new wetland. If these soils are not available, most other organic soils will allow the establishment of wetland vegetation as long as hydrologic conditions are adequate. An organic soil depth minimum of 4 inches is recommended.

Wetland Vegetation

A constructed wetland can be vegetated by spreading wetland soils in the pool area. These soils will generally contain a large number of wetland plant propagules that can be expected to become established in the new wetland.

In some situations, wetland vegetation may need to be planted. This can be done by gathering planting stock from local wetlands or purchasing it from suppliers of these materials. It is best to use the expertise of professionals who can choose the appropriate plants for the specific wetland (See Dindorf, 1993; Schueler, 1992; and Henderson *et al.*, 1999).

Wetland Treatment

The design criteria for wetlands are the same as those for active settling ponds. Wetland ponds 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. The outlet in wetland treatment areas is not specified in this manual because discharge requirements should be somewhat flexible. However, standard extended-detention-basin design should be used for wetland outlets.

There is basis (Walker, 1990) for assuming that wetland treatment can provide more effective solids removal for an equal treatment area due to:

- laminar settling in zero-velocity zones created by plant stems,
- the anchoring of sediments by root structure, helping to prevent scour in shallow areas,
- increased biological activity removing dissolved nutrients, and
- increased biological floc formation.

However, these parameters must be considered on a site-specific basis.

Two major problems with wetland treatment are the release of nutrients in the fall and the need to maintain vegetation under a variety of flow conditions. The potential damage to wetland vegetation from changes in hydraulic and pollutant levels should be carefully analyzed. Pondscaping design from Schueler (October 1992) can be used, but it should be modified for local conditions. When using wetlands as part of the treatment system, the wetland guidance *Storm Water and Wetlands: Planning and Evaluation Guidelines for Addressing Potential Impacts of Urban Storm Water and Snowmelt Runoff on Wetlands* (Minnesota, State of; June 1997) can also be consulted along with local experts and experienced professionals.

Outlet Design

Extended detention design criteria (parts 5.05 and 5.20) are strongly recommended for the outlet structure design. 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. See part 5.06 on outlet design for more information on outlet devices.

MAINTENANCE

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.

Sediment accumulation will be a major maintenance concern in shallow wetlands. Sediment accumulation could result in a loss of ponded area in the wetland or creation of channels that will cause short-circuiting of runoff through the wetland.

One way to avoid this is to provide one or more forebays in the wetland. The forebay pool should be located for easy access so that sediment can be removed regularly, before it threatens the wetland treatment efficiency. The pool can be deepened to extend the temporary storage volume, but when storage volume is reduced to the minimum that is acceptable, the forebay should be dewatered and the sediment removed.

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).

5.50 Ponds: MODIFIED DRY PONDS

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-detention 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 (Figure 5.50-1), weirs or other energy-dissipation and flow-spreading devices (Figure 5.50-2) constructed as part of the pond (Klein, December 1996). 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. This usually increases maintenance cost of the project, and may significantly affect the initial costs as well. Proposed treatment systems of this nature should have long-term maintenance commitments and an established source of income to assure proper implementation.

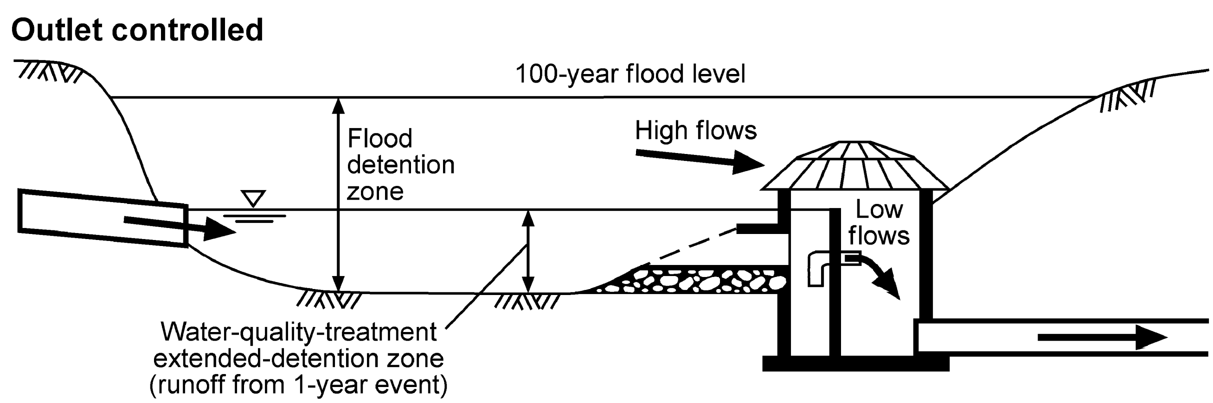


Figure 5.50-1 Dry pond: outlet control (source: Klein, December 1996)

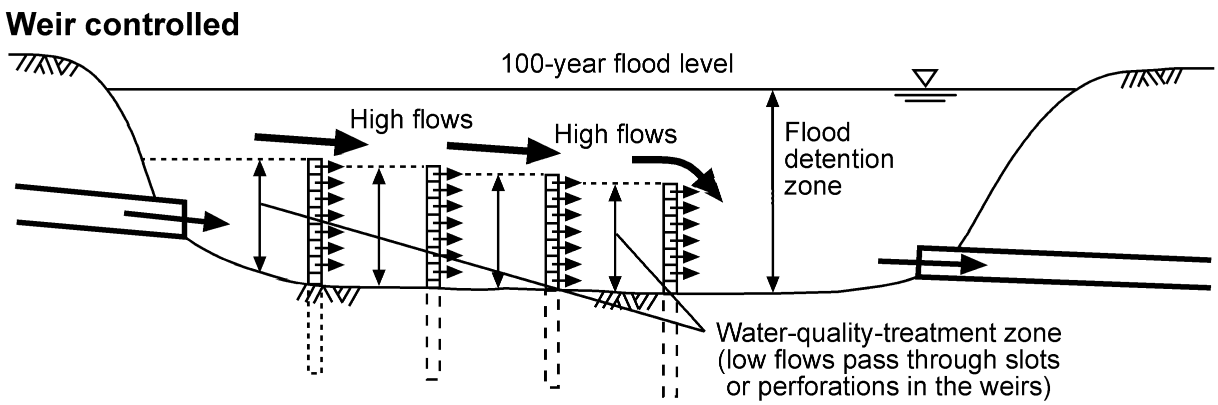


Figure 5.50-2 Dry pond: weir control (source: Klein, December 1996)

5.60 TEMPORARY PONDS

5.61 Temporary Ponds: SEDIMENT BASINS

DESCRIPTION AND PURPOSE

A temporary sediment basin is an impoundment that temporarily stores sediment-laden runoff and releases it at a reduced rate. During the time that the runoff is detained, sediment settles out and is trapped in the basin. This prevents the sediment from being transported off site.

EFFECTIVENESS

Sediment basins are relatively effective for trapping medium- and coarse-grained sediment particles. However, fine silts and clays that are suspended in runoff are very difficult to trap. Overall trapping efficiencies of approximately 70% can be achieved with typical sediment particle size fractions and typical basin design. If higher trapping efficiencies are desired, larger pool volumes and slower discharge rates can be used. However, the value of increased sediment-basin size diminishes rapidly once sand and silt fractions of the sediment have been removed. Larger volumes reduce the chance of resuspension at higher-flow events, but this is less of a concern with temporary basins.

PLANNING CONSIDERATIONS

Temporary sediment basins are normally used at the downstream end of disturbed areas of five to 250 acres. Temporary sediment basins are intended to be used only during the construction period of a development, usually less than two years. However, structures planned under this practice should be designed and constructed using the same standards as are used for permanent detention ponds, and may be restored after construction is completed to become permanent ponds.

If a permanent detention pond is desired, it should be built at the beginning of construction and also used and maintained for sediment control during construction. In this situation, the basin should be designed according to the applicable practice desired, with additional volume for the sediment and runoff expected during the construction period. Sediment should be removed from the pond at the end of the construction period to prepare it for permanent use.

Sediment basins should be located so that runoff from the largest possible erosion-prone area flows into them, but flows from the unaffected areas are diverted from them. Practices, such as diversions, can be used to control the area that is treated by a sediment basin. Temporary sediment basins should not be installed in streams. They should be located before the runoff from the site enters a stream.

DESIGN RECOMMENDATIONS

1. **Capacity.** Sediment basins are almost always associated with high-sediment-production areas, such as construction sites. For a sediment basin to be effective, it should have a permanent pool of water. However, special structures can be designed to control the flows in the sediment basin if the pool of water is not desired or maintainable. Figure 5.61-1 shows the

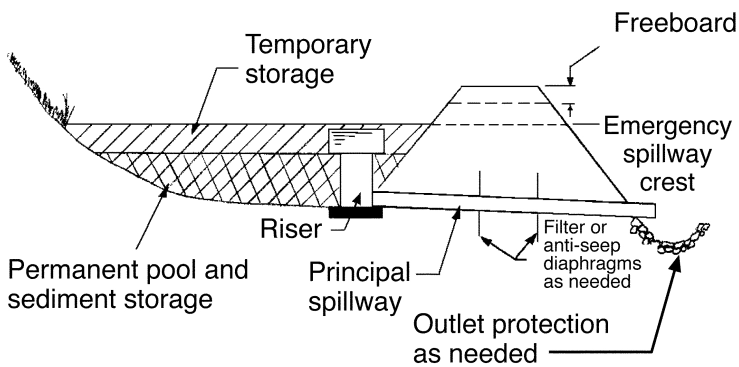


Figure 5.61-1 Typical sediment basin cross section

permanent and temporary volumes associated with typical sediment basins. The MPCA permit requires total storage volume below the principal spillway crest or first stage orifice to be at least 67 cubic yards per acre of drainage area (0.5 inch over the drainage area). When one-half of this volume is filled with sediment, the basin must be cleaned out to maintain its effectiveness.

2. **Principal spillway**. Principal spillways are often pipes that provide the main outlet for the temporary sediment basins. Principal spillways can be constructed of a variety of materials, such as corrugated metal, high-density polyethylene (HDPE), polyvinyl chloride (PVC) or concrete. For temporary sediment basins, corrugated metal is often used because it is relatively easy to remove and reuse once the basin has been abandoned. HDPE and PVC also are easily removed. The pipe must be watertight, but special coatings for corrosion protection are not typically needed because this is a temporary practice.

   Principal spillways should be designed with a maximum outflow (Q out) of 5.66 cfs or less per acre of pond surface area, up to the water quality volume. Smaller outflows will result in higher efficiencies, but larger temporary storage volumes. The required storage volume can be determined from the design procedures described in part 5.05. The storm that should be routed for the principal spillway depends upon the downstream environmental and safety impacts if the system exceeds design capacity.

   When determining the capacity of a principal spillway, first check the capacity of the pipe. Second, check weir flow and orifice flow at the riser entrance. If weir flow or orifice flow controls the peak flow from the structure, a larger riser may be required. In some cases, orifice flow at the entrance to the principal spillway pipe should be checked also.

   In some cases, the required discharge from a temporary sediment basin will be small enough that a slotted riser and PVC pipe may be used as a principal spillway. Figure 5.61-2 shows a slotted riser and PVC pipe that is used as an outlet for a sediment basin. Slotted risers can either be constructed from a solid pipe or they may be purchased as prefabricated components. Riser slots must be covered with filter fabric and/or gravel filter to prevent undesirable sediment washout.

At the inlet to the principal spillway, a skimmer-type debris trap should be used. If considerable amounts of floating debris are expected, a trash rack and anti-vortex baffle can be used. Figure 5.61-3 shows a typical installation for corrugated metal risers. These are recommended only for temporary facilities.

MAINTENANCE

Sediment basins require occasional maintenance to remain effective as sediment traps. When sediment reaches the maximum level assumed in the design (usually one-third to one-half the basin volume), it must be removed. Excavated sediment must be placed in a location where it will not easily be eroded again. In addition to sediment cleanout, sediment basins should be inspected after storms to determine whether the embankment or spillways sustained any damage that requires repair.

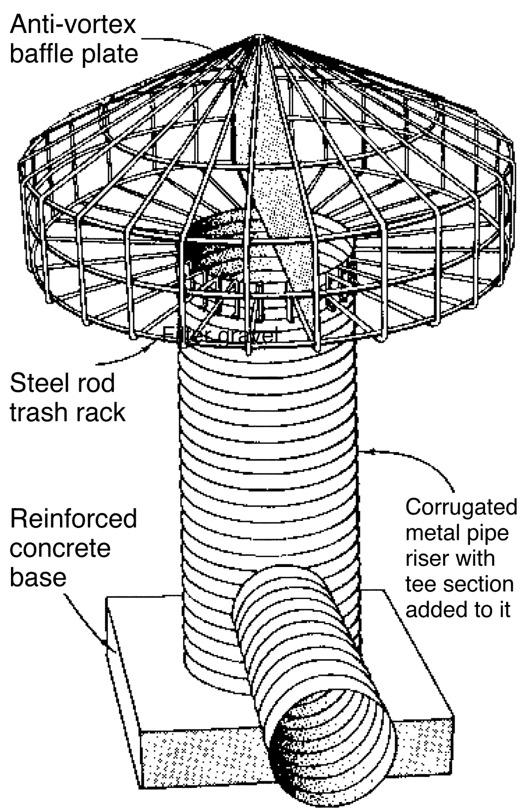


Figure 5.61-3 Typical corrugated metal riser

5.62 Temporary Ponds: SEDIMENT TRAPS

DESCRIPTION AND PURPOSE

A temporary sediment trap is a small, temporary ponding area formed by constructing an earthen embankment with a gravel outlet swale instead of using a pipe for the primary outlet. Temporary sediment traps are intended to detain sediment-laden runoff from small disturbed areas long enough to allow the majority of the larger sediment particles to settle out.

EFFECTIVENESS

Temporary sediment traps provide good control of coarse sediment and are moderately effective for trapping medium-sized sediment particles. However, they have a relatively low trapping efficiency for fine silt and clay particles suspended in runoff. If a higher trapping efficiency is desired, a temporary sediment basin with a larger storage volume and longer detention time should be used.

PLANNING CONSIDERATIONS

For maximum effectiveness, sediment traps should be located as close as possible to the disturbed area. Multiple sediment traps are often needed to treat runoff from ever-changing construction sites. Temporary diversions can be used to direct sediment-laden runoff to the sediment trap. Every effort should be made to exclude runoff from undisturbed areas. Sediment traps and other sediment-control measures should be installed before work is begun in the contributing drainage area.

DESIGN RECOMMENDATIONS

1. A temporary sediment trap should typically be used in a location with a drainage area of five acres or less and where it will be used for two years or less. The volume of the trap should be at least 67 cubic yards per acre of watershed.

2. The gravel outlet swale must be capable of handling the runoff from a 10-year frequency, 24-hour-duration storm without failure or significant downstream erosion.

3. If a pipe outlet is desired, see Stormwater Detention Pond Design Details and Examples (section 5.70) and Temporary Ponds: Sediment Basin (part 5.61) for design requirements.

4. The gravel outlet should be located in the low point of the embankment. The minimum length in feet of a gravel outlet should be four times the number of acres in the drainage area. The peak velocity in the basin should be 4 fps for the 10-year storm event. The crest of the gravel outlet should be level and should be 1 ft below the top of the embankment. See Figure 6.41-1.

5. The gravel used for the outlet should be 1- to 2-inch size, such as MnDOT CA-1 or CA-2 coarse aggregate. A filter fabric can be installed inside the gravel filter to improve the sediment-trapping efficiency of the structure. However, this increases the probability that the outlet will become clogged with sediment.

MAINTENANCE

As previously mentioned, the sediment should be removed when it fills one-third to one-half of the capacity of the sediment trap. If the outlet becomes clogged with sediment, it should be cleaned to restore its flow capacity.

The structure should be inspected after significant runoff events to check for damage or operational problems. Once the contributing drainage area has been stabilized, the structure can be removed or, if possible, modified to become part of the permanent control features.

5.63 Temporary Ponds: TEMPORARY SEDIMENT-CONTROL PONDS

Current regulations in Minnesota require “temporary sediment-control ponds,” which is a type of temporary pond required in the MPCA Construction Storm Water Permit. These temporary ponds are required where 10 or more contiguous acres of exposed soil contribute to a discernible point of discharge, prior to the runoff leaving the construction site or entering waters of the state.

The permit states that “the basin shall provide 1,800 cubic ft per acre drained of hydraulic storage below the outlet pipe.” This is equivalent to the 67 cubic yards recommended by the NRCS for sediment basins (USDA, NRCS, June 1988). The permit requires that the basin outlets be designed to prevent short-circuiting and the discharge of floating debris. The outlet should consist of a perforated riser pipe wrapped with filter fabric and covered with crushed gravel. The perforated riser pipe should be designed to allow complete basin drawdown. Although these basins are for temporary use, usually considered to be two years, the time period during which they can be utilized is not specified.

5.70 STORMWATER DETENTION POND DESIGN DETAILS AND EXAMPLES

5.71 Stormwater Detention Pond Design Details and Examples: SPECIFICATIONS

1. Embankments

The minimum recommended top width of embankments are given in Table 5.71-1.

Table 5.71-1 Minimum recommended top widths of embankments

Total Embankment Height (feet)	Top Width (feet)
< 10	6
11-14	8
15-19	10
20-25	12

The side slopes of the embankments should be flatter than 2:1 and the combined upstream and downstream slopes should be 5:1 or more. For example, 3:1 upstream and 2:1 downstream would be satisfactory.

A core trench is needed for all embankments more than 7 ft high (see Figure 5.71-1). If the core trench is not required, the base should be stripped and scarified before placing fill. If a core trench is needed, it must be at least 4 ft deep and should have side slopes of at least 1:1.

To prevent failure, the embankment for a temporary sediment basin needs to be constructed to the same standards as those for small dams. Materials used in the embankment must consist of soils that have adequate strength, low permeability and piping resistance to be used in a water-impounding structure. Fill materials containing sod, roots, trees or other debris should not be used.

During construction, the moisture content of the fill material should be such that a ball that does not readily crumble can be formed in the hand. Very wet or dry soil will not compact properly. The embankment should be relatively homogeneous and free of dry or uncompacted layers. Extra care is needed when compacting fill around the principal spillway. This fill should be tamped with hand-directed power tampers. The embankment should be compacted by routing the earth-moving equipment over it until the entire surface of each lift is covered by at least two passes of equipment with wheels or three passes of equipment with tracks. Each lift should not exceed 9 inches in thickness.

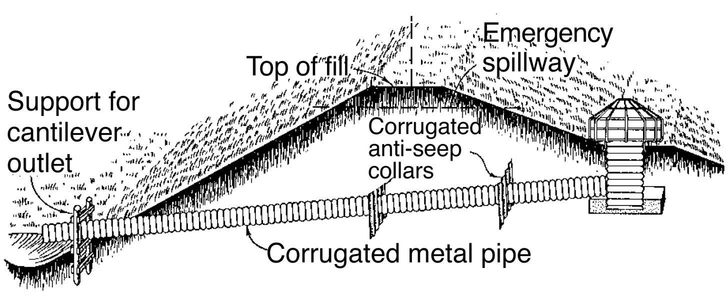


Figure 5.71-1 Typical installation with corrugated anti-seep collars

2. Filter Diaphragms or Anti-seep Diaphragms

Filter diaphragms have become the preferred method, but either filter diaphragms or anti-seep diaphragms can be used if properly installed.

Anti-seep diaphragms or filter diaphragms are needed on principal spillway conduits to control seepage and piping when one of the following conditions exists:

- The height of the dam exceeds 15 ft.
- The conduit is made of smooth pipe larger than 8 inches in diameter.
- The conduit is corrugated pipe larger than 12 inches in diameter.

When anti-seep diaphragms are used, they should be designed to increase the seepage length along the pipe by 15%. More than one diaphragm may be needed to achieve this. All connections for anti-seep diaphragms must be watertight. When installing a conduit with anti-seep diaphragms, it is very important to properly compact the earth fill adjacent to the diaphragms and adjacent to the pipe. Figure 5.71-1 shows a typical installation with anti-seep diaphragms.

Filter diaphragms are another acceptable means of controlling seepage along principal spillways. Figure 5.71-2 shows a typical filter diaphragm installation.

Filter diaphragms are constructed of granular material of proper gradation to allow seepage to pass through them while preventing migration of embankment soil particles. A geotextile may be used to prevent soil migration. A granular bedding for the pipe may be used downstream of the diaphragm as an outlet.

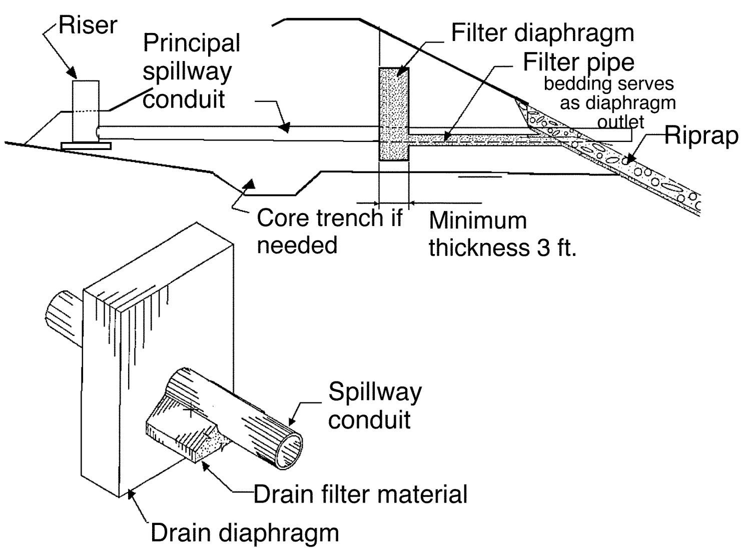


Figure 5.71-2 Typical filter diaphragm layout

A filter diaphragm should extend horizontally and vertically three times the outside diameter of the conduit. However, the diaphragm does not need to extend higher in elevation than the maximum pool level. The filter diaphragm should be at least 3 ft thick.

For more information on filter diaphragm design procedures, consult SCS Technical Release 60, *Earth Dams and Reservoirs* (SCS, USDA, October, 1985), and SCS Soil Mechanics Note 1, *Guide for Determining the Gradation of Sand and Gravel Filters* (SCS, USDA, 1985a).

Table 5.71-2 Recommended minimum design frequency

			Minimum Design Frequency (years)		
Drainage Area (acres)	Minimum Pipe Diameter	Effective Fill Height (ft)	Maximum Storage (ac-ft)	Principal Spillway	Emergency Spillway*
0-20	5	0-20	50	--**	10
0-20	5	20-35	50	2	25
20-80	6	0-20	50	5	25
20-80	6	20-35	50	5	50
80-250	10	0-20	50	10	25
80-250	10	20-35	50	10	50
All others	15	0-35	--	25	50

* Freeboard is the difference in elevation between the water surface in the vegetative spillway during the passage of the emergency-spillway-design storm and the top of settled fill. The minimum freeboard should be 1 ft.

** A principal is required on all embankment ponds except where the drainage area is under 20 acres *and* there is no spring flow or base flow *and* the emergency spillway is in good condition. If there is no principal spillway, a trickle tube or underground outlet is required.

3. Emergency Spillways

An emergency spillway is needed for all temporary sediment basins. As a minimum, the emergency spillway capacity should meet the requirements in Table 5.71-2. Emergency spillways should have a minimum bottom width of 10 ft and a level section of 30 ft or more. Emergency spillways should be excavated in undisturbed soil rather than fill material. Use Table 5.71-3 to determine the appropriate spillway width and depth of flow.

After determining the depth of flow, the freeboard from Table 5.71-2 must be added to determine the elevation of the top of dam. Figure 5.71-3 shows a typical emergency spillway layout.
Figure 5.71-4 shows some emergency spillway design features.

4. Basin Shape

The shape of the sediment basin should be laid out so that the length-to-width ratio is at about 3:1, but it can be any shape, including circular, if the flow is properly dispersed across the entire area. To disperse the flow, gabion or plunge pool inlets or other energy-diffusing devices may be used, especially if the inlet has a high velocity (see Figure 5.71-5). If site constraints prevent the construction of a basin that meets this criterion, baffles such as those shown in Figure 5.71-6 can be used.

5. Inlet Conditions

Measures should be taken to minimize turbulence that will disturb the settling conditions of the sediment basin. If a high velocity flow is allowed to enter directly into the basin, it can resuspend sediments and prevent settling within the basin.

Table 5.71-3 Emergency spillway widths (feet)

Cfs	Depth of Flow (feet) 1.0	1.5
	10	not applicable
20	13	not applicable
25	17	not applicable
30	20	not applicable
35	24	9
40	27	10
45	30	11
50	33	12
60	40	15
70	47	17
80	54	19
90	60	22
100	67	24
125	84	30
150	100	36
175	117	42
200	134	48
250	167	60
300	200	72

The exit slopes for emergency spillways with flow depths of 1.0 and 1.5 cubic ft per second must fall within the following ranges for this table to be used.

Flow Depth	Exit Slope (percent)	
	Minimum	Maximum
1.0	5	15
1.5	4	8

Pipe inlets that create a jet of water, or turbulence, in the sediment basin should be avoided. Measures that can be used to minimize turbulence are discussed in other chapters of this manual. They include baffles (see Figures 5.71-5 and 5.71-6), transition sections in channels, outlet dissipation devices and riprap.

6. Drawdown Devices

The pool below the principal spillway crest can be dewatered if this is done in a manner that preserves the trapping efficiency of the sediment basin. There are two methods of dewatering that can be used.

The first method is a slow discharge at the sediment pool level that will lower the pool level to that elevation over a period of several days. This can be done by using an orifice in the riser, a siphon or a separate dewatering device. A maximum rate of discharge of approximately 0.12 cfs per acre ft of pool volume between the sediment storage level and principal spillway crest is recommended. Figure 5.71-7 shows several methods of dewatering. Slotted riser specifications are shown in Figure 5.71-8. These outlets should be wrapped in filter fabric or gravel filters as shown in Figure 5.71-7. They are for temporary ponds only.

Another method of dewatering is to install a perforated drain in the bottom of the sediment basin pool (see Figure 5.71-9). This configuration has the advantage of also dewatering the sediment, which makes it easier to excavate. This type of outlet may be subject to clogging by fine sediments, especially at construction sites.

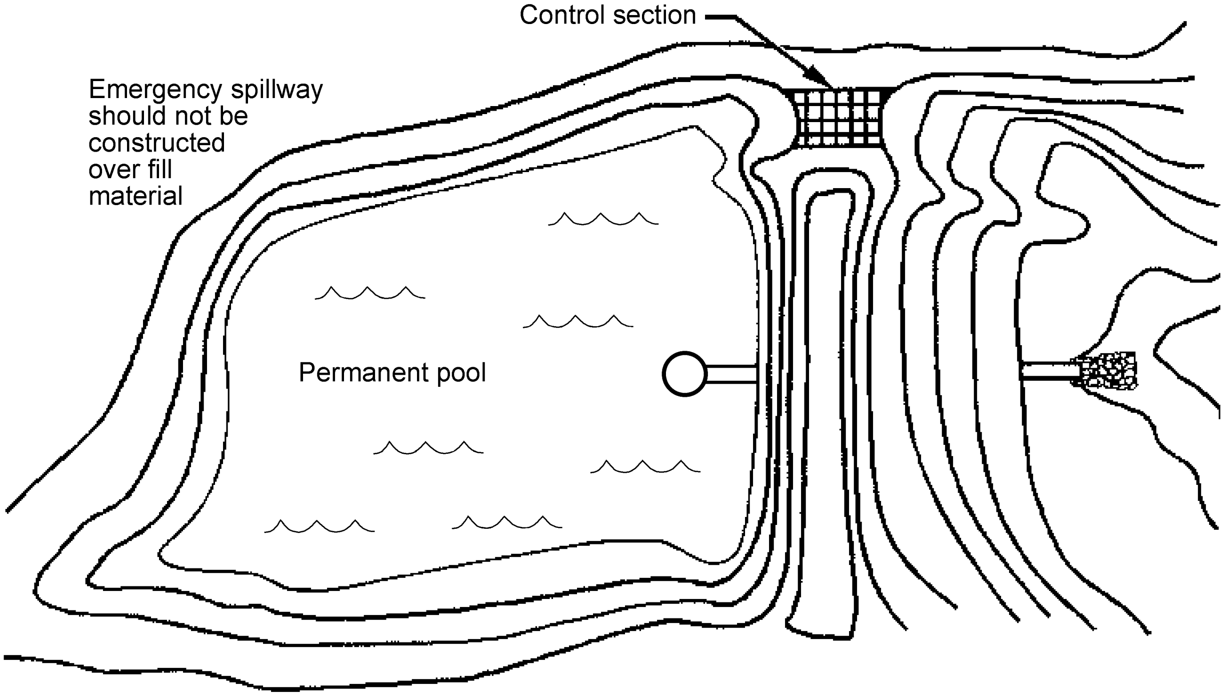
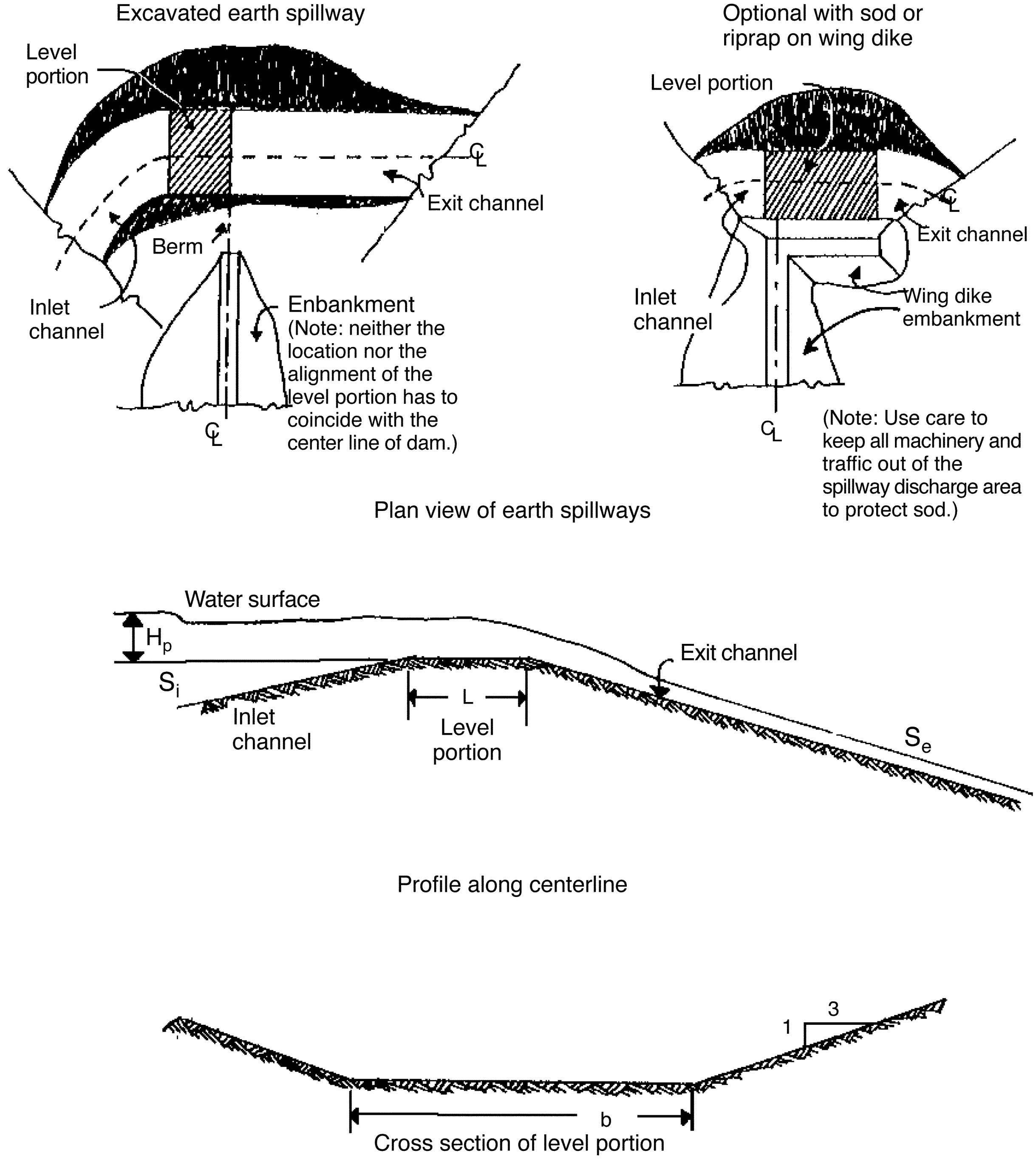


Figure 5.71-3 Emergency spillway (source: Virginia Department of Conservation and Recreation)



H_p= Depth of water in reservoir above crest
L= Length of level portion (minimum)
b= Bottom width of spillway
S_e= Slope for exit channel
S_i= Slope of inlet channel
C= Center line

Figure 5.71-4 Typical emergency spillway layout

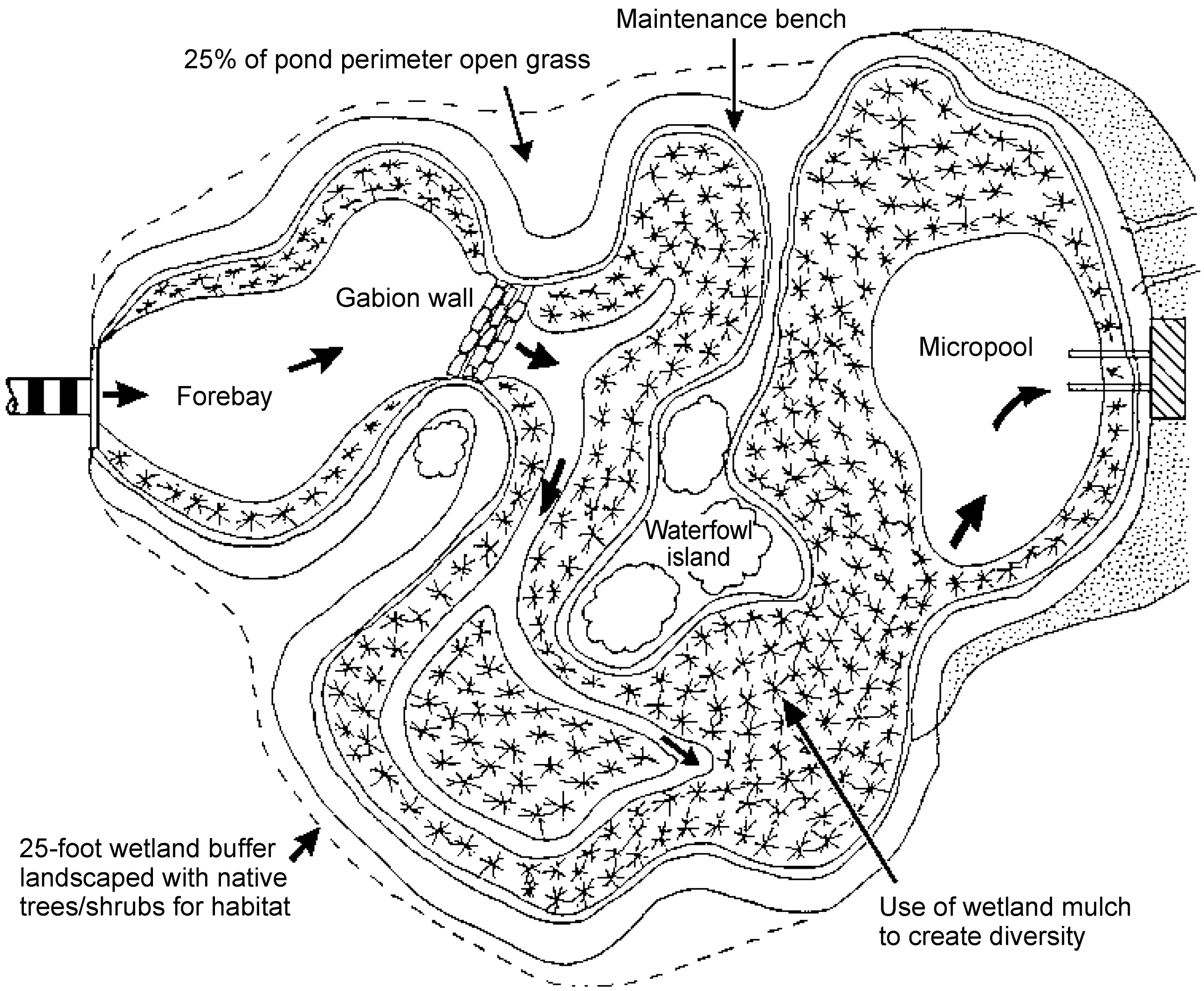


Figure 5.71-5 Pond with gabion wall for diffusion at the inlet (source: Schueler, October 1992)

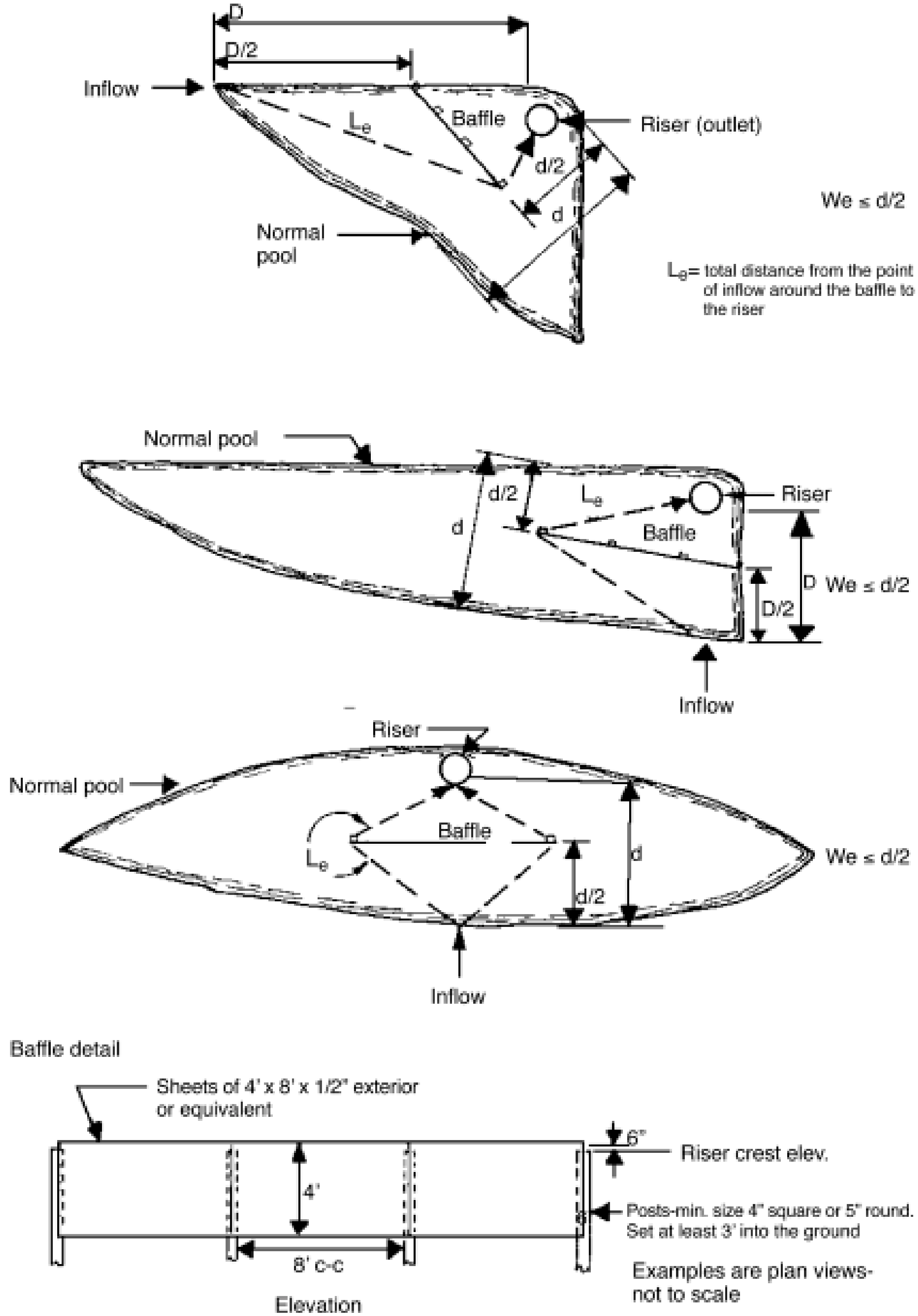
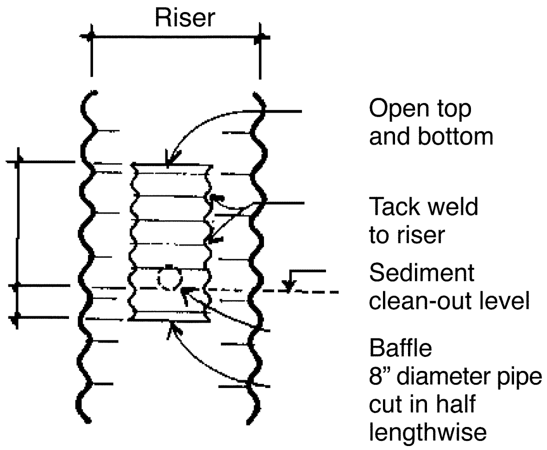
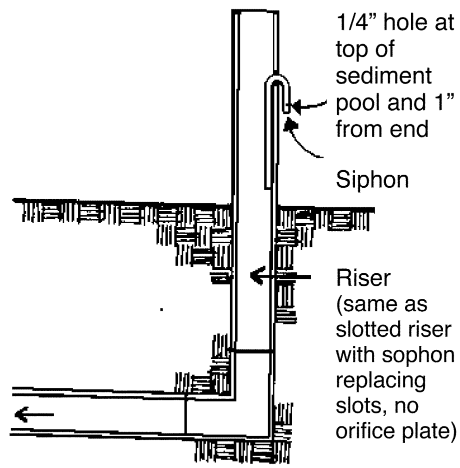


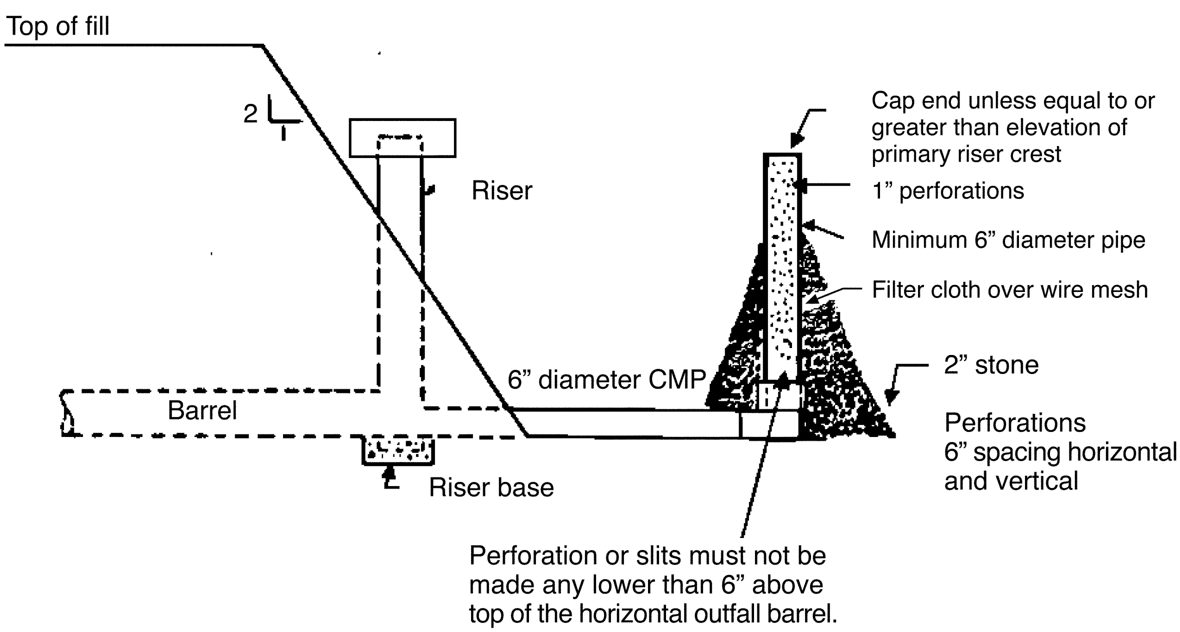
Figure 5.71-6 Sediment basin baffles for temporary ponds



Baffle inlet on principal spillway
(Baffle protects orifice from clogging.
Rate of discharge by orifice very
small under low head.)

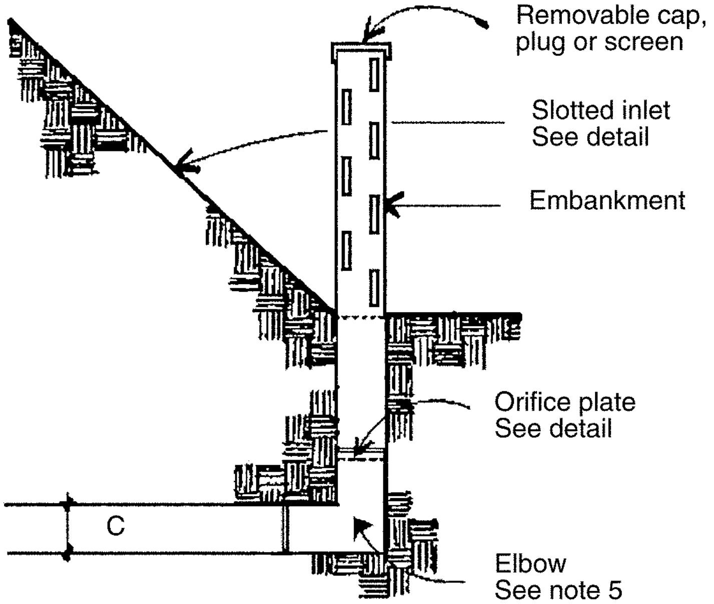


Method B: Principal spillway
pipe with siphon

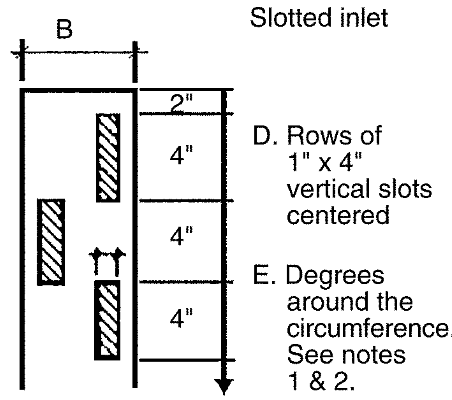


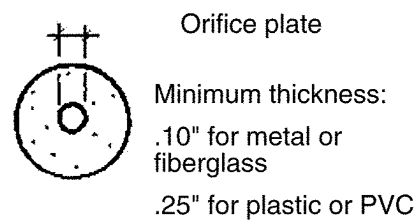
Optional sediment basin dewatering
device with 6” slotted riser

Figure 5.71-7 Sediment basin dewatering devices



Principal spillway pipe with slotted riser





Standard Dimensions Table

A in.	B in.	C in. Min.	D rows	E degr.	Slot area Ft^2/ft	Minimum wall thickness: corrugated metal base	Minimum wall thickness: smooth steel in.	Minimum wall thickness: PVC in.
1.50-3.50	6	4	4	90	.167	16	.10	.15
3.75-5.50	8	6	6	60	.250	16	.10	.20
5.75-6.00	10	8	8	45	.383	16	.13	.25

Notes and Comments

1. Slotted inlets shall be fabricated from corrugated metal, smooth steel or PVC plastic pipe. Materials shall have at least the minimum wall thickness given in the standard dimensions table.
2. Slots shall be cut cleanly and deburred. Ends of slots may be round or square.
3. Orifice plate, cap and all fittings shall be snug and securely fastened. Orifice plate shall be cleanly cut and free of burrs with care taken not to round the edges. It should be a minimum of 2.0 feet below grade for proper functioning.
4. The portion of the inlet below grade may be perforated with a gravel filter for additional dewatering of basin.
5. Fabricated or standard elbow, fabricated or standard tee with main tile line or plug in upstream and, or standard tee with one end embedded in concrete.
6. The height if inlet is above the sediment pool level shall be such that the velocity of flow through the slots is less than 2.0 feet per second.
7. Head on the orifice, if placed as suggested, may be figured by adding 0.7 times the maximum depth of impounded water plus the depth of the orifice below grade. Has a relatively constant rate of change.

Figure 5.71-8 Slotted riser standard dimensions

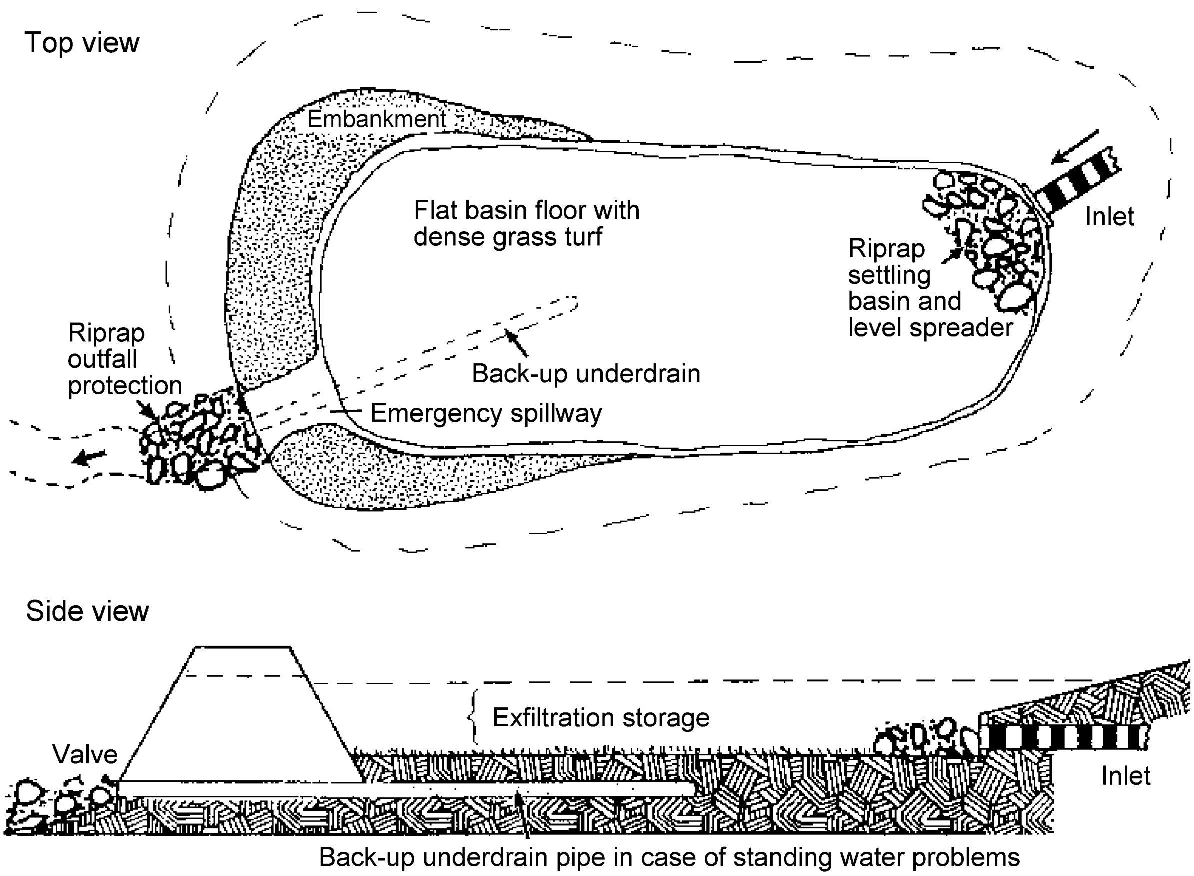


Figure 5.71-9 Pond with perforated underdrain outlet (source: Schueler, 1987)

5.72 Stormwater Detention Pond Design Details and Examples: EXAMPLE OF A SIMPLE DESIGN

Example site: 100-acre site, predevelopment CN = 70. Postdevelopment: Residential area with 1/3-acre lots. B soils (much of it disturbed). From TR55 Residential 1/3-acre lots = 30% impervious, CN options for pervious soils is 57-86, chose CN=80 for sodded but disturbed B soils.

Pond size: From Pitt, for residential 1/3-acre lots, 0.8% of 100 acres = 0.8 acres of permanent pond.

Volume of permanent pond (must meet sediment storage-, inlet- and outlet-design criteria). The minimum is the MPCA permit, which requires 250 ft^3 per impervious acre of area drained. 250 ft^3 x 30 acres / 43,560 ft per acre = **0.17 AF**. Another widely recommended volume is 0.5 inch times the impervious surface. 0.5 x 30 acres x 1/12 inch per foot = **1.25 AF.** The Metropolitan Council (Oberts, 1986) recommended 0.5 inch of runoff from entire watershed,: 0.5 inch x 100 acres / 12 inches per foot = **4.2 AF**. Wisconsin has recommended the water quality volume be used; in Minnesota, that would be the runoff from the 1.25-inch event or 0.29 inch x100 acres /12 inches per foot = **2.41 AF.**

Alternatively, we could use a quiescent storage design with runoff from 2 times the water quality event (1.25-inch event) which is the 2.5-inch event. Using NRCS composite CN methods, this event produces 0.89 inch of runoff or: 0.89 inch x 100 acres / 12 inches/foot = **7.41 AF** storage.

The specific volume is not as important as meeting the goals for treatment, and the design criteria for inlet, outlet, diffusion of flow, velocity dissipation, etc. For this example, use 2.41 AF storage below the outlet and extended detention for treatment.

Water Quality Volume

The water quality volume = 1.25-inch event; From TR55, runoff volume = 0.29 inch x 100 acres/12 in/ft = 2.41 acre ft.
Regulatory (MPCA Permit) water quality vol. = 0.5 inch from impervious surface; 0.5 x 0.3 x 100 acres x 1 foot /12 inches = 1.25 acre ft. **Use 2.41 acre ft for water quality volume.**

Water Quality Volume – Elevation

(Needs to be an actual, site-adjusted stage-area-discharge curve.)

Assume 0.8-acre permanent pond, 3.0 ft depth average. Assume a 1.0-acre pond at depth of water quality volume.

Estimate of water quality volume depth, Average area = (0.8+1.0) divided by 2, 1.8 acres, /2= 0.9 acre average area. Average depth = volume /average area = 2.41 acre ft / .9 acre = 2.7 ft deep. (Note: This is a modification of the normal process where the site areas and volumes are usually known or can be calculated from the site features.)

Water Quality Volume – Discharge
(Needs to be site-adjusted stage discharge curve.)

Restrict discharges up to 2.7 ft of depth by limiting outflow to 5.66 cfs per acre of surface area in pond, maximum pond surface area is 1.0 acre; therefore, maximum outflow = 5.66 cfs at 2.7 ft deep.

Flood Discharge
(Needs to be site-adjusted stage-discharge curve.)

Design outlet to discharge at a rate of 1/2 of the predevelopment two-year event, and equal to the predevelopment 10- and 100-year storms, routing the storms through the pond.

Velocity in Pond
(Needs to be site-adjusted stage-discharge curve.)

Demonstrate that critical velocities in the pond do not exceed guidance criteria. Velocity = flow out divided by critical cross sectional area. Limit to 2 fps at one-year storm, 3 fps at two-year storm, 5 fps at 10- and 100-year storm events using site-specific determinations.

5.73 Stormwater Detention Pond Design Details and Examples: EXAMPLE OF A COMPLEX DESIGN

The following example illustrates some key points that should be addressed in the design process. It is not meant to be all-inclusive. Professional knowledge of the models and methods of design are indispensable to this process.

Given Situation for This Example

A property owner proposes to develop 100 acres (2,087 ft x 2,087 ft) of open, grassed area. The present area is fairly well drained with a single point of discharge. Natural slope of the land is fairly level, about 1%, but slopes gradually increase near the outlet. In the northeastern corner, slopes average about 10:1, horizontal to vertical. The soil is group B (USDA, NRCS, October 1986). Predevelopment condition is short grass in good condition.

In the developed condition, about 20 acres (1,500 ft x 580 ft) would be commercial development. The 20-acre commercial site will have disturbed B soils, with impervious surfaces about 85%. Commercial impervious surfaces will all be connected directly to the pond.

The remainder would be 80 acres of residential development with 1/3-acre lots. About 30% impervious surfaces. Residential impervious surfaces will all be directly connected to drainage ways, but not to storm sewers.

Precipitation for 24-hour events (USWB, TP 40) is approximately:

two-year event = 2.75 inches;
10-year event = 4.2 inches;
100-year event = 6.0 inches.

Given the above situations, design a pond that meets state and local goals.

Step 1. Plan and site the stormwater-treatment pond.

The pond should be planned and sited in accordance with planning and design strategies recommended in this manual. Important considerations include the established goals for the watershed and the site-specific feasibility of on-site or regional ponds.

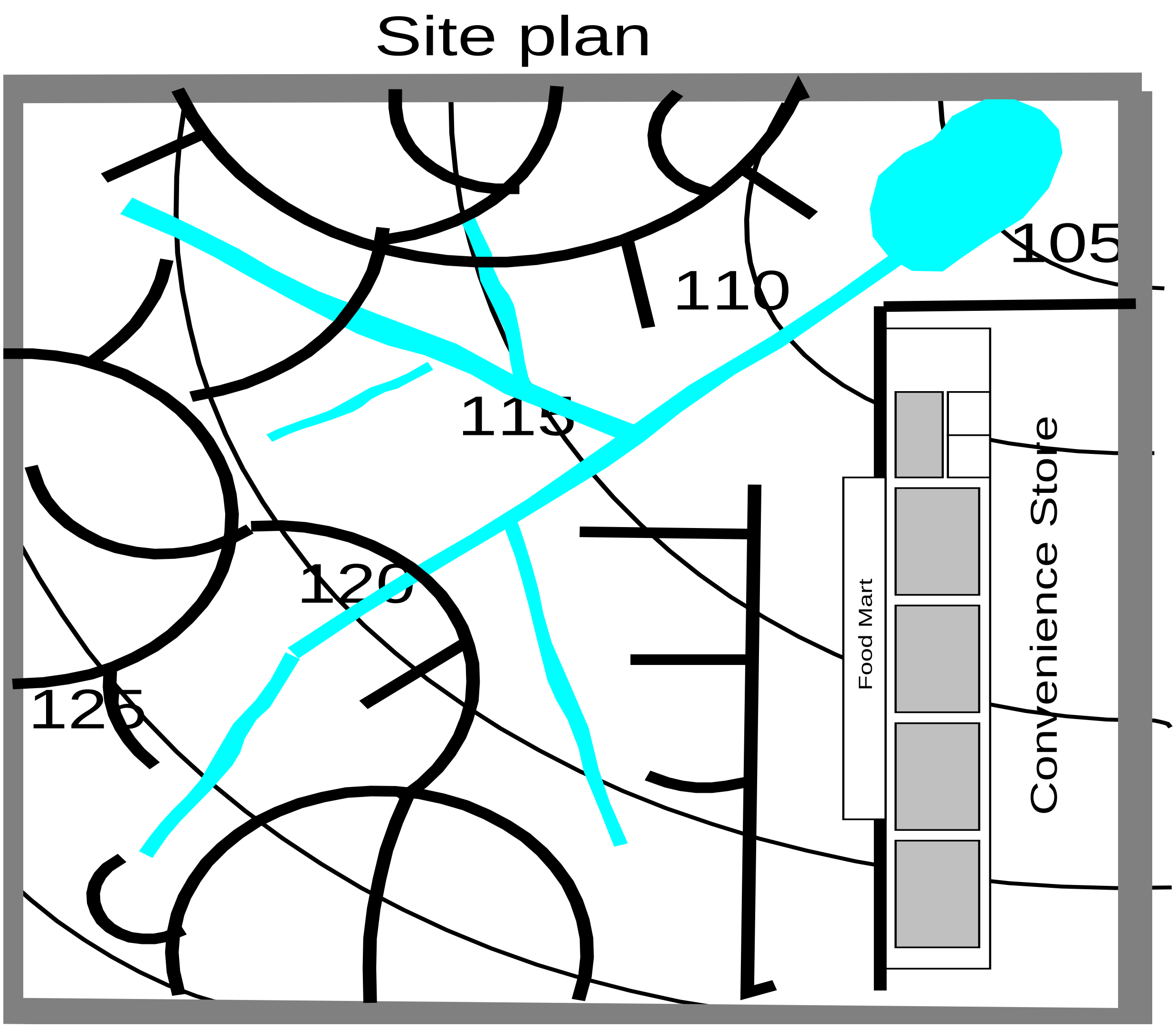


Table 5.73-1 Pond surface area required as a percent of drainage area, for a given land use and goal of 90% sediment removal (Pitt, 1998)

Land Use	Percent of Watershed
Totally Paved Areas	3.0
Freeways	2.8
Industrial Areas	2.0
Commercial Areas	1.7
Institutional Areas	1.7
Construction Sites	1.5
Residential Areas	0.8
Open Spaces	0.6

Step 2. Find the required pond layout and surface area.

Pond Layout

Analysis of runoff data (Pitt) indicates that the pond size should be based on the surface area and land use because of the effect these factors have on runoff. Pitt recommends using a pond with a surface area of 0.8% of the watershed for residential and 1.7% for commercial. The "Recommended Pond Surface Area" (Table 5.73-1) is a preliminary estimate of pond surface area needed for a wet stormwater-treatment pond.

This is a mixed-use watershed, so the actual size of the pond should be interpolated. Using the above estimates, we use 20 acres x 1.7% of the watershed and 80 acres x 0.8% of the watershed:

20 acres x .017 = 0.34 acre;
80 acres x .008 = 0.64 acre;
Total pond area = 0.34 acre + 0.64 acre = 0.98 acre ≈ 1.0 acre.

Based on the calculations, we select a pond, for demonstration purposes, with 1.0 acre of open water, which is about 1.0% of the watershed.

For comparison purposes, we can look at several local criteria. Based on various sizing criteria for water quality treatment in ponds, the following minimum values would be necessary:

Dual Purpose (Dry Ponds, Klein)	= 0.5 acre	Minimum area required by RMWD
Ramsey Metro Watershed District	= 0.5 acre	Minimum area required by RMWD
Pitt (above)	≈ 1.00 acre	Design guidance listed above
MPCA permit	≈ 1.00 acre	Approximation from Pitt
Metropolitan Council (Oberts)	2.0 acres	Recommended surface area pond / watershed ratio = (2% of watershed)
Pond Wetland (Schueler)	2.0 acres	2.0% of watershed area
Vadnais Lakes Area Watershed Management Organization (Walker)	≈ 1.0 to 2.0 acres	Volume-divided-by-depth calculation
Note: ≈ means approximately, usually that the size is not specifically given but can be calculated from other design factors or recommendations.		

The following calculations for the pond area are based on the above design requirements. For simplicity, we assume that the pond is approximately circular.

Radius of a 1.0-acre pond:

$A = \pi r^2$
$43{,}560 \text{ ft}^2 = 3.14 (r^2)$
$43{,}560 \div 3.14 = r^2$
$r^2 = 13{,}873$
$r = 117.8 \approx 118$ ft

Note: To get some idea of the routing, an iterative process is proposed. A 2.5-acre set-aside for a pond is tried: 1.0 acre for permanent pond and 1.0 acre for bounce. In addition, there will be setback restrictions on development structures so they are 2.0 ft above the 100-year event. A dike that limits the expansion of the bounce could be proposed, but it would be costly, and a more natural landscape would be more aesthetically pleasing. Also, the infrequently flooded areas can be used as common recreation area, natural buffer area or open space.

Step 3. Calculate the extended detention volume of the pond.

The Volume above the Outlet, or the Bounce

The amount of area needed for bounce needs to be determined in steps. The outflow is limited by MPCA permits and by other policy requirements placed on the system, especially flood-control policy.

Definition

The water quality volume is a calculation based on the runoff from a 1.25-inch precipitation event, or the 0.5 inch of runoff from the impervious areas.

The water quality treatment volume is to be considered a specific volume, not an inflow-outflow calculation. Another way to put this is that it is an instant volume provided for treatment in addition to the permanent storage; usually provided above the outlet of the basin. It can be included in the volume below the outlet if the permanent storage is at least twice the water quality volume or runoff from the 2.5-inch event. This takes into account a volume for scour and treatment.

Water Quality Volume Calculations

For this example, we will use the MPCA permit method as the first estimate of the water quality volume. **The MPCA permit method uses 0.5 inch of runoff from all impervious surface (connected and unconnected):**
Residential area of 80 acres x .30 (fraction impervious) x 0.5 inch x 1/12 ft/inch = 1.0 acre ft (V_1)
Commercial area of 20 acres x .85 (fraction impervious) x 0.5 inch x 1/12 ft/inch = 0.7 acre ft (V_2)
Total treatment volume = $V_1 + V_2$ = **1.70 acre ft** (See Note 5.73-1, Comparisons of Methods, for other calculations of this volume.)

Maximum Water Quality Treatment Discharge Rate

Qout ≤ Pond Area (in acres) x 5.66 cfs per acre

As noted in part 5.03, Barfield (1988) recommended an outflow rate to surface area design. Pitt (1994) found that a ratio of approximately 5.66 cfs of outflow for each acre of pond surface area resulted in a predicted sediment trapping efficiency of approximately 90% in urban storm water.

The national treatment goal for wet ponds is to remove about 90% of the suspended solids. Thus, a minimum ratio of 5.66 cfs of pond outflow per acre of pond surface area is recommended.

Peak Discharge Volumes

Controlling the two-, 10- and 100-year events starts with finding the predevelopment discharge rate for these storm events.

Two-year Event Control

As described in the planning section, it is recommend that the two-year event be discharged at ≤ 0.5 the predevelopment rate. The postdevelopment peak discharge for the two-year events should be released from stormwater ponds at one-half of the two-year peak discharge for the predevelopment watershed conditions.

Note 5.73-1 Comparison of Methods

As you will see, the calculation of runoff volume is not precise or accurate. Precision is getting the same result with each method or between each method. Accuracy, or accurate prediction of what will happen with a given event, requires knowledge of the actual site and therefore will always be subject to professional judgement and interpretation.

The following provides three methods to determine the water quality volume. The method used to design the pond should reflect good treatment that meets the outflow rate for at least an actual, calibrated 1.25-inch storm event. These examples have been simplified, but they illustrate some of the problems that will be encountered in actual design calculations.

In each example, notice that not only are the volumes different, but the fraction that each part is expected to contribute also changes. Areas that are mostly impervious or mostly undeveloped can often be considered homogeneous. The contribution of the highly impervious commercial area is very similar using either method. Mixed-use areas are very difficult. If a residential area actually has a high percentage of connected impervious surface, it would be expected to contribute more runoff at low-volume storm events. The examples demonstrate this characteristic of runoff analysis.

Calculations using 1.25-inch rain event (weighted NRCS method)

Treatment volume for:
Residential area of 80 acres x .0375 inch runoff (weighted CN of 72) x 1/12 ft/inch = 0.25 acre ft
Commercial area of 20 acres x 0.5 inch (weighted CN of 92) x 1/12 ft/inch = 0.8 acre ft
Total volume = 0.25 acre ft + 0.8 acre ft = **1.05 acre ft**
(The TR55 manual indicates that these are connected impervious surfaces, but as you see below, we do not recommend this be assumed unless there is actually substantial unconnected impervious surface.)

Calculations using NRCS methods (but assume all impervious is a connected subwatershed)

Residential impervious areas: 80 acres x .3 x 1 inch x 1/12 ft/inch = 2 acre ft (V_1)
Commercial impervious area: 20 acres x .85 x 1 inch runoff x 1/12 ft /inch = 1.4 acre ft (V_2)
Residential and commercial pervious areas: (use CN of 61) x = 0.0 runoff acre ft (V_3)
Total treatment volume = $V_1 + V_2 + V_3$ = 2.0 +1.4 + 0.0 = **3.4 acre ft**

Calculations using NRCS TR20 with inputs from the site including two subwatersheds, but a weighted curve for the residential area =**1.33 acre ft.**

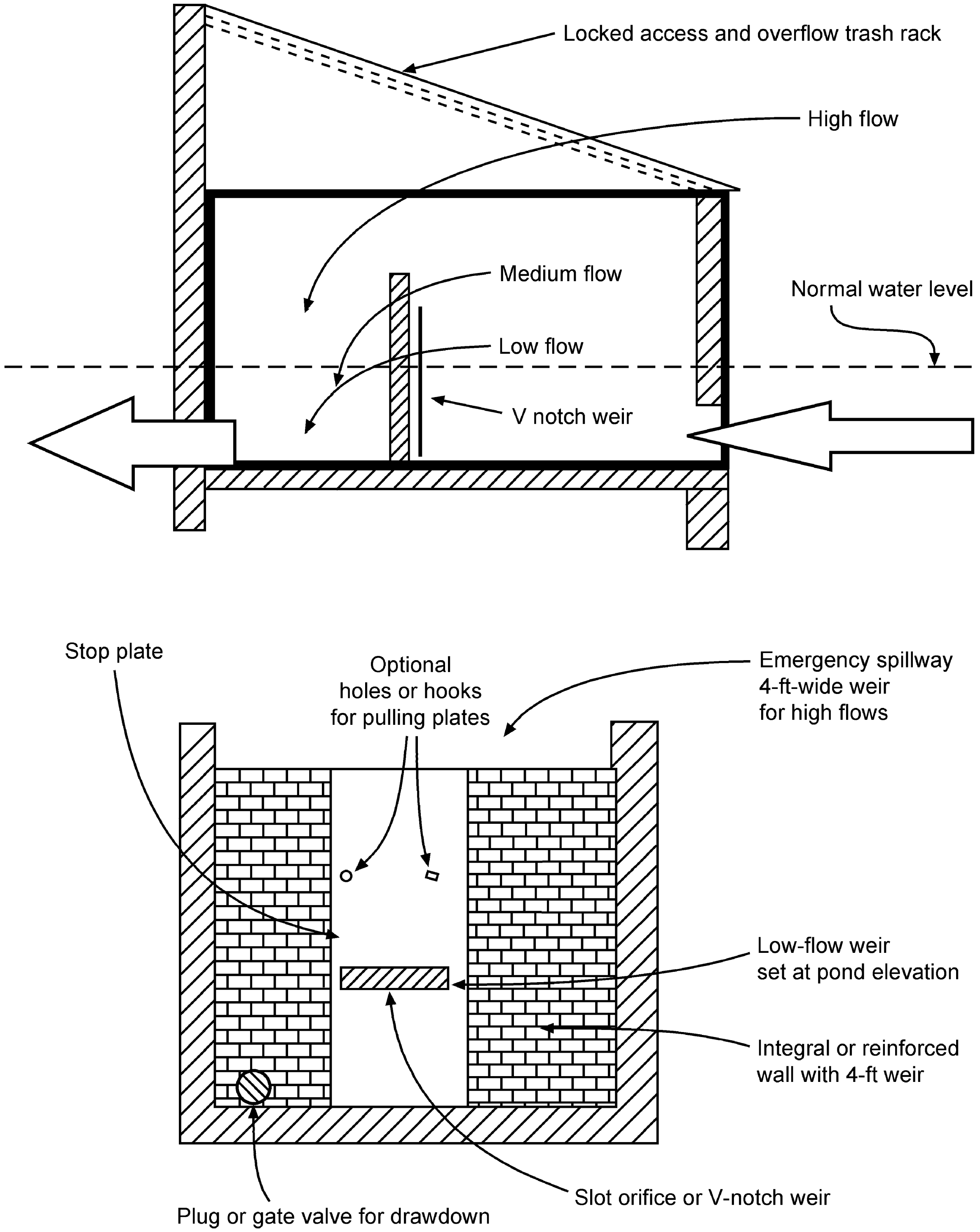


Figure 5.73-1 Schematic of outfall structure

Flood-control Goal

Criteria for two-year through 100-year precipitation events. Most watersheds require that postdevelopment runoff must equal the 10- and 100-year, 24-hour predevelopment events. Structures often must be 0.5 to 3.0 ft above the 100-year flood event. The topography and/or policy usually indicate that the bounce be limited to less than 6 ft.

Flood calculations

The following are the parameters estimated from data in step 1:
Predevelopment curve number, or CN (NRCS, 1986) = 61.
Time of concentration (T of c) = the sum of the times of travel (T of t).
T of t for sheet flow (0.32 hr) + T of t for concentrated flow (0.41 hr.) = T of c = 0.73 hr.

Based on the above conditions, using TR20 to calculate the predevelopment runoff conditions, we calculate the following:

Peak flow for a predevelopment 2-year event = **9.3 cfs.**
Therefore, one-half of the predevelopment 2-year event = 4.65 or ~ **4.7cfs.**
Peak flow for predevelopment 10-year event = **48.3 cfs.**
Peak flow for a predevelopment 100-year event = **120.5 cfs.**

Proposed Conditions

Using a water quality volume of 1.7 acre ft, the runoff from the residential area will be approximately equal to the predevelopment conditions. However, the CN for the commercial area will be 92. Time of concentration (T of c) will be about 800 seconds, or 0.22 hr. The residential area can use a composite CN of 72, although this is questionable if many impervious surfaces are directly connected to the drainage system.

Pond Outlet Design

Once the pond area and outflow rates have been established, the outlet area needs to be designed and sized. It is hoped that the size can be approximated and an iterative process set up to refine the design details. A stage discharge curve is usually established for a given outlet design, then a model is run to determine whether the peak outflows for the water quality volume and the two-, 10- and 100-year events are at or below the applicable criteria.

Outlet or spillway design is a key element for stormwater treatment and for controlling flood discharges. It also affects the velocities in the pond. The design must reflect the discharge limitations on water quality volume, two-year, 10-year and 100-year event restrictions. It also must meet the design features described in part 5.06. The key features are access, maintenance and flow control.

Table 5.73-2 shows the result of the calculations needed to design the pond, based on the hydraulics.

Using the project described above, the outlet can be inserted into a model or other design method using an assumed design. An iterative method can be used to refine the design estimates to better meet project requirements and goals. After several outlet designs had been tried, **we recommend**

Table 5.73-2 Stage discharge area table

Stage	Radius	Area	Average area in acres	Storage in acre ft	Discharge in cfs	Criteria	Basis
100.00	118.00	1.00	0.00	0.00	0.00	5.68	Water Quality Vol.
100.50	123.00	1.09	1.05	0.52	1.89	6.18	Water Quality Vol.
101.00	128.00	1.18	1.14	1.09	2.67	6.69	Water Quality Vol.
101.20	130.00	1.22	1.15	1.33	2.92	6.90	Water Quality Vol.
101.50	133.00	1.28	1.25	1.70	3.27	7.22	Water Quality Vol.
102.00	138.00	1.37	1.32	2.37	3.77	9.30 (4.7)	2-yr Discharge
102.50	143.00	1.47	1.42	3.08	4.22	9.30 (4.7)	2-yr Discharge
102.92	147.20	1.56	1.52	3.72	4.56	9.30 (4.7)	2-yr Discharge
103.00	148.00	1.58	1.57	3.84	4.62	9.30 (4.7)	2-yr Discharge
103.50	153.00	1.69	1.63	4.66	4.99	48.27	10-yr Discharge
104.00	158.00	1.80	1.74	5.53	17.64	48.27	10-yr Discharge
104.50	163.00	1.92	1.86	6.46	27.63	48.27	10-yr Discharge
104.92	167.20	2.02	1.96	7.28	37.02	48.27	10-yr Discharge
105.00	168.00	2.04	2.02	7.44	38.90	120.46	100-yr Discharge
105.50	173.00	2.16	2.10	8.49	51.06	120.46	100-yr Discharge
106.00	178.00	2.29	2.22	9.60	63.82	120.46	100-yr Discharge
106.16	179.60	2.33	2.30	9.97	67.99	120.46	100-yr Discharge
106.50	183.00	2.42	2.37	10.78	76.94	120.46	100-yr Discharge
106.66	184.60	2.46	2.44	11.17	81.19	120.46	100-yr Discharge
107.00	188.00	2.55	2.50	12.02	90.24	120.46	100-yr Discharge

using a 1-ft-by-4-inch slotted outlet in a 3.5-ft-high wall, with 4-ft weir overflow. The recommended outlet gives the results for computer runs using the assumptions of proposed conditions and recommended outlet design seen in Table 5.73-2.

Step 4. Calculate the storage volume below the outlet from the pond.

After the extended detention volume has been determined, the second set of volume calculations that must be addressed in the pond design is "storage volume." This includes sediment volume and permanent pool. Permanent pool volume includes a stilling component for velocity control and a resuspension-control component. In addition, the storage volume may encourage biochemical removal of phosphorus and/or quiescent treatment if the water quality treatment volume of the pond is "oversized."

For a 1-acre pond of approximately circular shape:

r = 118 at surface of pond
r = 108 at the base of the 10-ft bench (see Step 2)
r = 102 at the bottom of the pond

Volume below the outlet:

$$Vol = \left(\frac{r_1 + r_2}{2}\right)^2 \times 3.14 \times d$$

$$V_1 = \left(\frac{102+108}{2}\right)^2 \times 3.14 \times 2 = 69237\ ft^3$$

$$V_2 = \left(\frac{108+118}{2}\right)^2 \times 3.14 \times 1 = 40{,}095\ ft^3$$

$$V_t = V_1 + V_2 = 69{,}237 + 40{,}095 = 109{,}332\ ft^3$$

$$V_t = 109{,}332\ ft^3 \div 43{,}560\ ft\ per\ acre = 2.5\ acre\ feet$$

This example uses a standard design method, and is for illustration only. Many volume designs, including wetland designs or deeper ponds, can be used. Each has its advantages and drawbacks, as addressed in the discussion in this manual.

Bench Design

All ponds should be designed with a bench at 10:1 slope around the edge of the pond, starting at the normal water level. This can be included in the treatment area for most pond designs. The normal slope of a wet pond, inside the bench is 3:1, usually to a depth of 2 to 8 ft. Average pond depth in the treatment area is therefore often about 3 ft. The actual average depth can be 2 to 6 ft if proper design precautions are used.

Sediment Storage Design

Sediment volume should be at least the MPCA permit requirement of 250 cubic feet (ft^3) per acre of impervious surface. It 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:

$$\text{Vol} = \frac{E \times DR \times TE \times A \times Y}{217{,}800 \times G}$$

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 Area Design

At least 10-20% of the area of the pond should be allocated to the inlet area. Design features should include consideration of all the factors considered in the manual The inlet area depth should be at least 3 ft deep and at maximum up to 8 ft deep, depending on the inlet flow and pipe size. The depth should be two times the pipe size for designs that provide dispersion by plunge only. With pipes over 3 ft in diameter, consider having diffusion structures, oversized pipes, concrete walls, berms or other physical measures to create flow dispersion.

Outlet Area Design

The outlet area is recommended as part of the wet pond design. A stilling pool 3 to 8 ft deep usually provides 10-20% of the pond volume, depending on the treatment area design. It usually is located in front of the outlet and is sized to reduce outflow velocities to levels that prevent scour and resuspension.

"Oversized" Ponds

Oversized ponds are designed to include the water quality volume in the permanent pool below the outlet. As has been discussed, in section 5.30 we recommend that this volume provide storage for an event twice the water quality volume, or the runoff from the annual event, which in the metropolitan area is about the 2.5-inch event. Note that the water quality volume is based on an instantaneous volume, not a storage-discharge calculation. Also, the calculation is not twice the water quality volume, but an event twice as large as the water quality event.

Past practice has shown that a smaller volume (*i.e.,* the 2.0-inch event) can be used as an alternative to the 2.5-inch size criteria if the sediment volume is "oversized" to provide 25 years of storage based on NRCS sediment storage calculation methods (see below).

Oversized ponds do not need to meet the outflow rate requirements for the water quality volume, but generally the water quality storm will have a peak discharge less than the water quality outflow rate of 5.66 cfs per acre of pond surface. To prevent resuspension of sediments, these ponds must meet the velocity requirements in the pond for the 1.25-inch and the one-, two-, 10- and 100-year events. Generally, this can be checked by routing the various storms through the pond. The high-flow events (two-, 10- and 100-year events) should also have peak discharges less than the predevelopment discharge, or other rate set by local policy.

Wetlands

Wetlands are another option that can be used in place of an open pool. We encourage the use of wetlands for treatment, but detailed designs of wetland treatment systems is beyond the scope of this manual. We refer you to Schueler and others in the references within this chapter.

Step 5. Address special design considerations.

Special design considerations should address design features described in part 5.08. These include:

Water Quality Standards
Ground Water Pollution
Pollutants in Sediments
Sediment Removal
Permitting Requirements
Dam Safety Requirements
Wetland Impacts
Natural Wetlands
Wetland Conversion
Constructed Wetlands
Wetland Replacement
Other Regulations
Design for Small Watersheds
Design for Winter Runoff Conditions
Dry-weather Flows

Step 6. Address aspects of operation and maintenance.

Operation and maintenance of fences, sediment, erosion, and vegetation must be addressed as described in part 5.07.

CHAPTER 6

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6.00A EROSION PREVENTION AND SEDIMENT CONTROL

This chapter covers the practices that are applicable to construction sites and other clearing, grading or filling that is usually of a temporary nature. Avoiding erosion in the first place by preserving vegetation and using proper site design is always the best choice for water quality. Unfortunately, this is not always possible on an active construction site. Under these circumstances, sediment-control practices that trap sediment before it is carried off site are used. Although many of these practices are effective for trapping coarse sediment, most fine, suspended sediment will not be stopped.

In addition to causing turbid conditions, fine sediment carries a significant load of nutrients and other pollutants that can harm water quality. Effective control of fine sediment is difficult, and requires the use of sediment basins that maintain a permanent pool of water. Even when these structures are used, all fine sediment will not be trapped. That is why it is important to stabilize construction sites and prevent erosion as soon as possible. Virtually all construction sites will affect water quality; however, proper erosion and sediment control can minimize these problems.

HOUSEKEEPING

Many of the best management practices (BMPs) in chapter 7, Pollution Prevention, are applicable to the construction site, including storage, stockpiles, spills and vehicle maintenance. These measures must be addressed by the pollution-control plan for the site. The erosion-and-sediment-control plan is one part of the overall pollution-control plan.

EROSION- AND SEDIMENT-CONTROL PLAN

Careful planning is an important part of erosion and sediment control. With careful planning, problem areas can be avoided, which will minimize both the erosion potential and the cost of sediment-control measures. Also, staging construction to not open up the whole site all at once should be required where possible.

An erosion and sediment control plan should be prepared to document planning decisions and to explain this information to reviewing officials and the contractor. The following steps are generally recommended when preparing an erosion- and sediment-control plan as appropriate for the nature of the project and the sensitivity of the site.

1. Data Collection

The existing site conditions should be evaluated to gather information that will be needed for the erosion-and-sediment-control plan. The information obtained should be plotted on a site map and explained in the narrative portion of the plan. The following data should be collected and may be marked on a topographic map of the site.

a. **Topography.** Prepare a topographic map of the site to show the existing contour elevations at intervals of not more than 2 feet (ft).

b. **Drainage patterns.** Locate and clearly mark all existing drainage patterns on the topographic map.

c. **Soils.** Determine major soil type(s) on the site topographic map. Soils information can be obtained from a soil survey if one has been published for your county. If a soil survey is not available, one can be requested from the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service office. Or, one can enlist the services of a commercial soil-evaluation firm.

d. **Ground cover.** Show the existing vegetation on the site. Features, such as tree clusters and unique vegetation, should be shown on the map. In addition, existing denuded or exposed soil areas should be indicated.

e. **Adjacent areas.** Delineate areas adjacent to the site on the topographic map. Features, such as streams, roads, houses or other buildings and wooded areas, should be shown. Streams which will receive runoff from the site should be surveyed to determine their capacity and stability.

f. **Sensitive areas.** Special note should be made of all environmentally sensitive areas, such as lakes, streams, wetlands, fens, rare biological communities and rare wooded areas.

2. Data Analysis

When all of the data in Step 1 are considered together, a picture of the site's potential and limitations will begin to emerge. The site planner should be able to determine those areas that have potentially critical erosion hazards. The following are some important points to consider in site analysis:

a. **Topography.** The primary topographic considerations are gradient of slope and slope length. The erosion potential increases with slope and length of flow for potential runoff. When the slope has been determined, areas of similar gradient should be outlined. Slope gradients can be grouped into three general ranges of soil erodibility: (1) 0-6%, low-to-moderate erosion hazard; (2) 6-12%, moderate-to-high erosion hazard; and (3) 12% and over, severe erosion hazard.

   Within these slope-gradient ranges, the greater the slope length, the greater the erosion hazard. Highly erosive soils, such as silt sands, will also increase erosion potential. Therefore, when determining potentially critical areas, the site planner should be aware of excessively long slopes and erosive soil conditions.

b. **Natural drainage.** Natural drainage patterns exist on the land. These patterns, which consist of overland flow through swales, depressions and natural watercourses, should be identified in order to plan around critical areas where water will concentrate. Where possible, natural drainageways should be used to convey runoff over and off the site to avoid the expense and problems of constructing an artificial drainage system. Man-made ditches and waterways will become part of the erosion problem if they are not properly stabilized. Care should also be taken to ensure that increased runoff from the site will not cause instability or flooding downstream. Possible sites for stormwater detention should also be located at this time.

c. **Soils.** Soil properties, such as flood hazard, natural drainage depth to bedrock, depth to seasonal water table, permeability, shrink-swell potential, texture and potential erodibility, will exert a strong influence on land-development decisions.

d. **Ground cover.** Ground cover is the most important factor in terms of preventing erosion. Any existing vegetation that can be saved will help prevent erosion. Trees and other vegetation protect the soil as well as beautify the site after construction. If the existing vegetation cannot be saved, the planner must consider staging construction, temporary seeding or temporary mulching. Staging of construction involves stabilizing one part of the site before disturbing another. In this way, the entire site is not disturbed at once and the time without ground cover is minimized. Temporary seeding and mulching involve seeding or mulching areas that would otherwise lie open. The National Pollutant Discharge Elimination System (NPDES) construction stormwater permit requires that temporary cover be installed within 7-21 days depending on the slope for all exposed slopes within 100 ft of the waters of the state of Minnesota. Temporary cover is the most economical way to limit the time of exposure and reduce the hazard of erosion.

e. **Adjacent areas.** This should be the primary focus of all plans. An analysis of adjacent properties should focus on areas downslope from the construction project. Waters that will receive direct runoff from the site should be the major concern. The potential for sediment pollution of these waters should be considered as well as the potential for downstream channel erosion due to increased volume, velocity and peak flow rate of stormwater runoff from the site. The potential for sediment deposition on adjacent properties due to sheet and rill erosion should also be analyzed so that appropriate sediment-trapping measures can be planned.

3. Development of the Site Plan

The principles explained in this manual can be used to minimize long-term effects on water quality from the site, as well as at the time of construction. However, erosion and sediment control planning must be an integral part of the site-planning process, not just an afterthought. The potential for soil erosion should be a significant consideration when deciding upon the layout of buildings, parking lots, roads and other facilities. Costly erosion- and sediment-control measures can be minimized if the site design can be adapted to existing site conditions and good conservation principles are used.

4. Preparing the Plan

When the layout of the site has been decided, a plan to prevent erosion and control sedimentation from leaving the disturbed areas must be formulated.

The site planner should be guided primarily by the NPDES General Construction Permits or local permits which establish a minimum level of control for all projects. The site planner should determine which of these criteria are applicable to the site and select conservation practices that can be used to satisfy the permits.

The following general procedure is recommended for erosion and sediment control planning:

a. **Determine limits of clearing and grading.** Decide exactly which areas must be disturbed to accommodate the proposed construction. Pay special attention to critical areas that must not be disturbed, such as critical slopes or areas where trees should be saved. Where possible, leave a protective zone around critical areas that should not be disturbed. Buffer zones/filter strips around wetlands and adjacent to streams, rivers and lakes should be staked and posted to protect them from construction activity.

b. **Divide the site into drainage areas.** Determine how runoff will travel over the site. Consider how erosion and sedimentation can be controlled in each small drainage area before looking at the entire site. Remember, it is easier to prevent erosion than to contend with sediment after it has been carried downstream.

c. **Select erosion- and sediment-control practices.** Erosion- and sediment-control practices can be divided into three broad categories: (1) vegetative controls, (2) structural controls and (3) management measures.

   Vegetative controls are the first line of defense to prevent erosion. The best way to protect the soil surface is to preserve the existing ground cover. If land disturbance is necessary, temporary stabilization must be used on areas that will be inactive for long periods (7 to 21 days, depending on slope, are described in the NPDES permit).

   Structural controls are generally more costly and less efficient than vegetative controls. Structural controls are usually necessary, since not all disturbed areas can be protected with vegetation. They are usually the second or third lines of defense used to capture sediment before it leaves the site.

   Management measures include:

   - staging the construction on large projects so that one area can be stabilized before another is disturbed.
   - developing and carrying out a regular maintenance schedule for erosion- and sediment-control practices.
   - marking off limits of land disturbance on the site with tape, signs, orange safety fence or other methods, so workers can see areas that are to be protected.
   - making sure all workers understand the major provisions of the erosion and sediment control plan; for example, by holding regular erosion-control meetings before and during the life of the project with owners, contractors and other affected parties, and keeping these people updated if plans are changed.
   - delegating responsibility for implementing the erosion and sediment control to one individual (preferably the job superintendent or foreman).

d. **Plan for post-project stormwater management.** Where increased runoff will cause the capacity of a receiving channel to be exceeded, the site planner will need to select appropriate stormwater-management measures. Any changes to discharges from a site must be in compliance with regulations of the local watershed district or water-management organization. Ponds may be required by MPCA permits, local ordinances or other agencies.

The final step is consolidating the pertinent information and developing it into a specific erosion-and-sediment-control plan for the project. The general criteria planning flow charts at the end of this chapter can help the planner identify needs and select appropriate practices.

The plan consists of two parts: (1) a narrative, commonly known as project specifications and special provisions, and (2) a site plan. The narrative explains site problems and their solutions with all necessary documentation. The site plan is one or a series of maps or drawings that contain information explained in the narrative.

Checklists of items that should be included in a narrative and a site plan are shown in section 6.00b. These checklists can be used by a site planner as a quick reference to determine whether all the major items are included in the erosion-and-sediment-control plan.

Technical Assistance

A number of possible sources of erosion and sediment control planning assistance are available within the state:

Soil and Water Conservation Districts. One of the primary functions of these districts is to provide assistance to landowners for soil conservation planning and implementation. There are 91 soil and water conservation districts throughout the state serving its 87 counties. These districts have elected representatives (supervisors) from each locality.

USDA Natural Resources Conservation Service. The NRCS provides technical assistance and conservation planning and implementation to landowners throughout the country through local soil and water conservation districts. In addition, the NRCS, along with the University of Minnesota, prepares soil surveys within the state.

University of Minnesota Extension Service. The extension service can provide valuable information on establishment of turf and plant materials. The extension service has a number of useful publications and will have soil samples analyzed upon request to determine requirements for turf establishment on a particular site.

PERMITS

A NPDES permit may be required from the Minnesota Pollution Control Agency (MPCA) for activities that involve clearing, grading or filling. Work in waters, including wetlands, may require Minnesota Department of Natural Resources or U.S. Army Corps of Engineers permits. Local units of government may also require permits. For details, contact the appropriate agencies.

LOCAL PROGRAMS

In many areas, erosion and sediment control on construction sites is regulated by local ordinance. These ordinances can be an effective tool for achieving sediment control when there is a program in place to support them. There is a wide diversity in local approaches to these ordinances and the programs used to implement them. Because of the differences in local needs and programs, a model ordinance or program is not presented here. For information about the local erosion-and-sediment-control program and ordinances that are in effect, contact your local unit of government or the local soil and water conservation district.

PLAN REVIEW

When a state or local program requires development of erosion-and-sediment-control plans, a review process involving the owner, contractor and local reviewer should be used. The reviewing team will need a certain level of technical expertise to properly evaluate a plan. The reviewing team needs to be able to read a topographic map and be familiar with the BMPs and general criteria presented in this manual. Experience in soil and water management is helpful in anticipating problem areas. This manual should help a review team become familiar with the practices and criteria. With experience, the review team will learn to detect trouble areas and determine the most effective erosion-control practices.

Several resources, which supplement the information in the plan, may be helpful to the review team. These resources include local stormwater-management plans, wetland inventories, lake inventories, topographic maps and soil surveys. The checklists for site plan and narrative preparation can also be used as checklists for review.

A preconstruction conference with the owner or developer, contractor, and local review team is strongly recommended. During this meeting, the plan can be jointly reviewed, any problems or misconceptions resolved, and a basis for clear communication and good working relations established.

INSPECTIONS

Regular on-site inspections are strongly recommended after construction begins, and are required as a part of compliance with the NPDES Storm Water permit, and possibly other permits. The NPDES permit requires inspections after every rainfall and/or every 7 days. Inspection insures that the approved plan is implemented, provides the land developer with technical assistance as needed, provides a means to determine whether changes to the plan are necessary and to note deviations from the plan when they first occur.

Essential elements of an inspection program include:

- inspection during or immediately following initial installation of sediment controls, in particular, silt fence sediment basins, sediment traps, diversions and other structural measures;
- inspection following every rain event which results in runoff that leaves the construction site, to check for damage to controls;
- inspection prior to seeding deadlines, particularly in the fall;
- final inspection of projects nearing completion to ensure that temporary controls have been removed, stabilization is complete, drainageways are in proper condition, and that the final contours agree with the proposed contours on the approved plan. This inspection should be made prior to the release of any performance guarantees.

In addition, interim inspections should be made, giving particular attention to the maintenance of installed controls.

All inspections must be documented by a written report or log. These reports should contain all rainfall events, the date and time of inspections, dates when land-disturbing activities begin, comments concerning compliance or noncompliance, and notes on any verbal communications concerning the project. A sample inspection log is shown in section 6.00b.

6.00B Erosion Prevention And Sediment Control: INSPECTOR'S COMPLIANCE GUIDE (under Minnesota's General Storm Water Permit for Construction Activity)

When doing inspections:

1. Document time and date of the inspection, weather conditions and on-site contact persons.
2. Report any potential violations to the general contractor and representative of the owner.
3. Document all potential problems in field notes and photographs.

RECORDS

The project's final plans and specifications, which include both temporary and permanent control plan requirements, must be available at the construction site in either a field office or an inspector's or contractor's vehicle.

Temporary Erosion and Sediment Control Plan, completed in accordance with the permit Appendix A must be available within 24 hours.

Permanent Erosion and Sediment Control Plan, completed in accordance with the permit Appendix B must be available within 24 hours.

Records of all inspections must be available within 24 hours, including:

- date of all rainfall events
- date and time of inspections,
- finding of inspections,
- corrective actions taken (including dates and times), and
- documentation of all changes to the Temporary Erosion and Sediment Control Plan made during construction.

If the records requirements are not being complied with, it may be a violation of permit provisions (see permit provisions parts I.C.1, I.C.2.a, I.C.2.b, I.C.2.c).

Permit Coverage Card

A notice of stormwater permit coverage card must be placed in a visible location at the construction site throughout the duration of the project. The card can be placed at any of the following locations:

- construction site entrance, visible from the nearest public roadway;
- where no construction site entrance exists, at a location visible from the nearest public roadway;
- at the field office (if applicable); or

- for linear utility and noncontiguous municipal projects (*i.e.*, city street improvements), at the office responsible for the project's administration.

If the records requirements are not being complied with, it is a violation of permit provisions (see permit provisions parts I.C.2.d, I.C.3).

EROSION AND SEDIMENT CONTROL DURING CONSTRUCTION

Erosion Control. Permittee must use horizontal slope grading, construction phasing, temporary diversions, and/or other practices that minimize erosion.

Exposed slopes within 100 lineal feet from a water of the state, or from a curb, gutter, storm sewer inlet, or temporary or permanent drainage ditch that is connected to a water of the state should have temporary protection or permanent cover within the following time frames:

- steeper than 3:1, within 7 days.
- less than 3:1, but steeper than 10:1, within 14 days.
- flatter than 10:1, within 21 days.

If erosion control is not being complied with, it is a violation of permit provisions (see permit provisions parts I.D.1.a, I.D.1.b).

Ditch and Outlet Stabilization. The bottom of any temporary or permanent drainage ditch constructed to drain water from a construction site must be stabilized within 100 lineal feet from a water of the state. Stabilization must be initiated ***within 24 hours*** of connecting the drainage ditch to a water of the state, existing gutter, storm sewer inlet, drainage ditch or other stormwater-conveyance system that discharges to waters of the state. Stabilization must be completed within five calendar days. (Note: Normally this should be completed before connection)

Before to connecting any pipe to a water of the state or drainage ditch, the pipe's outlet must be provided with temporary or permanent energy dissipation to prevent erosion.

If the ditch and outlet stabilization is not being complied with, it is a violation of permit provisions (see permit provisions parts I.D.1.c, I.D.1.d).

PERIMETER CONTROLS. All down gradient perimeter sediment-control bmps must be in place before any up gradient land-disturbing activity begins.

The permittee must minimize vehicle tracking of sediment off-site wherever vehicles exit the construction site onto paved surfaces. In areas where curb and gutter exist, inlet protection must be in place, along with a plan to keep impervious surfaces free of sediment.

Where 10 or more contiguous acres of exposed soil contribute to a discernible point of discharge, temporary sedimentation basins meeting the following criteria must be provided prior to runoff leaving the site of entering waters of the state:

- Basins must provide 1,800 cubic ft of storage per exposed acre drained.

- Basin outlets must be designed to prevent short circuiting and the discharge of floating debris.

If the perimeter controls are not being complied with, it is a violation of permit provisions (see permit provisions parts I.D.2.a, I.D.2.b, I.D.2.c.1, I.D.2.c.2).

If permanent ponds are required, they can often be used in place of temporary ponds, but construction sediment should be removed before final Notice of Termination has been submitted.

BMP INSPECTION

Inspect all erosion- and perimeter-sediment-control BMPs to ensure integrity and effectiveness. All nonfunctional perimeter-sediment-control BMPs should be repaired when the trapped sediment reaches one-third of the height, or replaced or supplemented with functional BMPs ***within 24 hours of discovery***. All nonfunctional erosion-control BMPs should be repaired or ***replaced within 24 hours*** of discovery, or as soon as field conditions allow access.

Inspect all sedimentation basins to ensure their effectiveness. When the depth of the sediment collected in the basin reaches the heights of the riser, or the storage volume, the basin should be drained and the sediment removed within 72 hours of discovery, or as soon as field conditions allow access.

If inspection and maintenance is not being complied with, it is a violation of permit provisions (see permit provisions parts I.E.1.a, I.E.1.b).

SEDIMENT LEAVING THE SITE

Inspect all drainage ditches and other waters of the state for evidence of sediment leaving the site. Unless the project has received approval or certification for depositing fill into waters of the state, the permittee should remove all sediment in drainageways, catch basins or other waters of the state and restabilize the areas where sediment removal results in exposed soil. The removal and stabilization must take place ***within seven days*** of discovery unless precluded by legal, regulatory or physical access restraints. If precluded, removal and stabilization must take place within seven calendar days of obtaining access.

Inspect all construction site vehicle exit locations for evidence of sediment being tracked off-site. Sediment should be removed from paved surfaces which do not drain back into the construction site ***within 24 hours of discovery***.

If sediment leaving the site is not being inspected and corrected, it is a violation of permit provisions (see permit provisions parts I.E.1.c, I.E.1.d).

VIOLATION FOLLOW-UP

Alleged violations must be brought to the attention of the on-site general contractor and representative of the owner (if that person is present) before leaving the site.

Inspectors should follow this procedure:

1. Thoroughly and accurately document all potential violations through the use of field-inspection notes, photographs and audiovisual equipment, if possible.
2. Write up a detailed inspection report and transmit it to the responsible party as soon as possible after the inspection.
3. Request all potential violations be corrected in accordance with the time frames specified in the permit.
4. Report continued potential violations and inadequate response to inspections to the MPCA.

Violations not remediated in accordance with the time frames specified in the permit are subject to MPCA enforcement action, pursuant to Minn. Stat. §§ 115.071, 116.072, and 609.671, for violation of water-quality environmental laws.

Sample Check List:

CHECKLIST FOR RESOURCE MANAGEMENT PLAN REVIEW
BY: SCOTT SOIL AND WATER CONSERVATION DISTRICT

General information to be included with or as part of the Resource Management Plan (RMP):

- ❑ Project Description – narrative describing the nature and extend of the land disturbing activity.
- ❑ Existing Site Conditions – describe existing topography, drainage patterns and wetlands.
- ❑ Soils – show soil boundaries, include: mapping unit, soil name, slopes and hydrologic group.
- ❑ Location Map – show the site with respect to the surrounding areas.
- ❑ Drawing Data – indicate north, show scale and include benchmark for horizontal and vertical datum.
- ❑ Plan Preparer – name and phone number of individual responsible for plan preparation.
- ❑ Existing Contours – show existing 2 foot contours (at least 200 ft beyond property boundaries).
- ❑ Final Contours – show proposed 2 ft contours for proposed grading.
- ❑ Existing Vegetation – show different cover conditions for the entire site with approximate areas.
- ❑ Property Boundaries – show property boundaries, lot lines, section lines and adjacent plats.
- ❑ Adjacent Areas – narrative describing which neighboring properties will be affected by proposed plat.
- ❑ Elevation and Grade – street and ditch grades, pond, wetland, lake NWL and HWL, pipe inverts.
- ❑ Location of BMP's – location of erosion and sediment control features (BMP Criteria).
- ❑ Location of Utilities – location of existing and proposed utilities if known.

Stormwater Management information to be included on or with the Resource Management Plan

- ❑ Drainage Areas – show existing and proposed drainage areas used for stormwater analysis.

- ❑ Runoff Curve Numbers (RCN's) – detailed breakdown of existing and proposed RCN's used.
- ❑ Impervious Coverage – list assumptions for determining impervious area (house pad, driveway, etc.).
  List new impervious area for each subwatershed (if 1 acre or more drains to a discernible point, a wet detention pond is needed for treatment of runoff prior to discharge to water of the state according to W.W. Walker criteria. If development does not require a pond based on these standards and the development will be creating over an acre of impervious, a wet detention pond is still needed).
- ❑ Drainage Calculations – show calculations for 2, 10 and 100 year peak discharge rates comparing existing and proposed conditions with comparable subwatersheds (TR 55 method or similar methodologies).
- ❑ Precipitation Events – rainfall depths for the 2, 10 and 100 year 24-hour frequency storm events are 2.8, 4.2 and 6.0 inches respectively (reference US Weather Bureau Technical Paper 40). Stormwater ponding will be based on the 6.0 inch event. On site conveyance systems will be designed for the 4.2 inch event.
- ❑ Detention Pond – calculations for pond used to control peak discharge rates (BMP Criteria)
- ❑ Wet Detention Pond – NURP pond used for nutrient removal and peak discharge rate control. Show calculations for estimated inflow and outflow, permanent and temporary storage volumes, mean depth, outlet design, downstream stabilization, emergency spillway, pond profile and pond cross section. (W.W. Walker criteria.)
- ❑ Floatable Skimmers – included on outlet of wet detention ponds. Show construction details on plan.
- ❑ Volume Increase – increased RCN's will increase the volume and duration of runoff leaving the site. These increases in volume and duration may have a negative effect on downstream conveyance.
- ❑ Ground Water Sensitivity – areas identified as being highly susceptible to ground water contamination need the following standards incorporated into the design of the wet detention pond: pond will be lined with 2 ft of impermeable soil.
- ❑ Flood Plain – show protected waters on the grading plan with associated predicted 100 year flood plain. Show calculations for 100 year flood plain predictions.
- ❑ Any land locked areas need to be accounted for in the design analysis for existing conditions. If no outlet is present, what is the predicted 100 year flood elevation and how will this be maintained?
- ❑ Show existing tile lines. Design should plan as though tiles will no longer function unless an easement is supplied for future maintenance.

Erosion Control information to be included on or with the Resource Management Plan

- ❑ Implementation Schedule – list the order of operations for construction activities. Include:
  1. Phasing of construction – start and completion dates for each phase.
  2. List order of operations – all erosion control measures shall be installed and must be functional prior to upslope grading activities taking place.
  3. Contact Person – individual responsible maintaining the erosion and sediment control features.
  4. Disposal or removal of erosion and sediment control features upon final stabilization of project.
  5. Pond clean out – removal of sediment from pond upon final stabilization to design elevations.
- ❑ Critical Erosion Areas – describe areas with potential for serious erosion problems.
- ❑ Limits of Disturbed Area – if 5 acres or more drain to a discernible point, then a temporary sediment control basin is needed to treat runoff.
- ❑ Stabilization of exposed and soil stockpile areas.
- ❑ Stabilizing of waterways and outlets – on site conveyance systems capable of handling the 5 year
  24-hour frequency storm (3.6") without erosion.
- ❑ Adjacent properties protected from erosion.
- ❑ Storm Sewer Inlets – protection provided to prevent sediment laiden water from entering (if applicable).
- ❑ Permanent Erosion Control – grass seed, fertilizer and mulching specifications and rates listed. Mulch anchoring methods and time requirements for permanent seeding listed. (15 days after substantial grading completed).
- ❑ Rip Rap – rip rap placed at all culvert outfalls to minimize scour.
- ❑ Rock Construction Entrances – entrances planned where applicable to minimize tracking onto roads.
- ❑ BMP Construction Details – include on the erosion control plan all construction details for BMP's used.
- ❑ Incorporate horizontal slope grading where applicable.

Wetlands

- ❑ Has wetland delineation been submitted to the LGU and the Scott Soil and Water Conservation District for review.
- ❑ Have the wetlands been surveyed as part of the plat.
- ❑ Show normal water levels and 100 year flood elevations for all wetlands.
- ❑ Have wetland easements been identifed around all wetland areas delineated as wetland.
- ❑ Have wetland regulations been complied with prior to approval of preliminary plat.

6.00C Erosion Prevention and Sediment Control: PROVISIONS IN CONTRACTS

Once the planner has decided upon methods of pollution prevention and control, the plan must be implemented. Work that is being constructed under unit-priced contracts will require a clear and concise explanation of the requirements in contract documents.

The specifications for the job should include a detailed description of the pollution-prevention-and-control work required, stating clearly what is required, when it is required and who is responsible for carrying it out. Do not rely upon a boilerplate statement of the contract that states that the contractor must comply with all local ordinances to cover all pollution-prevention-and-control work. Any work that will be required should be clearly described and included in appropriate bid items. Unit-priced bid items are suggested because they provide more flexibility for quantity variations than do lump-sum bid items. A sample contract specification for including details on this work is shown below.

The best construction-and-management practices possible will not help if they are not installed at the proper time. The contract should specify that sediment-control structures must be installed before the contributing drainage area is disturbed. There are times when this may not be possible, but those are the exception and not the rule. Also, sediment-control structures will not be effective unless they are maintained. Specifications should indicate how and when practices should be maintained. Another provision that may be important to include on some jobs is to require approval for the contractor to open new work areas. This provision is not intended to prevent the contractor from having an efficient operation; it is intended to prevent areas from being stripped several months before they are needed. It also provides an opportunity to discuss sediment-control measures for the area that is about to be opened.

The drawings for a job should show the location for planned pollution-prevention-and-control structures. Details of structures should also be shown so they are installed and maintained properly.

During construction, change orders may be needed to address additional pollution-prevention-and-control needs that are identified in the field. Also, the contractor's operation may eliminate the need for certain measures or may alter the location where they will be most effective. All changes to the plan should be documented.

Sample Construction Specification for Pollution Control

1. **Scope**

   The work should consist of installing measures or performing work to control erosion and minimize delivery of sediment and other pollutants to water and air during construction operations in accordance with these specifications.

2. **Materials**

   All materials should meet the requirements of the Material Specifications listed in these specifications.

3. **Erosion- and Sediment-control Measures**

   The measures should include, where appropriate, but not be limited to, the following (as shown on the drawings or as specified in the appropriate section of this specification).

   - Staging of Earthwork Activities. The excavation and moving of soil materials should be scheduled so that the smallest possible area will be unprotected from erosion for the shortest time feasible.
   - Seeding. Seeding to protect disturbed areas should be used as specified on the drawings or in the appropriate sections of this specification.
   - Soil Stabilization. Soil stabilizers, mulching, sodding, erosion-control blankets or turf-reinforcement mats should be used as appropriate to temporarily protect soil surfaces from erosion.
   - Diversions. Diversions should be used to divert water away from work areas or to collect runoff from work areas for treatment and safe disposition.
   - Stream Crossings. Stream crossings should be used where fording of streams by equipment is necessary.
   - Sediment Basins. Sediment basins should be used to settle and filter out sediment from eroding areas to protect water quality and properties below the construction site.
   - Silt Fences. Silt fences should be used to trap sediment from areas of limited runoff. Silt fences are temporary and should be removed when the contributing area is permanently stabilized.
   - Inlet Protection. Inlet protection is required in the permit and should be used as appropriate.
   - Waterways. Waterways should be protected by the safe disposal of runoff from surface areas, diversions, and other structures or measures.

Sample Construction Specification for Pollution Control *(cont.)*

4. **Chemical Pollution**

   Gasoline, oil, sanitary facilities, such as toilets, and other chemicals or tanks should not be located next to streams, wells or springs. They should be located a sufficient distance to prevent water contamination, and should be installed in accordance with all state and local regulations.

   The contractor should provide tanks, barrels, secondary containment, dikes, spill-collection materials or sumps (using approved materials) to collect pollutants produced as a byproduct of the project's work (for example, drained lubricating or transmission oils, hydraulic fluid, antifreeze/ coolants, greases, soaps or asphalt). At the completion of work, the pollutants should be removed from the site and disposed of in accordance with state and local regulations.

5. **Air Pollution**

   State and local regulations concerning the burning of brush, slash or other materials must be adhered to. In no case will tires be allowed to ignite or be burned with tree or brush piles.

   All public or haul roads used during construction of the project should be maintained as necessary to suppress dust.

6. **Maintenance and Removal**

   All measures and works should be adequately maintained in a functional condition as long as needed during the construction operation. All temporary measures should be removed and the site restored as nearly to original condition as practicable as directed by the engineer.

7. **Measurement and Payment**

   For all items of work for which specific unit prices are established in the contract, each item will be measured to the nearest unit applicable. Payment for each unit will be made at the contract unit price for that item. Such payment will constitute full compensation for all labor, materials, equipment, tools, labor, and other items necessary and incidental to the completion of the work.

8. **Withholding**

   Payment will be subject to withholding of a portion of the contract amount to cover the reasonable value of any uncompleted operation that is designated as a part of the complete project. The amounts withheld for erosion control will be based upon the estimated surface area exposed to probable erosion without the required surface-finishing and turf-establishment operations being completed.

9. **Items of Work and Construction Details**

   In this section, you should list specific practices that are required, material specifications, maintenance requirements, etc. Be certain to specify when they must be installed, and how long they must remain in place.

6.00D Erosion Prevention and Sediment Control: CONSTRUCTION SEQUENCE SCHEDULING

Reduce on-site erosion and off-site sedimentation by performing land-disturbing activities and installing erosion-protection and sedimentation-control practices in accordance with a planned schedule.

CONDITIONS WHERE PRACTICE APPLIES

All land development that clears, grades or fills a significant land area.

PLANNING CONSIDERATIONS

The removal of existing surface ground cover leaves a site vulnerable to accelerated erosion. Good planning will reduce land clearing, provide necessary controls, and restore protective cover.

DEFINITION

A construction sequence schedule is a specified work schedule that coordinates the timing of land-disturbing activities and the installation of erosion-protection and sedimentation-control measures.

PURPOSE

Purpose of the construction sequence schedule is to address erosion prevention and sediment control in an efficient and effective manner. Appropriate sequencing of construction activities can be a cost-effective way to help accomplish this goal. The plan can be open to changes that should be discussed at the erosion control project meetings.

Scheduling considerations are summarized in Table 6.01a. The generalized construction activities shown in the table do not usually occur in a specified linear sequence, and schedules will vary due to weather and other unpredictable factors. However, the proposed construction sequence should be indicated clearly in the erosion-and-sedimentation-control plan.

Construction access is normally the first land-disturbing activity. Exercise care not to damage valuable trees or disturb designated buffer zones. Trees should be protected around the drip line of the branches. Avoid activities that will compact the root zone.

Principal sediment basins and traps should be installed before any major site-grading takes place. Erect additional sediment traps and silt fences as grading takes place to keep sediment contained on site at appropriate locations.

Key runoff-control measures should be located in conjunction with sediment traps to divert water from planned undisturbed areas out of the traps and sediment-laden water into the traps. Install diversions above areas to be disturbed prior to grading. Place necessary perimeter dikes with stable outlets before opening major areas for development. Install additional needed runoff-control measures as grading takes place.

Table 6.00D-1 Considerations for construction scheduling

Construction Activity	Schedule Consideration
Identify and label protection areas (*e.g.*, buffer zones, filter strips, trees).	Site delineation should be completed before construction begins.
Construction access. Construction entrance, construction routes, equipment parking areas and cutting of vegetation (necessary perimeter controls).	First land-disturbing activity -- Establish protected areas and designated resources for protection. Stabilize bare areas immediately with gravel and temporary vegetation as construction takes place.
Sediment traps and barriers. Basin traps, sediment fences, and outlet protection (necessary perimeter controls).	Install principal basins after construction site is accessed. Install additional traps and barriers as needed during grading.
Runoff control. Diversions, silt fence, perimeter dikes, water bars, and outlet protection.	Install key practices after principal sediment traps and before land grading. Install additional runoff control measures during grading.
Runoff conveyance system. Stabilize stream banks, storm drains, channels, inlet and outlet protection, and slope drains.	Where necessary, stabilize stream banks as early as possible. Install principal runoff conveyance system with runoff-control measures. Install remainder of system after grading.
Grubbing and grading. Site preparation: cutting, filling and grading, sediment traps, barriers, diversions, drains, surface roughening.	Begin major grubbing and grading after principal sediment and key runoff control measures are installed. Clear borrow and disposal areas only as needed. Install additional control measures as grading progresses.
Surface stabilization: temporary and permanent seeding, mulching, sodding and installing riprap.	Apply temporary or permanent stabilization measures immediately on all disturbed areas where work is delayed or complete.
Building construction: buildings, utilities, paving.	Install necessary erosion and sedimentation control practices as work takes place.
Landscaping and final stabilization: topsoiling, planting trees and shrubs, permanent seeding, mulching, sodding, installing riprap.	Last construction phase - Stabilize all open areas, including borrow and spoil areas. Remove and stabilize all temporary control measures.
Maintenance	Maintenance inspections should be performed weekly, and maintenance repairs should be made immediately after periods of rainfall.

The main runoff-conveyance system with inlet and outlet protection devices should be installed early, and used to convey stormwater runoff through the development site without creating gullies and washes. Install inlet protection for storm drains as soon as the drain is functional to trap sediment on site in shallow pools and to allow flood flows to safely enter the storm-drainage system. Install outlet protection at the same time as the conveyance system to prevent damage to the receiving stream.

Normally, install stream stabilization, including necessary stream crossings, independently and ahead of other construction activities. It is usually best to schedule this work as soon as weather conditions permit. Site clearing and project construction increases storm runoff, often making stream-bank-stabilization work more difficult and costly.

Begin grubbing and grading as soon as key erosion- and sediment-control measures are in place. Once a scheduled development area is cleared, grading should follow immediately so that protective ground cover can be re-established quickly. Do not leave any area bare and exposed for extended periods (see NPDES permit requirements). Leave adjoining areas planned for development or ones that are to be used for borrow and disposal undisturbed as long as possible to serve as natural buffer zones.

Runoff control is essential during the grading operation. Temporary diversions, slope drains, and inlet and outlet protection installed in a timely manner can be very effective in controlling erosion during this critical period of development.

After the land is cleared and graded, apply surface stabilization on graded areas, channels, dikes and other disturbed areas. Stabilize any disturbed area where active construction will not take place for 21 working days (see NPDES permit requirements) by temporary seeding and/or mulching or by other suitable means. Install permanent stabilization measures after final grading, in accordance with the vegetative plan. Temporary seeding and/or mulching may be necessary during extreme weather conditions with permanent vegetation measures delayed until a more suitable installation time.

Coordinate building construction with other development activities so that all work can take place in an orderly manner and on schedule. Experience shows that careful project scheduling improves efficiency, reduces cost and lowers the potential for erosion and sedimentation problems.

Landscaping and final stabilization is the last major construction phase, but the topsoil stockpiling, tree preservation, undisturbed buffer area, and well-planned road locations established earlier in the project may determine the ease or difficulty of this activity. All disturbed areas should have permanent stabilization practices applied. Unstable sediment should be removed from sediment basins and traps and incorporated into the topsoil, not just spread on the surface. All temporary structures should be removed after the area above has been properly stabilized. Borrow and disposal areas should be permanently vegetated or otherwise stabilized.

In planning construction work, it may be helpful to outline all land-disturbing activities necessary to complete the proposed project. Then list all practices needed to control erosion and sedimentation on the site. These two lists can then be combined in logical order to provide a practical and effective construction-sequence schedule.

DESIGN CRITERIA

At a minimum, the construction sequence schedule should show the following:

- the erosion- and sedimentation-control practices to be installed,
- principal development activities,
- the measures that should be in place before other activities are begun, and
- compatibility with the general construction schedule of the contract.

CONSTRUCTION SPECIFICATIONS

Many timely construction techniques, such as shaping earthen fills daily to prevent overflows and constructing temporary diversions ahead of anticipated storms, can reduce the erosion potential of a site. These type of activities cannot be put on the construction sequence but should be used whenever possible.

Following a planned construction-sequence schedule to control erosion should help keep field personnel aware of the possibilities of erosion prevention through construction management.

MAINTENANCE

Follow the construction sequence throughout project development. When changes in construction activities are needed, amend the sequence schedule in advance to maintain management control.

Orderly modification assures coordination of construction and erosion-control practices to minimize erosion and sedimentation problems. When major changes are necessary, you may want to send a copy of the modified schedule to the local permitting authority.

6.00E Erosion Prevention and Sediment Control: PRESERVATION AND PROTECTION DESIGNATION

DEFINITION

Preservation and protection designation includes practices to preserve and protect desirable features of the landscape (especially endangered species habitats, rare biological communities, wetlands, fens, trees or tree stands, erodible slopes and waters) from damage during project development.

PURPOSE

The purpose is to preserve and protect areas that have present or future value for use in protection from erosion, for landscape and aesthetic value, or for other environmental benefits.

CONDITIONS WHERE PRACTICE APPLIES

Preservation and protection designation should be used on development sites that contain important resources.

PLANNING CONSIDERATIONS

Preserving and protecting trees and other natural plant groups often results in a more stable and aesthetically pleasing development. During site evaluations, note where valuable trees and other natural landscape features should be preserved, then consider these trees and plants when determining the location of roads, buildings or other structures.

Trees that are near construction zones should be either protected or removed, because damage during construction activities may cause their death later.

Features of the landscape should be considered for preservation when they:

- are rare or endangered or have historical significance.
- stabilize the soil and prevent erosion.
- reduce stormwater runoff by intercepting rainfall, promote infiltration, and lower the water table through transpiration.
- moderate temperature changes, promote shade and reduce the force of wind.
- provide buffers and screens against noise and visual disturbance, providing a degree of privacy.
- filter pollutants from the air, remove carbon dioxide from the air and produce oxygen.
- provide a habitat for animals and birds.
- increase property values and improve site aesthetics.

Consider the following characteristics when selecting areas to be protected and saved:

Tree vigor. Preserve healthy trees. Where there are many trees or a large forested area, consider the use of a professional natural resources manager. This person can provide on-site, expert advice on methods to minimize damage to the remaining trees. In areas where oak wilt disease is likely, try to time land-clearing operations so they do not coincide with the spring-summer danger season for insect-caused transmission of this disease. The period from April 15 to July 1 is the critical time when oaks should not be damaged lest they attract the insects that spread oak wilt. (Repair and paint immediately if damaged.)

Vegetation age. Old, picturesque trees may be more aesthetically valuable than smaller, younger trees, but they may require more extensive protection or may be at the end of their life cycle. Remnants of native grass prairies are also very rare and should be protected.

Species. Preserve those species that are most suitable for site conditions and landscape design. Vegetation that is short-lived or susceptible to storm damage or is susceptible to attack by insects or disease may be poor choices for preservation.

Aesthetics. Choose trees that are aesthetically pleasing, shapely, large or colorful. Avoid trees that are leaning or in danger of falling. Occasionally, an odd-shaped tree or one of unusual form may add interest to the landscape if it is strategically located. However, be sure the tree is healthy.

Wildlife benefits. Choose areas that are preferred by wildlife for food, cover, migration or nesting. A mixture of evergreens and hardwoods may be beneficial. Evergreen trees are important for cover during the winter months, whereas hardwoods are more valuable for food.

Water-quality benefits. Preserve vegetation adjacent to lakes, streams and wetlands and in areas of potentially erodible soils.

DESIGN CRITERIA

Construction activities can significantly injure or kill vegetation unless protective measures are taken. Although direct contact by equipment is an obvious means of damaging trees, most serious damage is caused by root zone stress from compacting, filling, or excavating too closely to the tree. Clearly mark boundaries to maintain sufficient undisturbed area around the trees. Consider the use of a professional arborist or forester in the development of the plan.

The following criteria should be considered when developing sites in wooded areas:

- Leave critical areas (such as flood plains, steep slopes and wetlands) with desirable trees in their natural condition or only partially clear them.
- Locate roadways, storage areas and parking pads away from valuable tree stands. Follow natural contours, where feasible, to minimize cutting and filling in the vicinity of trees.
- Select trees to be preserved before siting roads, buildings or other structures.
- Plan ahead for utility installation. Minimize trenching in areas with trees.
- Designate groups of trees and individual trees to be saved on the erosion-and-sedimentation-control plan.
- Do not excavate, traverse or fill closer than 25 ft of the dripline, or perimeter of the canopy, of trees to be saved (MnDOT 2572).
- If possible, disturb no more than 25% of the roots within the dripline of any tree. For forest-grown trees, use the critical root radius approach, which is calculated by multiplying the tree

height by 40%. This approach increases the protection zone for forest-grown trees, which have a smaller canopy spread.

CONSTRUCTION SPECIFICATIONS

1. Place barriers to prevent the approach of equipment within 25 ft of the dripline of trees to be retained (see Figure 6.00E-1).

2. Do not nail boards to trees during building operations.

3. Do not cut tree roots inside the tree dripline.

4. Do not place equipment (including vehicle parking), construction materials, topsoil or fill dirt within the limit of the dripline of trees to be saved.

5. If a tree marked for preservation is seriously damaged, remove it and replace it with a tree of the same or similar species, 2-inch caliper or larger, from balled-and-burlapped nursery stock when activity in the area is complete.

6. During final site cleanup, remove barriers around trees.

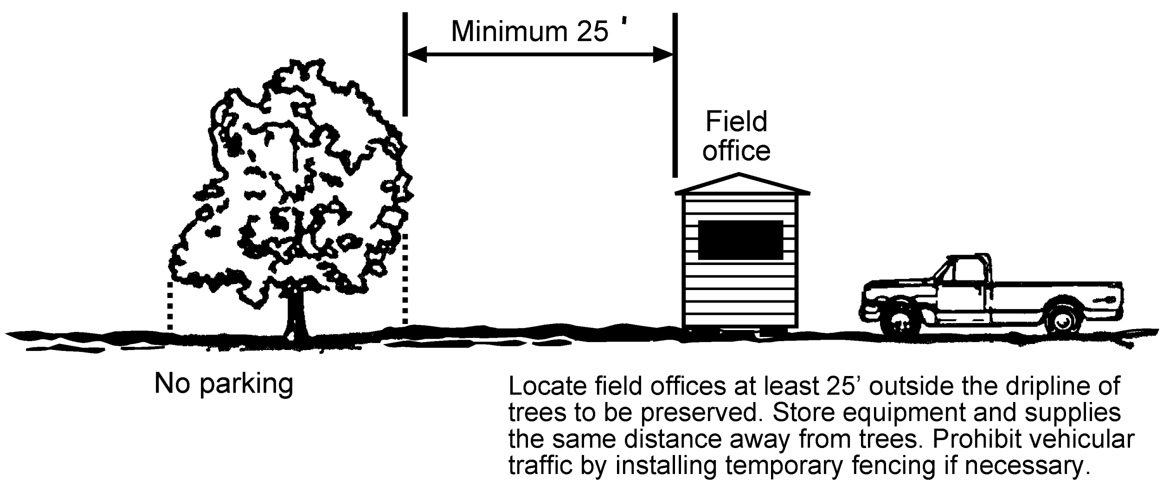


Figure 6.00E-1 Dripline setback (source: Minnesota Department of Transportation, February 1997)

MAINTENANCE

Inspect daily and repair barriers and stakes as needed.

In spite of precautions, some damage to protected trees may occur. In such cases:

- Repair any damage to the crown, trunk or root system immediately.
- Repair roots by cutting off the damaged areas and painting the wounds with tree paint. Spread peat moss or moist topsoil over exposed roots.
- Repair damage to bark by trimming around the damaged area as shown in Figure 6.00E-2, taper the cut to provide drainage, cut out only the injured area--do not paint. During April, May and June, damage to oak trees should be repaired within 15 minutes to prevent against oak wilt. Wounds on oak trees should be painted.
- Cut off all damaged limbs above the tree collar at the trunk or main branch. Use three separate cuts as shown in Figure 6.00E-3 to avoid peeling bark from health areas of the tree.

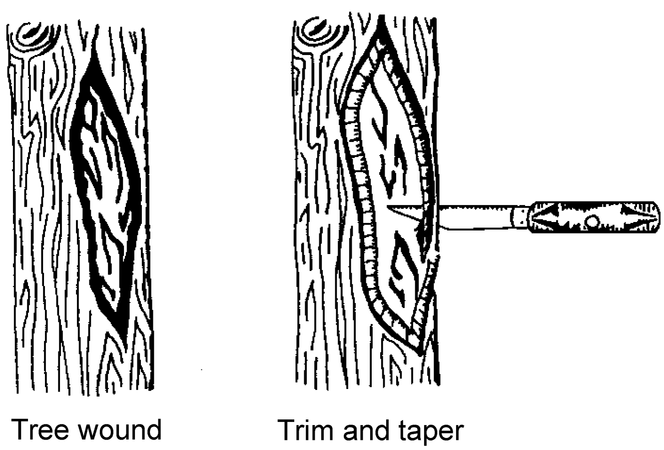


Figure 6.00E-2 Trimming a tree wound (source: North Carolina, May 1994)

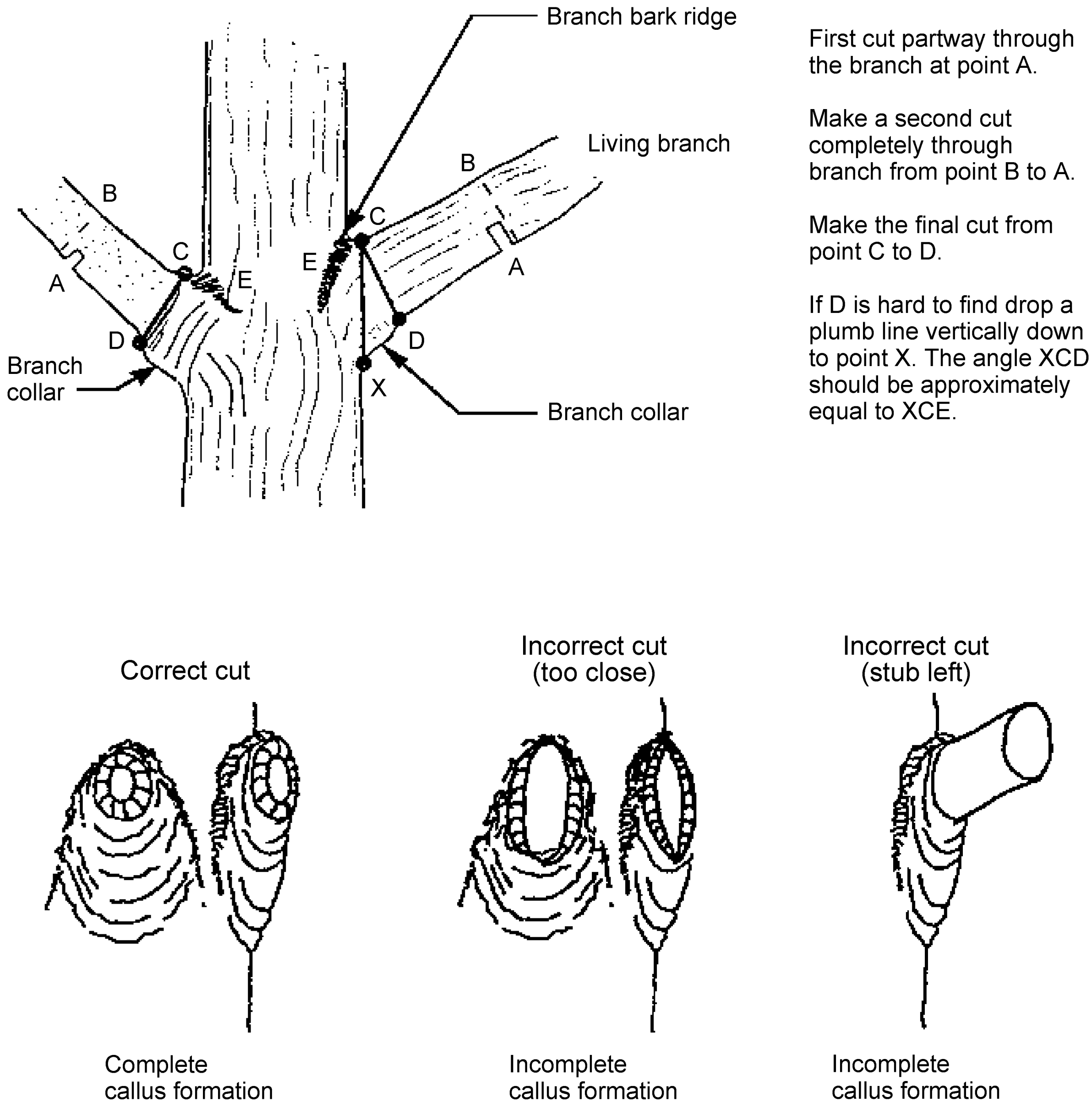


Figure 6.00E-3 The Shigo pruning method leaves a branch collar. Flush pruning does not leave a collar, making it impossible for the wound to close completely and leaving an entry point for decay organisms, insects and diseases. (Source: North Carolina, May 1994.)

6.01 Site Preparation: LAND GRADING

DEFINITION

Land grading is reshaping the ground surface to planned grades as determined by engineering survey evaluation and layout.

PURPOSE

The purpose of grading is to provide more suitable topography for buildings, facilities and other land users; to control surface runoff; and to minimize soil erosion and sedimentation both during and after construction. The plan should define areas that must not be disrupted by grading and filling, including staking, marking and fencing required to prevent damage to these areas.

These practices are applicable where grading to a planned elevation is necessary and practical for the proposed development of a site and for proper operation of sedimentation-control practices.

PLANNING CONSIDERATIONS

Fitting a proposed development to the natural configurations of an existing landscape reduces the erosion potential of the site and the cost of installing erosion- and sedimentation-control measures. It may also result in a more desirable and less costly development.

Before grading begins, decisions must be made on the gradient of cut-and-fill slopes, how they will be protected from runoff, how they will be stabilized and how they will be maintained. The grading plan establishes drainage areas, directs drainage patterns and affects runoff velocities.

The grading plan forms the basis of the erosion-and-sedimentation-control plan. Key considerations that affect erosion and sedimentation include deciding which slopes are to be graded, when the work will start and stop, the degree and length of finished slopes, where and how excess material will be disposed of, and where borrow is needed.

Leaving undisturbed temporary and permanent buffer zones (*i.e.*, vegetated buffer strips) in the grading operation may provide an effective and low-cost erosion-control measure that will help reduce runoff velocity and volume and off-site sedimentation. In developing the grading plan, always consider how to take advantage of undisturbed water-disposal outlets before storm drains or other constructed outlets are installed.

DESIGN CRITERIA

Base the grading plan and installation upon adequate surveys and soil investigations. In the plan, show disturbed areas, cuts, fills, and finished elevations of the surface to be graded. Include in the plan all practices necessary for controlling erosion on the graded site and minimizing sedimentation downstream. Such practices may include--but are not limited to--sediment basins, diversions, mulching, vegetation, vegetated and lined waterways, grade-stabilization structures, and surface and subsurface drains. The practices may be temporary or permanent, depending upon the need after construction is completed.

In the grading plan, make provisions to intercept and conduct all surface runoff to stable watercourses to minimize erosion on newly graded slopes.

Use slope breaks, such as diversions or benches, as appropriate to reduce the length of cut-and-fill slopes to limit sheet and rill erosion and prevent gullying. A spacing guide is shown in Table 6.01-1.

Table 6.01-1 Spacing guide for slope breaks

Slope	Spacing (ft)
50% (2:1)	20
33% (3:1)	35
25% (4:1)	45
15-25%	50
10-15%	80
6-10%	125
3-6%	200
< 3%	300

Stabilize all graded areas with vegetation, crushed stone, riprap or other ground cover as soon as grading is completed or work is interrupted for 21 working days or more. Use mulch, or other temporary measures, to stabilize areas temporarily where final grading must be delayed. The finished cut-and-fill slopes, which are to be vegetated with grass and legumes, should not be steeper than 2:1. Slopes that will be mowed should not be steeper than 3:1. Slopes in excess of 2:1 may warrant mechanically stabilized earth walls, reinforced soil slopes or retaining walls. Roughen the surface of all slopes during the construction operation to retain water, increase infiltration and facilitate vegetation. Finish grade slopes vertically so that machine tracks act as check dams instead of allowing rills to develop.

Do not place cuts or fill so close to property lines without adequately protecting adjoining properties from erosion, sedimentation, slippage, subsidence or other damages, especially at the toe of the slope.

Provide subsurface drainage to intercept seepage in areas with high water tables that would affect slope stability or bearing strength or create undesirable wetness.

Do not place fill next to a channel bank, where it can create bank failure or result in deposition of sediment downstream.

Show all borrow and disposal areas within the project limits in the grading plan, and ensure all disposal locations are adequately drained and stabilized. (Note: Erosion prevention and sediment control is also required for these areas when NPDES permits are required.)

Show environmentally sensitive areas on the grading plan and ensure that they are adequately identified and protected.

Provide stable channels and floodways to convey all runoff from the developed area to an adequate outlet without causing increased erosion or off-site sedimentation.

MAINTENANCE

Periodically check all graded areas and the supporting erosion control practices, especially after heavy rainfalls (or as required by the NPDES permit). Promptly remove all sediment from diversions and other water-disposal practices. If washouts or breaks occur, repair them *immediately*. Prompt maintenance of small, eroded areas before they become significant gullies is an essential part of an effective erosion-and-sedimentation-control plan.

6.02 Site Preparation: BORROW AND STOCKPILE AREAS

PURPOSE

The objective is to control the potential erosion and runoff from borrow or stockpile areas.

DEFINITION

This section deals with borrow and stockpile areas for construction-related activities. Borrow or stockpile areas are areas cleared, graded or filled to provide borrow material or where earthen material for grading or filling is stockpiled. This does not include stockpiles of other materials, such as salt or concrete, which are covered in other sections.

PLANNING CONSIDERATIONS

These areas should be considered a part of the erosion-control plan and should be stabilized on any cleared, graded or filled areas of a construction site.

6.03 Site Preparation: CONSTRUCTION ROAD STABILIZATION

DEFINITION

This practice involves the stabilization of temporary construction-access routes, on-site vehicle transportation routes, and construction parking areas.

PURPOSE

The purpose of this practice is to control erosion on temporary construction routes and parking areas.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all traffic routes and parking areas for temporary use by construction traffic.

PLANNING CONSIDERATIONS

Improperly planned and maintained construction roads can become a continual erosion problem. Excess runoff from roads causes erosion in adjacent areas, and an unstabilized road may become a dust problem. Construction vehicle traffic routes are especially susceptible to erosion because they become compacted and collect and convey runoff water along their surfaces. Rills, gullies and troublesome muddy areas form unless the road is stabilized.

During wet weather, unstabilized dirt roads may become so muddy they are virtually unusable, generating sediment and interrupting work. Proper grading and stabilization of construction routes often saves the contractor money by improving the overall efficiency of the construction operation while reducing the erosion problem.

Situate construction roads to reduce erosion potential, following the natural contour of the terrain. Avoid steep slopes, wet or rocky areas and highly erosive soils.

Controlling runoff from the road surface and adjoining areas is a key erosion-control consideration. Generally, locate construction roads in areas where seasonally high water tables are deeper than 18 inches. Otherwise, subsurface drainage may be necessary. Minimize stream crossings and install them properly (see Practices 6.70, Temporary Stream Crossing, and 6.71, Permanent Stream Crossing).

When practical, install permanent paved roads and parking areas and use them for construction traffic early during the construction operation to minimize site disruption.

DESIGN CRITERIA

Road grade. A maximum grade of 10 to 12% is recommended, although grades up to 15% are permissible for short distances.

Road width. The width of roads should be 14-foot minimum for one-way traffic, 20-foot minimum for two-way traffic.

Side slope of road embankment should be 2:1 or flatter.

Ditch capacity. Roadside ditch and culvert capacities should be designed for the 10-year peak runoff.

Stone surface. Use a 6-inch course aggregate base material or other base specified in *Minnesota Department of Transportation Standard Specifications*.

Permanent road standards. Design standards are available from the Minnesota Department of Transportation (MnDOT) district engineer. Follow these specifications for all permanent roads.

CONSTRUCTION SPECIFICATIONS

1. Clear roadbed and parking areas of all vegetation, roots and other objectionable material.

2. Ensure that road construction follows the natural contours of the terrain if possible.

3. Locate parking areas on naturally flat areas if they are available. Keep grades sufficient for drainage but generally not more than 2-3%.

4. Provide surface drainage, and divert excess runoff to stable areas by using water bars and level spreaders (see part 4.14, Runoff-control Measures).

5. Keep cuts and fills at 3:1 or flatter for safety and stability and to facilitate establishment of vegetation and maintenance.

6. Spread base material evenly over the full width of the road and smooth to avoid depressions.

7. Where seepage areas or seasonally wet areas must be crossed, install subsurface drains and/or geotextile fabric before placing the base material (see Practice 6.81, *Subsurface Drains*).

8. Stabilize and vegetate all roadside ditches, cuts, fills and other disturbed areas or otherwise appropriately stabilize them as soon as grading is complete (*see: Surface Stabilization*).

9. Provide appropriate sediment-control measures to prevent off-site sedimentation.

MAINTENANCE

Inspect construction roads and parking areas periodically for condition of surface. Topdress with new gravel and regrade as needed. Check road ditches and other seeded areas for erosion and sedimentation after runoff-producing rains. Maintain all vegetation in a healthy, vigorous condition. Sediment-producing areas should be treated immediately.

6.04 Site Preparation: TEMPORARY CONSTRUCTION ENTRANCE

DESCRIPTION AND PURPOSE

A temporary construction entrance is a stone pad located where vehicles leave a construction site. The purpose of the stone pad is to provide an area where mud can be removed from tires before a vehicle leaves the site. The stone pad consists of clean rock designed in such a way that vehicle tires will sink in slightly. This helps remove mud from the tires as the vehicle passes over the pad. If a wash rack is used, it provides an area where vehicle tires can be washed.

EFFECTIVENESS

The effectiveness of temporary rock construction entrances for trapping sediment depends upon the length, depth of rock, frequency of use and maintenance, as well as the type of structure used. A newly installed rock construction entrance meeting the recommendations included here will be relatively effective for removing mud from tires before construction vehicles leave the site. However, once the rock voids become clogged with mud, the practice will not serve its intended purpose until the rock is replaced. Washing vehicle tires with pressurized water over a wash rack is very effective for removing mud.

PLANNING CONSIDERATIONS

It is always preferable to prevent mud from being deposited upon a road rather than cleaning the road off later. Mud on a road can create a safety hazard as well as a sediment pollution problem.

In some cases, the action of tires moving over a gravel pad may not adequately clean tires. In those cases, the tires may need to be washed with water before the vehicle leaves the site. When water is used to wash tires, a wash rack will keep the driving surface mud-free. Wash water will need to be treated or recycled.

DESIGN RECOMMENDATIONS

1. The rock used for gravel pads should be a minimum 1- to 3-inch size, such as MnDOT coarse aggregate. The aggregate should be placed in a layer at least 6 inches thick. Generally, the larger the aggregate, the better.

2. The rock entrance should be at least 50 ft long; however, longer entrances may be required to adequately clean tires.

3. Geotextile fabric may be needed under the rock to prevent migration of mud from the underlying soil into the stone.

4. If tires are cleaned with water, the wash water should be directed to a suitable settling area. A wash rack installed on the rock pad may make washing more convenient and effective. The wash rack would consist of a heavy grating over a lowered area. The grating may be a prefabricated rack, such as a cattle guard, or it may be constructed on site of structural steel.

In any case, the wash rack must be strong enough to support the vehicles that will cross it. Figure 6.04-1 shows a typical wash rack installation.

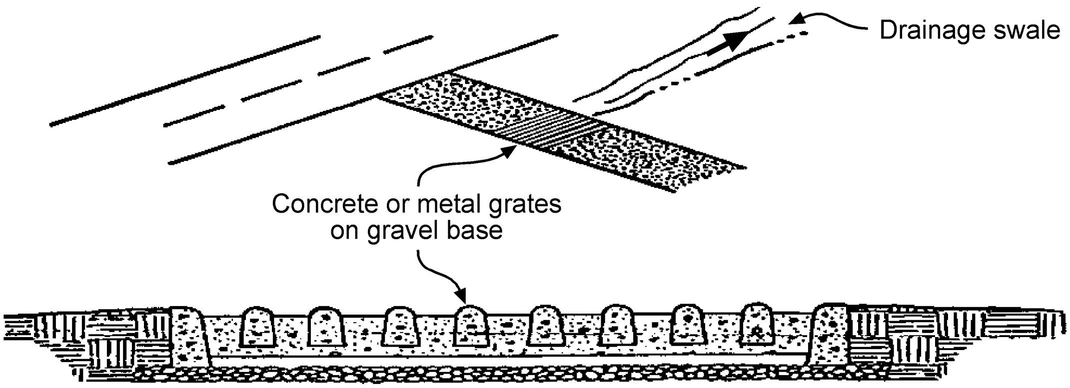


Figure 6.04-1 Typical wash rack installation

MAINTENANCE

The rock pad needs occasional maintenance to prevent the tracking of mud onto paved roads. This may require periodic topdressing with additional rock or removal and reinstallation of the pad.

6.05 Site Preparation: LOT BENCHING

DESCRIPTION AND PURPOSE

Lot benching is the grading of lots within a subdivision so that the runoff from each lot is directed to a stable outlet rather than to an adjacent lot. This practice is most applicable in subdivision developments on hilly or rolling topography.

Lot benching will reduce the slope and length of slope of disturbed areas, thereby reducing the erosion potential. This practice also establishes drainage patterns on individual lots within a subdivision at the time of rough grading. This prevents drainage problems later during home construction.

EFFECTIVENESS

Lot benching can be very effective for controlling erosion on hilly developments. By reducing slope lengths and the steepness of slopes, the potential for erosion is lowered. The amount of benefit derived from this practice depends upon the steepness of the slopes and the erodibility of soils on the site. For example, on a site with 6% slopes and typical slope lengths of 150 ft, lot benching can reduce erosion rates by 85%.

PLANNING CONSIDERATIONS

Lot benching should be done during rough grading operations on the site. In addition to the erosion-control benefits, this allows the planner to establish drainage patterns for the development. After rough grading, the lots should be protected from erosion by temporary or permanent seeding and mulching, depending upon the length of time expected until home construction.

DESIGN RECOMMENDATIONS

1. The lots should be graded so that runoff flows towards the cut slope of the lot located on the uphill side of the lot. This prevents runoff from being directed over a steep slope to a lower lot.

2. Runoff from each lot should be directed to the street, a road ditch or another stable outlet rather than onto an adjacent lot.

3. The final grade of the building site should be as flat as possible.

MAINTENANCE

If an extended period of time passes before homes are built, maintenance of the vegetation may be required. Maintenance may include mowing or spraying to control noxious weeds.

6.06 Site Preparation: TEMPORARY STREAM CROSSINGS

DEFINITION

A temporary stream crossing is a bridge, ford or temporary structure installed across a stream or watercourse for short-term use by construction vehicles or heavy equipment.

PURPOSE

Temporary stream crossing provide a means for construction vehicles to cross streams or watercourses without moving sediment into streams, damaging the stream bed or channel, or causing flooding.

CONDITIONS WHERE PRACTICE APPLIES

Temporary stream crossings are used where heavy equipment must be moved from one side of the stream channel to another, or where light-duty construction vehicles must cross the stream channel frequently for a short time.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Careful planning can minimize the need for stream crossings. Try to avoid crossing streams. Whenever possible, complete the development separately on each side and leave a natural buffer zone along the stream. Temporary stream crossings are a direct source of water pollution, they may create flooding and safety hazards, they can be expensive to construct, and they cause costly construction delays if they are washed out.

Select locations for stream crossings where erosion potential is low. Evaluate stream channel conditions, overflow areas, and surface runoff control at the site before choosing the type of crossing. When practical, locate and design temporary stream crossings to serve as permanent crossings to keep stream disturbance to a minimum.

Plan stream crossings in advance of need and, when possible, construct them during dry periods to minimize stream disturbance and reduce cost. Ensure that all necessary materials and equipment are on-site before any work is begun. Complete construction in an expedient manner and stabilize the area immediately.

When construction requires dewatering of the site, construct a bypass channel before undertaking other work. If stream velocity exceeds that allowed for the in-place soil material, stabilize the bypass channel with riprap or other suitable material. After the bypass is completed and stable, the stream may be stabilized (See also section 4.50, Riprap Stabilization, and part 4.13, Diversion Structures.).

Unlike permanent stream crossings, temporary stream crossings may be allowed to overtop during peak storm periods. However, the structure and approaches should remain stable. Keep any fill needed in flood plains to a minimum to prevent upstream flooding and reduce erosion potential. Use riprap to protect locations subject to erosion from overflow.

A sediment trap is generally not recommended, and may be more damaging to the stream than if none were installed. Where they may be found to be appropriate, in-stream sediment traps may be used immediately below stream crossings to reduce downstream sedimentation. When using an in-stream sediment trap, excavate the basin a minimum of 2 ft below the stream bottom and approximately two times the cross-sectional flow area of the existing channel. Ensure that the flow velocity through the basin does not exceed the allowable flow velocity for the in-place soil material; otherwise, the basin should not be excavated. The use of manufactured sediment-removing mats may also be applicable.

Temporary stream crossings may need local, state or federal permits.

Stream crossings are of three general types: bridges, culverts and fords. Consider which method best suits the site conditions.

Bridges. Where available materials and designs are adequate to bear the expected loading, bridges are preferred for temporary stream crossing (Figure 6.06-1). Bridges usually cause the least disturbance to the streambed, banks and surrounding area. They provide the least obstruction to flow and fish migration. They generally require little maintenance, can be designed to fit most site conditions, and can be easily removed and their materials salvaged. However, bridges are generally the most expensive temporary stream crossings to design and construct. Further, they may offer the greatest safety hazard if they are not adequately designed, installed and maintained, and if washed out, they cause a longer construction delay and are more costly to repair.

In steep watersheds, tie a cable or chain to one corner of the bridge frame and secure the other end to a substantial object. This will prevent flood flows from carrying the bridge downstream, where it may damage other property.

Culvert crossings. Culverts are the most common stream crossings. In many cases, they are the least costly to install, can safely support heavy loads, and are adaptable to site conditions. Construction materials for culverts are readily available and can be salvaged. However, the installation and removal of culverts causes considerable disturbance to the stream and surrounding area. Culverts also offer the greatest obstruction to flood flow and are subject, therefore, to blockage and washout (Figure 6.06-2).

Fords. Fords made of stabilizing material, such as rock, are often used in steep areas subject to flash flooding, where normal flow is shallow (less than 3 inches deep) or intermittent. Fords should only be used where crossings are infrequent. Fords are especially adapted for crossing wide, shallow watercourses (Figure 6.06-3).

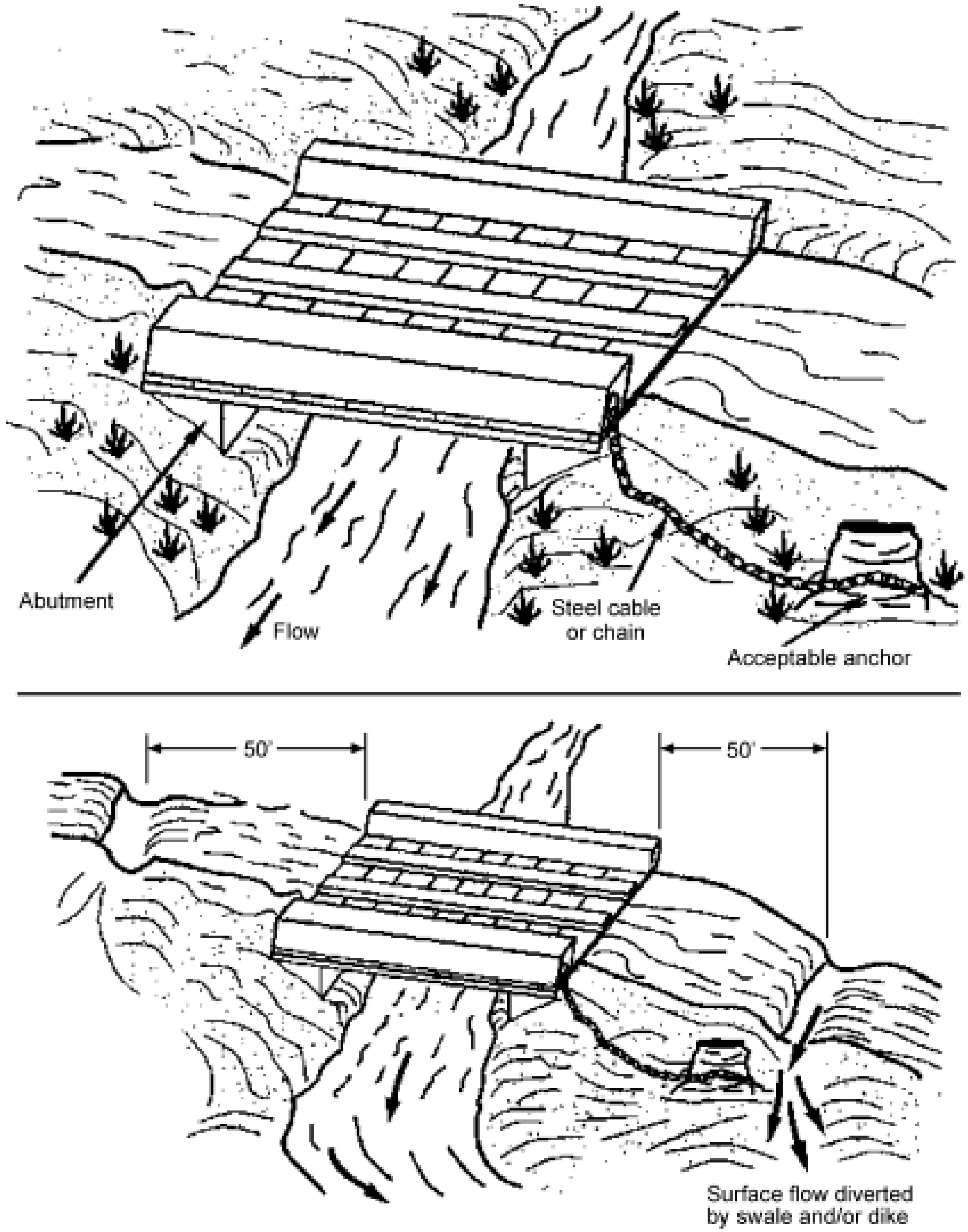


Figure 6.06-1 Temporary bridge crossing (source: *1983 Maryland Standards and Specifications for Soil Erosion and Sediment Control*)

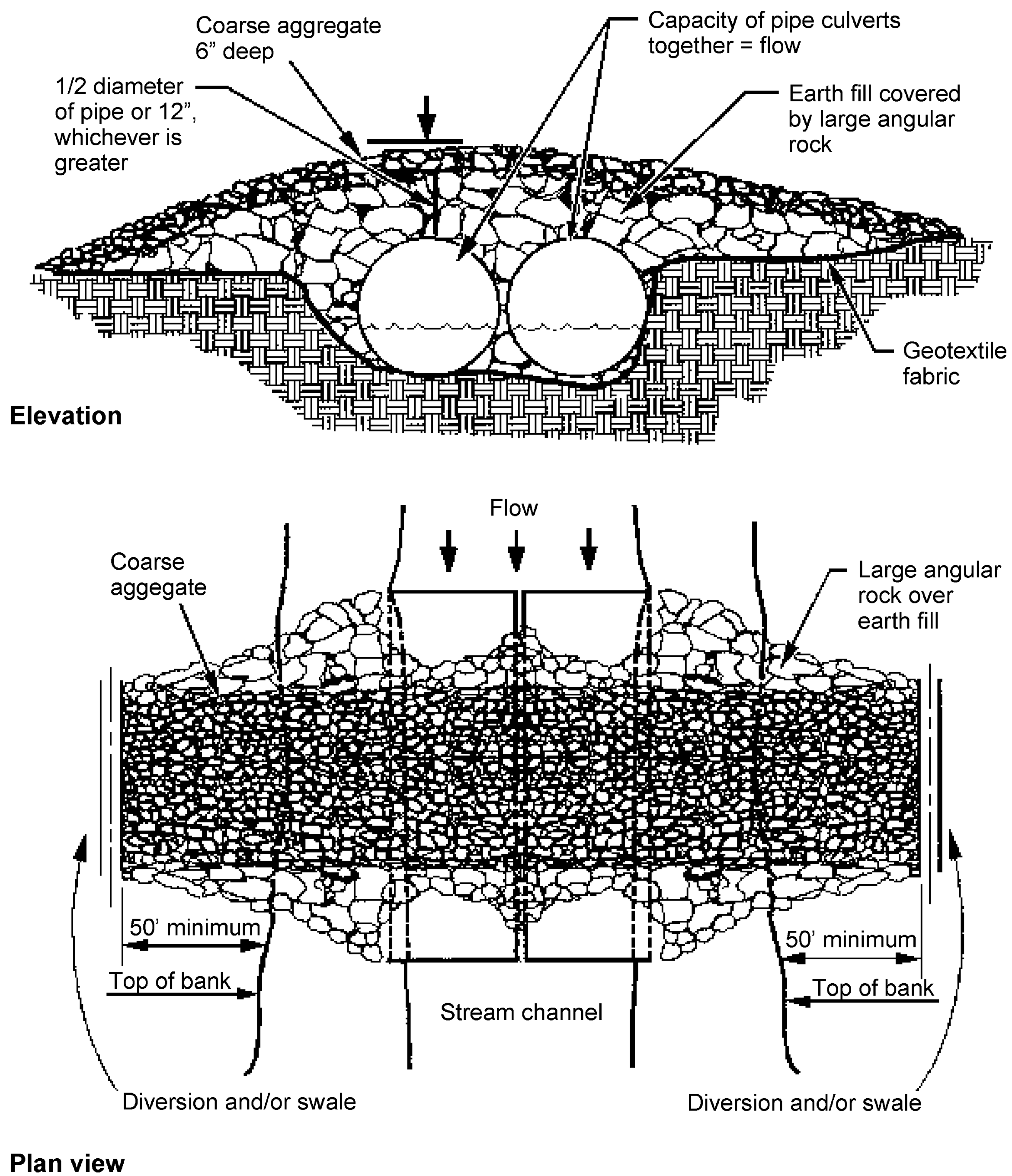


Figure 6.06-2 Temporary culvert crossing (source: Virginia Department of Conservation and Recreation, 1992)

When properly installed, fords offer little or no obstruction to flow, can safely handle heavy loading, are relatively easy to install and maintain, and, in most cases, may be left in place at the end of the construction.

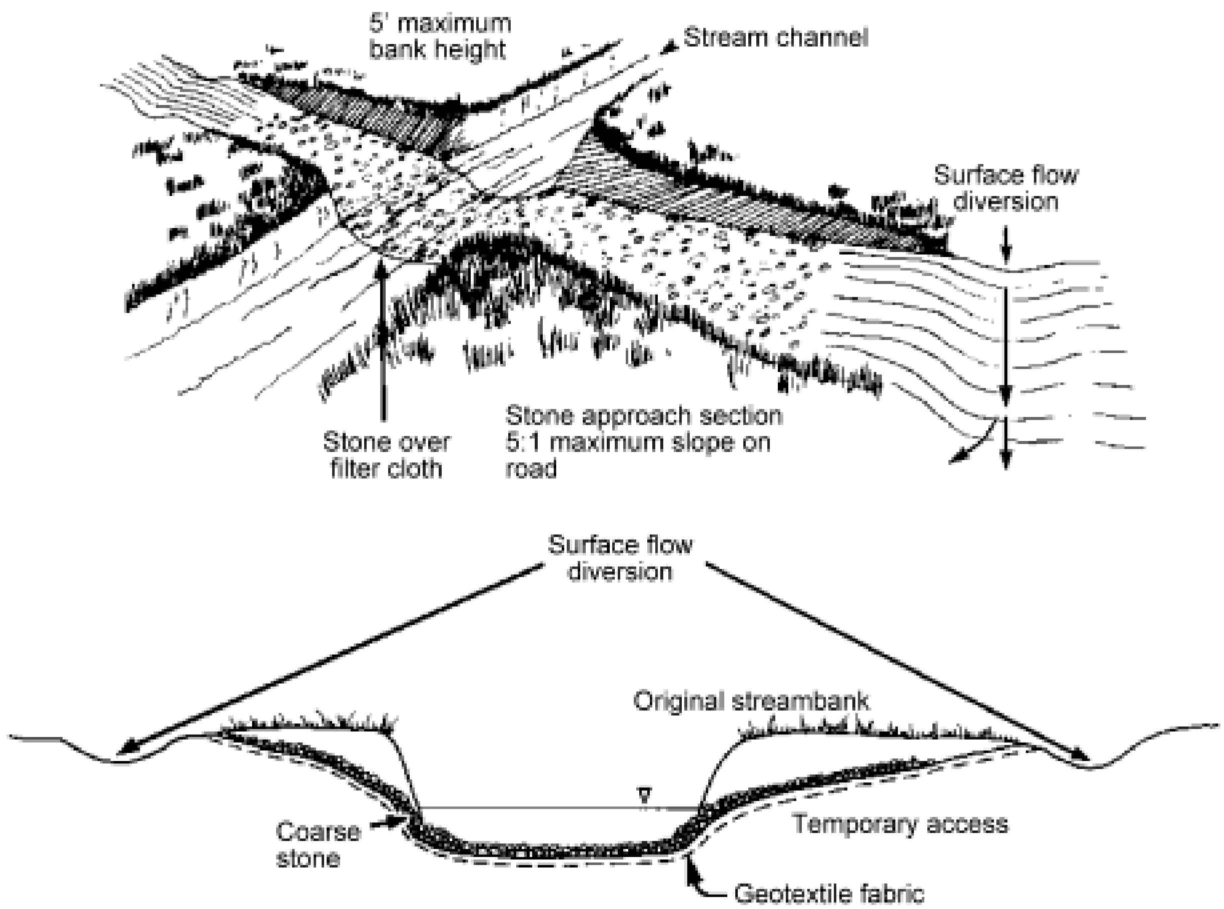


Figure 6.06-3 A well-constructed ford offers little obstruction to flow, while safely handling heavy loadings. (Source: Virginia Department of Conservation and Recreation, 1992.)

Problems associated with fords include the following:

- Approach sections are subject to erosion. Generally, do not use fords where bank height exceeds 5 ft.
- Excavation for the installation of the riprap-gravel bottom and filter material causes major stream disturbance. In some cases, fords may be adequately constructed by shallow filling without excavation.
- The stabilizing material is subject to washing out during storm flows and may require retrieval and replacement.
- Mud and other contaminants are brought directly into the stream on vehicles unless the use of crossings is limited to no-flow conditions.

DESIGN CRITERIA

Temporary stream crossings may be subject to local, state or federal requirements and restrictions. In addition to erosion and sedimentation control, structural stability, utility and safety must be taken into consideration when designing temporary stream crossings. Bridge designs, in particular, should be undertaken by a qualified engineer.

- The anticipated life of a temporary stream crossing structure is usually considered to be one year or less. Remove the structure immediately after it is no longer needed.

- As a minimum, design the structure to pass bankfull flow or peak flow, whichever is less, from a two-year peak storm, without overtopping.

- Ensure that design flow velocity at the outlet of the crossing structure is nonerosive for the receiving stream channel (see part 4.53, Riprap, or part 4.45, Outlet Stabilization Structures).

- Consider overflow for storms larger than the design storm and provide a protected overflow area.

- Design erosion-control practices associated with the stream crossing to control erosion from surface runoff at the crossing and during a 10-year peak storm runoff.

CONSTRUCTION SPECIFICATIONS

1. Keep clearing and excavation of the stream banks and bed and approach sections to a minimum.

2. Divert all surface water from the construction site onto undisturbed areas adjoining the stream. Line unstable stream banks with riprap or otherwise appropriately stabilize them.

3. Keep stream crossings at right angles to the stream flow. This is particularly important when culverts are used.

4. Align road approaches with the center line of the crossing for a minimum distance of 30 ft. Raise bridge abutments and culvert fills a minimum of 1 ft above the adjoining approach sections to prevent erosion from surface runoff and to allow flood flows to pass around the structure.

5. Stabilize all disturbed areas subject to flowing water, including planned overflow areas, with riprap or other suitable means if design velocity exceeds the allowable for the in-place soil.

6. Ensure that bypass channels necessary to dewater the crossing site are stable before diverting the stream. Upon completion of the crossing, fill, compact and stabilize the bypass channel appropriately.

7. Remove temporary stream crossings immediately when they are no longer needed. Restore the stream channel to its original cross section, and smooth and appropriately stabilize all disturbed areas.

8. Leave in-stream sediment traps in place to continue capturing sediment.

MAINTENANCE

Inspect temporary stream crossings after runoff-producing rains to check for blockage in channel, erosion of abutments, channel scour, riprap displacement or piping. Make all repairs immediately to prevent further damage to the installation.

6.07 Site Preparation: PERMANENT STREAM CROSSINGS

DEFINITION

A permanent stream crossing is a structure installed across a stream or watercourse for the purpose of crossing.

PURPOSE

Permanent stream crossings provide a suitable means for construction and post-construction traffic to cross a watercourse.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Planning considerations for permanent stream crossings are essentially the same as for temporary ones except that permanent stream crossings should not be subject to frequent overflow.

Permanent stream crossing locations are selected primarily on flooding potential, traffic safety and traffic patterns of the area served, but erosion and sediment control must also be considered. To minimize flooding and erosion problems, locate permanent stream crossings in the higher, better-drained sections of the stream reach whenever practical.

Where road water enters the stream, install permanent protection measures, such as paved flumes, concrete head walls, riprap outlet structures or stabilized pipe drops, to prevent erosion. During installation of the crossing, locate sedimentation-control measures to protect the stream. Protect the stream section at the crossing from erosion from flood-flow velocities by using paving or properly designed riprap.

DESIGN CRITERIA

Design permanent stream crossings in accordance with standards and specifications, considering maximum loading anticipated, safety, flow capacities and other requirements for MnDOT installation approval. Crossings are also subject to Minnesota Department of Natural Resources or federal permit requirements.

Minimum design criteria for erosion control are:

- Ensure that the 10-year peak flow velocity at the stream crossing outlet is nonerosive to the receiving stream.
- Ensure that all permanent erosion-control practices provide adequate protection for the 10-year peak storm runoff.

CONSTRUCTION SPECIFICATIONS

1. Keep clearing and excavation of the stream banks and bed and approach sections to a minimum.

2. Divert all surface water from the construction site onto undisturbed areas adjoining the stream. Line unstable stream banks with riprap or otherwise appropriately stabilize them.

3. Keep stream crossing at proper angles to the stream flow. This is particularly important when culverts are used.

4. Align road approaches with the center line of the crossing for a minimum distance of 30 ft. Raise bridge abutments and culvert fills a minimum of 1 ft above the adjoining approach sections to prevent erosion from surface runoff and to allow flood flows to pass around the structure.

5. Ensure that bypass channels necessary to dewater the crossing site are stable before diverting the stream. Upon completion of the crossing, fill, compact and stabilize the bypass channel appropriately.

6. Install protective ground covers to provide permanent erosion protection and improve the appearance. However, choose protective ground cover that does not interfere with driver site distance from roadway.

7. Ensure that permanent measures needed to control erosion from road-water runoff (such as riprap and paved channels, paved flumes, or riprap outlet protection) meet all construction requirements for those practices.

MAINTENANCE

Inspect permanent stream crossings periodically and after major storms to check for channel blockage, erosion of abutments, channel degradation, riprap displacement, slope failure and piping. Make all needed repairs immediately to prevent further damage to the installation.

6.10 Flow Control

This part describes practices that prevent pollution by controlling flow. The basic concept is to keep flows off areas that can cause problems.

6.11 Flow Control: TEMPORARY DIVERSIONS

DESCRIPTION AND PURPOSE

A temporary diversion is a temporary ridge of compacted soil, a channel, a flexible conduit such as a poly tube, or any combination of these located across a slope above a disturbed area.

Temporary diversions prevent erosion by diverting runoff away from unprotected slopes to a stable outlet. They can also be used to direct sediment-laden runoff to a sediment-trapping structure.

EFFECTIVENESS

Although temporary diversions will not control the detachment of soil particles from raindrop impact, they will reduce the amount of runoff flowing over a disturbed area. This will limit the potential transport of these particles by runoff. Temporary diversions can also be effective for controlling rill and gully erosion by preventing concentrated runoff from flowing over erosion-prone areas.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Temporary diversions normally have a life of two years or less.

If the temporary diversion will remain in place for longer than 30 days, it should be protected with vegetation. The grade of the diversion channel should be flat enough so that an erosion problem is not created.

If the diversion will be left in place permanently, it should meet the criteria for Storm Water Conveyance Channels (see part 4.12).

DESIGN RECOMMENDATIONS

1. Capacity is based upon maximum drainage area rather than storm frequency.

2. The maximum drainage area should be five acres.

3. Channel grades of less than 2% should be stabilized with vegetation. Grades greater than 2% should be stabilized with erosion-control blankets or turf-reinforcement mats. If flow velocities could exceed 9 ft per second (fps), rock riprap or turf reinforcement mats should be considered.

4. The temporary diversion should be at least 1.5 ft in height when measured from the channel. The side slopes should be at least 1:1. See Figure 6.11-1 for a typical cross section.

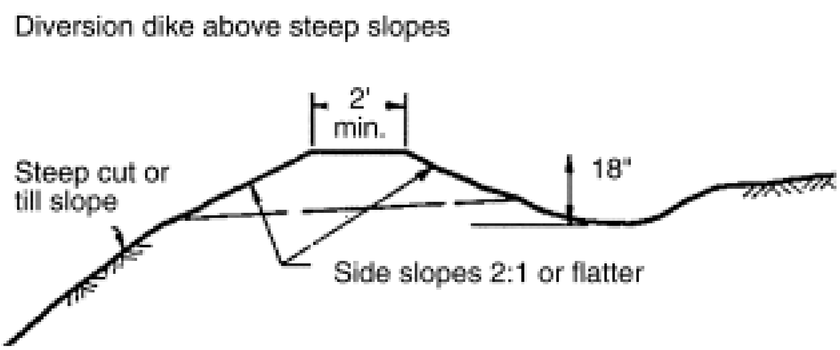


Figure 6.11-1 Cross section of temporary earthen diversion dike

5. If the diverted runoff is sediment-free, it should be released through a stable outlet or channel. If the runoff is sediment-laden, it should be diverted to a sediment-trapping structure.

MAINTENANCE

The diversion should be inspected after all significant runoff events. Any damage should be repaired promptly.

6.12 Flow Control: DIVERSION DIKES (Perimeter Protection)

DEFINITION

A diversion dike is a dike or dike and channel constructed along the perimeter of a disturbed construction area.

PURPOSE

Diversion dikes are used to prevent storm runoff from entering the work area or to prevent sediment-laden runoff from leaving the construction site.

CONDITIONS WHERE PRACTICE APPLIES

Diversion dikes may be located at the upslope side of a construction site to prevent surface runoff from entering the disturbed area or at the downslope side of the work area to divert sediment-laden runoff to on-site sediment traps or basins. Diversion dikes do not usually encircle the entire area.

The upslope dike can improve working conditions at the construction site and prevent erosion. The downslope dike assures that sediment-laden runoff will not leave the site without treatment.

PLANNING CONSIDERATIONS

A diversion dike is a special application of a temporary or permanent diversion. It differs from other diversions in that the location and grade are usually fixed, and the cross section and stabilization requirements are based on the existing grade of the work boundary. Hence, the design cross section may vary significantly throughout the length. Give special care to avoid erosive velocities in steep areas. Identify areas where sedimentation will occur since they are often subject to overtopping.

Immediately stabilize diversion dikes after construction, but make sure the channel-flow area is stabilized during construction. Exercise caution in diverting flow to be certain that the diverted water is released through a stable outlet and that the flow will not cause flood damage. Diversion dikes may be either temporary or permanent depending on site conditions (Figure 6.12-1).

DESIGN CRITERIA

Drainage area. Use diversion dikes to protect areas of five acres or less.

Capacity. The capacity of a diversion dike should be consistent with the hazard involved and design life and with a 10-year peak runoff minimum.

Velocity. See part 4.12. Stormwater Conveyance Channels, for channel-lining measures to use for expected flow velocity and shear stresses.

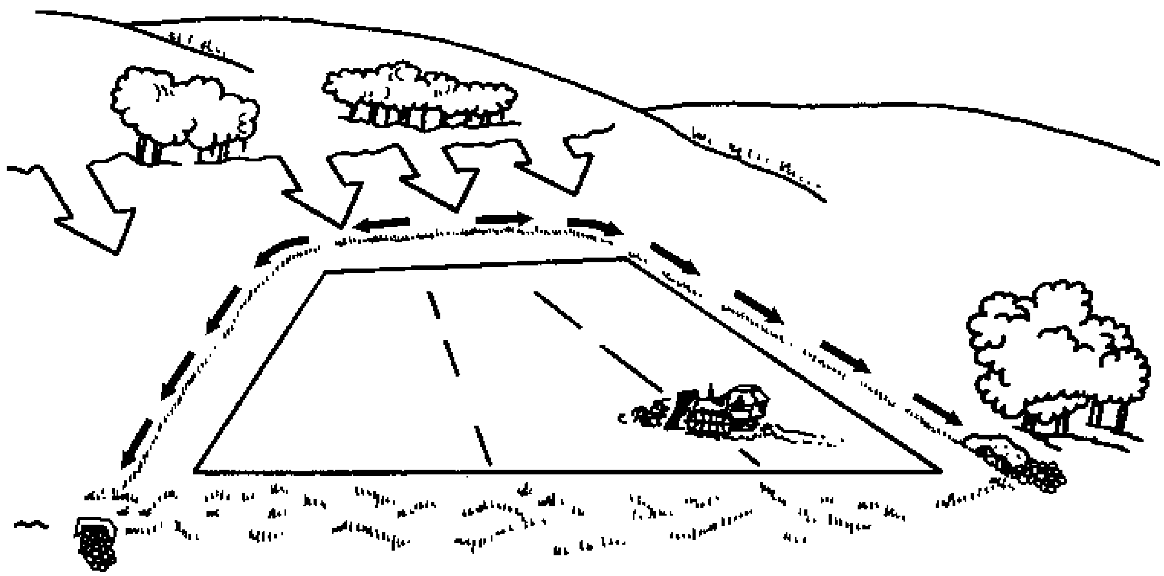


Figure 6.12-1 Perimeter dikes prevent surface runoff from entering construction sites. (Source: North Carolina, May 1994.)

Dike Design. Side slope: 2:1 or flatter; 3:1 or flatter where vehicles must cross; Width: 2.0 ft minimum top width. Height: 1.5 ft minimum. Freeboard: 0.5 ft minimum. Settlement: 10% of fill height minimum.

Channel Design. Shape: parabolic, trapezoidal, or V-shaped. Side slope: 2:1 or flatter; 3:1 or flatter where vehicles must cross. Stabilization: based on velocity by reaches.

Grade. Dependent on site topography. Channel should have positive grade.

Outlet. Divert sediment-laden water into a temporary sediment trap or sediment basin. Runoff from undisturbed areas should empty into an outlet-protection device, such as a level spreader or riprap outlet structure, unless well-stabilized natural outlets exist.

CONSTRUCTION SPECIFICATIONS

1. Remove and properly dispose of all trees, brush, stumps and other objectionable material. Fill and compact, to natural ground level or above, all ditches and gullies that will be crossed by machinery.

2. Disk the base of the dike before placing fill.

3. Ensure that the constructed cross section meets all design requirements.

4. Compact the dike by tracking with compaction equipment.

5. Ensure that the top of the dike is not lower at any point than the design elevation plus the specified settlement after it has been compacted.

6. Leave sufficient area along the dike to permit machine regrading and cleanout.

7. Immediately stabilize and vegetate the dike after its construction and stabilize the flow portion in accordance with design requirements.

MAINTENANCE

Inspect diversion dikes once a week and after every rainfall. Immediately remove sediment from the flow area and repair the dike.

Check outlets and make timely repairs as needed to avoid gully formation. When the area above the temporary diversion dike is permanently stabilized, remove the dike and fill and stabilize the channel to blend with the natural surface.

6.13 Flow Control: TEMPORARY RIGHT-OF-WAY DIVERSIONS

DESCRIPTION AND PURPOSE

A temporary right-of-way (roadway) diversion is a ridge of compacted soil, loose rock or gravel placed across roads, disturbed right-of-ways or similar long sloping areas that are disturbed (see Figure 6.13-1). This ridge is used to divert water onto stabilized areas and to shorten the distance that runoff will flow down a long slope. This reduces the erosion potential of the runoff.

This practice is normally used where there will be little or no construction traffic using the right-of-way until it is stabilized. Gravel diversions are more applicable where traffic must use the right-of-way before it is stabilized.

EFFECTIVENESS

The effectiveness of temporary right-of-way diversions for controlling erosion depends upon the land slope and erodibility of the soil. In most cases, use of this practice will provide good control of rill and gully erosion in the disturbed right-of-way area.

PLANNING CONSIDERATIONS

Construction of overhead utilities, underground utilities and roads often requires the clearing of long strips of right-of-way over sloping terrain. Runoff may concentrate on these disturbed areas and can have a high potential for erosion. If the runoff is diverted off these disturbed areas onto stabilized areas at regular intervals, the potential for erosion can be greatly reduced. This will also aid in the establishment of permanent cover by reducing the potential for rills and gullies. Once the right-of-way is stabilized, temporary diversions can be removed.

DESIGN RECOMMENDATIONS

1. Temporary right-of-way diversions should be spaced according to the land slopes as shown in Table 6.13-1.

Table 6.13-1

Land Slope (percent)	Diversion Spacing (feet)
1	300
2	200
3-5	150
5 or greater	100 (or less)

2. The maximum drainage area above the diversions should be three acres. With increase in slope, the watershed should be smaller.

3. The width of a diversion base should be at least 6 ft. When vehicles will cross the diversion, the base should be 16 ft with a top width of 4 ft. This is to prevent vehicles from becoming hung up on the ridge.

4. The diversion should be at least 18 inches high. The slope of the diversion channel should be less than 2%.

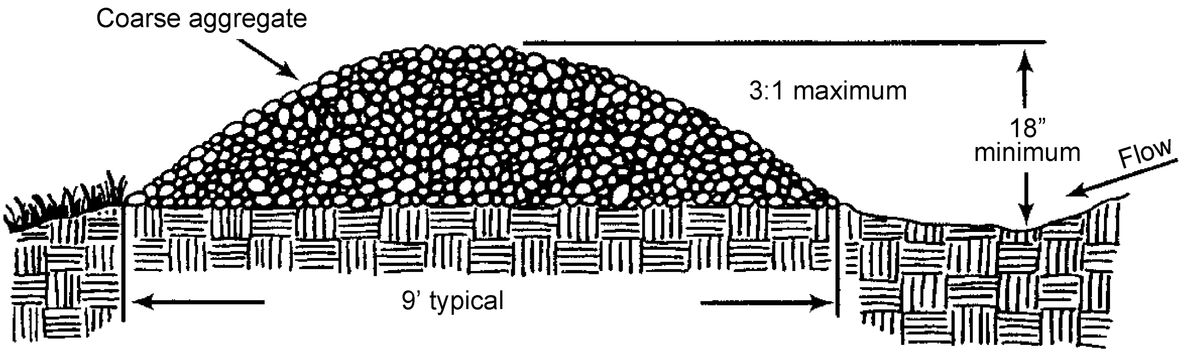


Figure 6.13-1 Temporary gravel diversion dike for vehicle crossing (modified from Virginia Department of Conservation and Recreation, 1992)

5. Before the diversion is constructed, the base should be scarified to provide a bond between the existing soil and the fill material.

MAINTENANCE

Diversions should be inspected regularly and repaired as needed for scour, bank failure, breaching, obstructions and other damage.

6.14 Flow Control: RIGHT-OF-WAY DIVERSIONS (WATER BARS)

DEFINITION

A right-of-way diversion, or water bar, is a ridge or ridge and channel constructed diagonally across a sloping road or utility right-of-way that is subject to erosion.

PURPOSE

Water bars are used to limit the accumulation of erosive volumes of water by diverting surface runoff at predesigned intervals.

CONDITIONS WHERE PRACTICE APPLIES

Use a water bar where protection is needed to prevent erosion from runoff on sloping access rights-of-way or other long, narrow, sloping areas generally less than 100 ft in width.

PLANNING CONSIDERATIONS

Construction of access roads, power lines, pipelines and similar installations often requires clearing long, narrow rights-of-way over sloping terrain (Figure 6.14-1). Disturbance and compaction promotes gully formation in these cleared strips by increasing the volume and velocity of runoff. Gully formation may be especially severe in tire tracks and ruts. To prevent gullying, runoff can often be diverted across the width of the right-of-way to undisturbed areas by using small, predesigned diversions. Give special consideration to each outlet area as well as to the cumulative effect of added diversions. Use gravel to stabilize the diversion where significant vehicular traffic is anticipated.

DESIGN CRITERIA

Height. A water bar should have a 18-inch minimum, measured from the channel bottom to the ridge top.

Side slope. The side slope should be 2:1 or flatter; 3:1 or flatter where vehicles cross.

Table 6.14-1 Spacing of water bars on right-of-way less than 100 ft wide

Slope (%)	Spacing (ft)
< 5	125
5 to 10	100
10 to 20	75
20 to 35	50
> 35	25

Base width of ridge. The base width of a water bar should have a 6 ft minimum (Figure 6.14-2).

Spacing of water bars is shown in Table 6.14-1.

Figure 6.14-1 Water bars to protect utility right-of-way (source: North Carolina, May 1994)

Grade and angle. A crossing angle should be selected to provide a positive grade not to exceed 2%.

Outlet. Diversions should have stable outlets, either natural or constructed. Site spacing may need to be adjusted for field conditions to use the most suitable areas for water disposal.

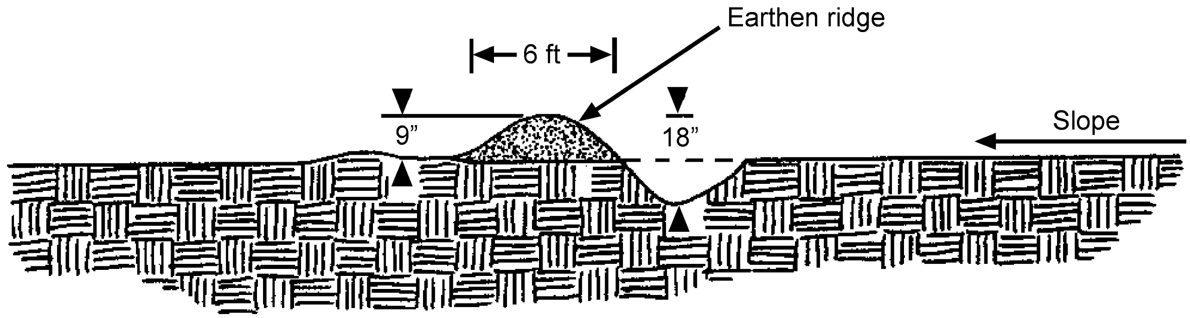


Figure 6.14-2 Section view of a water bar (source: North Carolina, May 1994)

CONSTRUCTION SPECIFICATIONS

1. Install the diversion as soon as the right-of-way has been cleared and graded.

2. Disk the base for the constructed ridge before placing fill.

3. Track and compact the ridge to the design cross section.

4. Locate the outlet on an undisturbed area. Adjust field spacing of the diversion to use the most stable outlet areas. When natural areas are not deemed satisfactory, provide outlet protection (see Level Spreaders, and Outlet-stabilization Structures).

5. Immediately stabilize and vegetate the portions of the diversions not subject to construction traffic. Stabilize with gravel areas to be crossed by vehicles.

MAINTENANCE

Periodically inspect right-of-way diversions for wear and after every heavy rainfall for erosion damage. Immediately remove sediment from the flow area and repair the dike. Check outlet areas and make timely repairs as needed. When permanent road drainage is established and the area above the temporary right-of-way diversion is permanently stabilized, remove the dike and fill the channel to blend with the natural topography, and appropriately stabilize the disturbed area.

6.15 Flow Control: CHANNELIZATION

DESCRIPTION AND PURPOSE

Channelization is the process by which the total flow or the primary flow of a channel or waterway is changed. Channelization may be for various purposes, including flood control, erosion control, and to create new contiguous land. The changes may be temporary or permanent, depending on the project needs and objectives.

DESIGN RECOMMENDATIONS

1. All dredging and/or work on the bed and banks of waters of the state should be conducted in such a manner as to minimize the extent of the bottom disturbance and minimize any increase in suspended solids in the waters. Diversion structures (see part 4.13) or temporary cofferdams (see part 6.19) may be options in certain cases.

2. The stream bank should be stable. Stream-stabilization measures, such as riprap or vegetation, should be used if needed to prevent erosion and should be constructed of site-appropriate materials.

3. These projects may require state, federal or local permits, so check with the appropriate agencies for their requirements.

CONSTRUCTION SPECIFICATIONS

Before the start of the project, develop construction specifications, which include water-pollution-abatement plans, that adhere to the following applicable steps:

1. Material, labor and equipment for temporary control measures and acceptable maintenance should be provided during the life of the project. To effectively prevent water pollution, the use of berms, dikes, dams, sediment basins, fiber mats, netting, gravel, mulches, grasses, slope drains and other erosion-control devices or methods is encouraged in the disturbed areas. Surface cover materials should be anchored to prevent their entering waters of the state by erosion or rising water levels.

2. Temporary pollution-control measures should be included for all construction activity associated with the project where such work is necessary (for example, spoil-disposal areas, haul roads, equipment storage, and plant or waste-disposal sites).

3. The temporary pollution-control provisions should be coordinated with any permanent erosion-control features to the extent practical to assure economical, effective and continuous erosion control throughout the construction and postconstruction period.

4. The surface area of erodible earth material exposed by clearing and grubbing, excavation, borrow and fill operations should be minimized and immediate permanent or temporary

control measures should be taken to prevent contamination of adjacent streams and other water courses, lakes, ponds and areas of water impoundment. Cut slopes should be stabilized by seeding with mulching or with erosion-control blankets as the excavation proceeds. Slopes should be graded properly to minimize erosion. The project should be phased so that stabilization can be accomplished before the channel becomes a water of the state.

5. All permanent erosion-control features should be incorporated into the project at the earliest practicable time. Provisions should be made for continual checking and maintenance of all control measures, particularly during periods of rainfall, to insure maximum effectiveness. Temporary pollution-control measures will be used to correct conditions that develop during construction. Temporary measures may also be needed before installation of permanent erosion-control features; or to control erosion that develops during normal construction practices, but are not associated with the project's permanent control features.

6. Control the area of excavation, borrow and embankment operations commensurate with the progress of finish grading, mulching, seeding, and other such permanent erosion-control measures. Should seasonal limitations make such coordination unrealistic, temporary erosion-control measures should be taken.

7. Placement of fill in wetlands and waterways should be minimized as much as practicable, while maintaining adequate slope safety and protection to prevent erosion. Placement of fill is only allowed with the proper permits. Slopes that provide safe and stable banks, while minimizing the extent of filling in wetlands and waters, should be utilized on a case-by-case basis.

8. Upon completion, the project area should be rehabilitated by landscaping, planting and maintaining vegetation or other work, so that the area will be restored to as natural a condition as possible.

9. Other BMPs to reduce overall impacts, such as green belts, timing of fertilization, and the preservation of wetlands, should be considered and, when feasible and practical, adopted.

6.16 Flow Control: TEMPORARY STREAM DIVERSION

DESCRIPTION AND PURPOSE

A temporary stream diversion is a channel or flexible conduit, such as a poly tube, that is used to temporarily change the course of a stream.

Temporary stream diversions allow work to be conducted in the permanent stream channel without its being subjected to water flows. Stream diversions are typically used for relatively large structures or projects in the stream channel when cofferdams cannot be used.

EFFECTIVENESS

Properly designed stream diversions will limit erosion and sediment transport (see Figure 6.16-1).

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Temporary stream diversions will generally have a life of two years or less, depending on the time needed for construction of the structure or completion of the project.

The two main considerations when designing a stream diversion are adequate channel capacity and sufficient erosion resistance (see Figure 6.16-2).

When calculating capacity of a channel, the maximum expected retardance should be used. If the channel will be vegetated, maximum retardance would usually be when vegetation reaches its maximum growth. When calculating velocity, the minimum retardance should be used. For vegetated channels, this would usually be the early-season, dormant condition. Rock-lined or paved channels will not have this seasonal variation in retardance, so one retardance can be used for both designs.

A number of other factors must be considered when designing a channel. The type of cross section selected is very important to these considerations. The section on Stormwater-conveyance Channels covers these considerations.

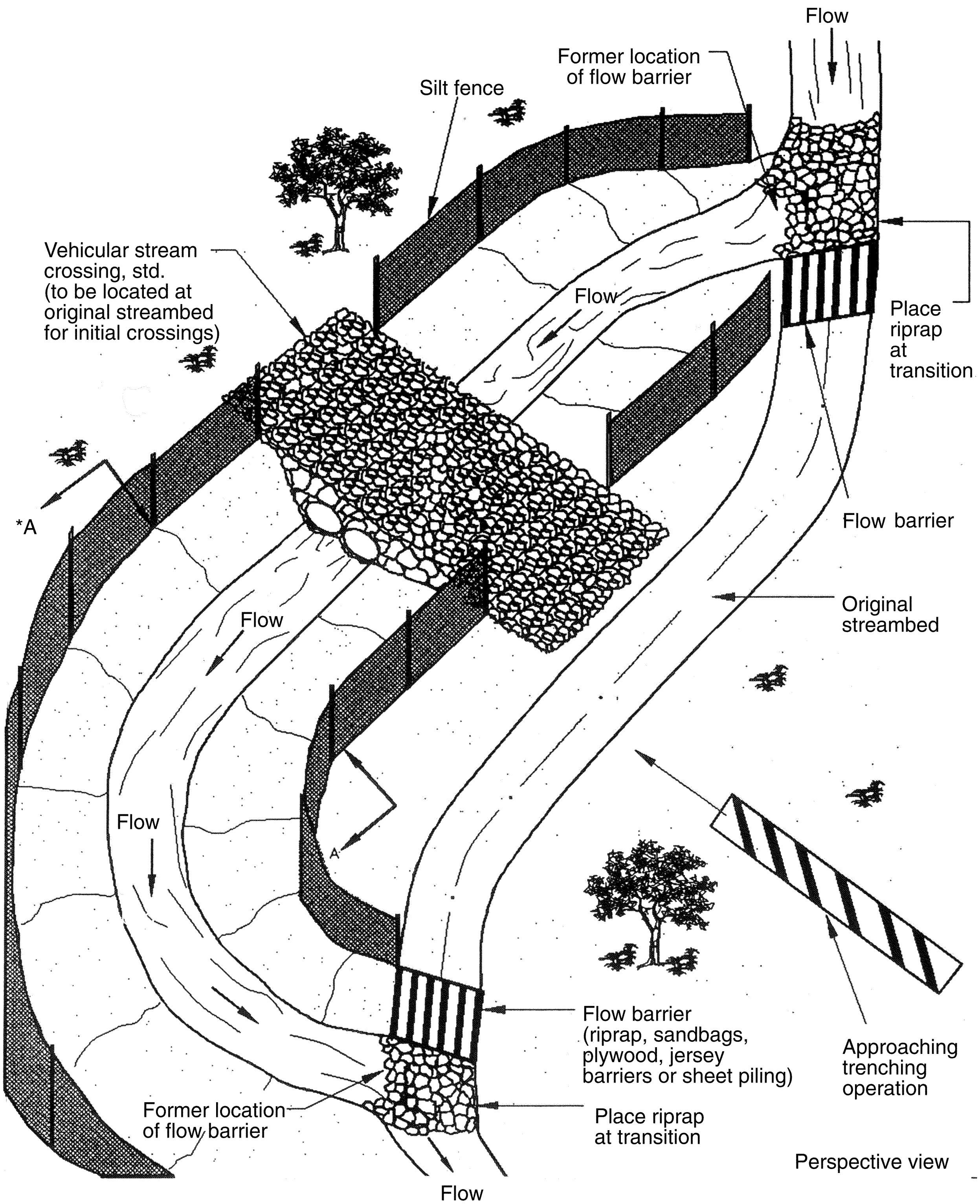
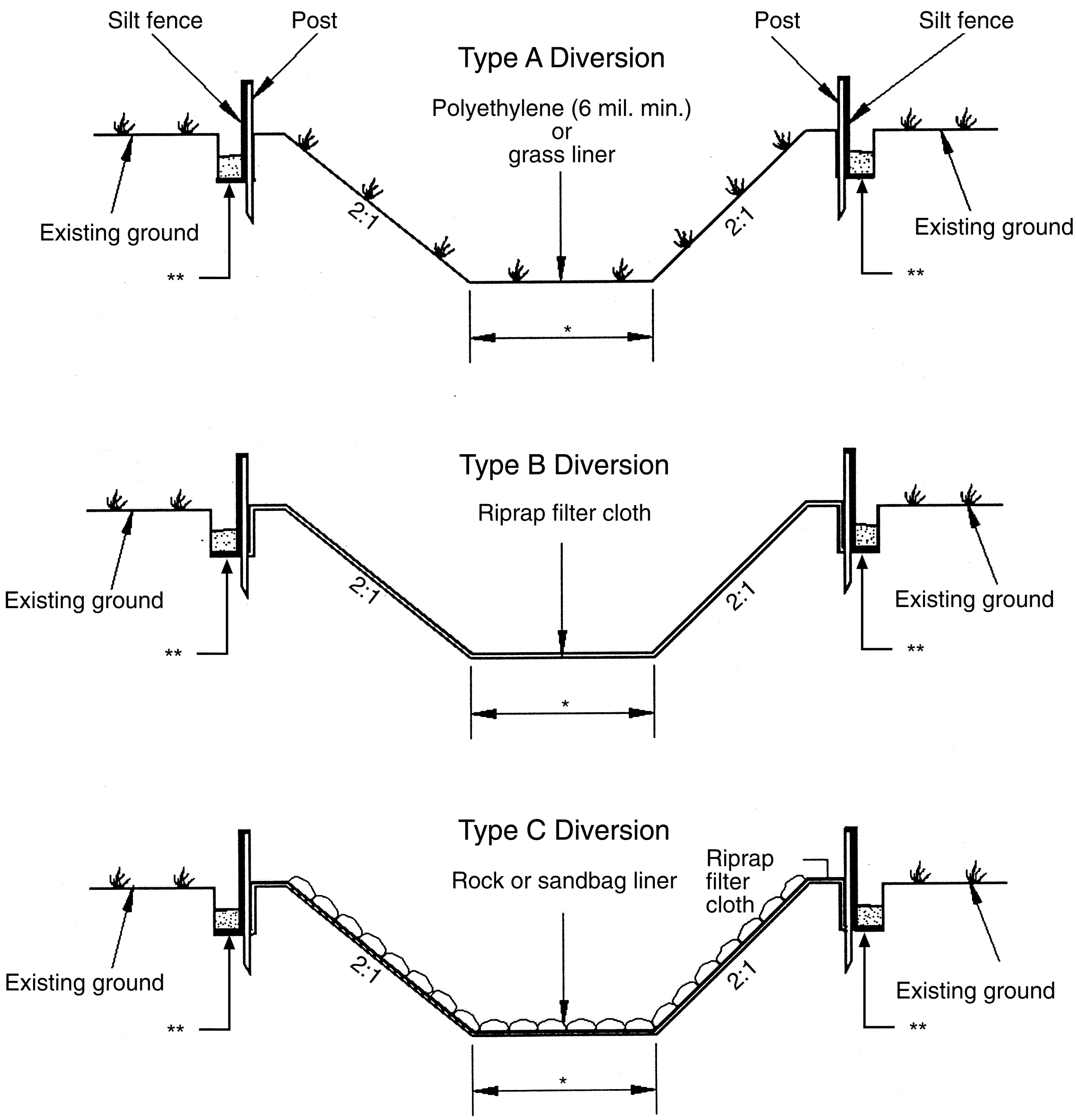


Figure 6.16-1 Perspective of a diversion channel crossing (source: Virginia Department of Conservation and Recreation)



* 6' minimum or width of existing stream whichever is less
** Entrench silt fence and filter cloth in same trench

Figure 6.16-2 Cross section of diversion channel crossing, showing acceptable linings (source: Virginia Department of Conservation and Recreation)

DESIGN RECOMMENDATIONS

In addition to the design recommendations for capacity, velocity, and channel cross section in the section on Stormwater-conveyance Channels, the following steps should be taken.

1. Construct the new diversion channel during dry conditions, usually in late summer or winter. Avoid disturbance during known breeding times of affected fish and animals in and around the stream.

2. Stabilize the diversion channel before connecting to the permanent waterway by lining the channel with geotextile erosion-control blankets, turf-reinforcement mats, or by using rock riprap. If flow velocities could exceed 9 fps, rock riprap or turf reinforcement mats should be considered.

3. Excavate from landward to the water with breakthrough occurring at the last practical moment.

4. Connect the diversion channel by breaking through the natural barrier at the downstream end first, then the upstream end.

5. Divert flow to the new temporary diversion channel.

6. Dewater the old channel, discharging to a treatment system -- not into a diversion channel or downstream.

7. Construct the structure or conduct the project in the permanent channel.

8. Stabilize the permanent channel.

9. Re-establish permanent channel flow. Close the temporary diversion channel by blocking the upstream end first, then the downstream end. Then, dewater the diversion channel and backfill.

10. Again, it should be emphasized that permits will probably be required.

MAINTENANCE

Temporary stream diversions should be inspected regularly and repaired as needed for scour, bank failure, breaching, obstructions and other damage. Upon completion of the project, the area should be completely restored so that it will recover to its original condition or better.

6.17 Flow Control: TEMPORARY SLOPE DRAINS

DESCRIPTION AND PURPOSE

A temporary slope drain is a flexible conduit which extends from the top to the bottom of a disturbed slope that serves as a temporary outlet for a diversion. Temporary slope drains convey runoff from the top to the bottom of the disturbed slope without causing erosion on or at the bottom of the slope. These are temporary structures which typically are used for up to two years (Figure 6.17-1).

EFFECTIVENESS

Temporary slope drains can eliminate gully erosion problems on a disturbed slope that would have resulted from concentrated flows discharged at a diversion outlet.

PLANNING CONSIDERATIONS

There is often a significant lag time between the grading of a slope and the installation of permanent drainage structures that dispose of runoff from a drainage area above the slope. During this time, the slope is vulnerable to severe gully erosion from concentrated runoff. A temporary slope drain used in conjunction with a diversion can prevent this erosion until permanent structures are installed.

DESIGN RECOMMENDATIONS

1. The area drained by a temporary slope drain should not exceed five acres.

2. The conduit should consist of heavy-duty material, such as corrugated metal or plastic such as PVC or ABS, manufactured for this purpose. The conduit should have grommets for anchoring at a spacing of 10 ft or less.

3. When a detailed design is not available, the chart below may be referred to for minimum recommendations of slope-drain diameter.

4. The entrance section should consist of a standard flared end section. The pipe that passes through the diversion should be in good condition and capable of making watertight joints at the ends. It is very important that all joints remain watertight and that backfill around the pipe is hand-compacted to prevent a failure of the diversion.

5. The diversion used to divert water to the temporary slope drain should meet the requirements for Diversions or Temporary Diversions. The height of the diversion at the pipe should be the diameter of the pipe plus 0.5 ft. Where this is higher than the normal diversion height, the fill elevation should be carried level until it intersects with the normal diversion height.

6. The outlet should be located at an erosion-resistant location or protected according to Outlet Protection.

7. Tie pipes and solidly anchor them as needed to prevent failure.

MAINTENANCE

The slope drain should be inspected after each rainfall that produces runoff. Any needed repairs should be made promptly. The slope drain should not be crossed by construction equipment.

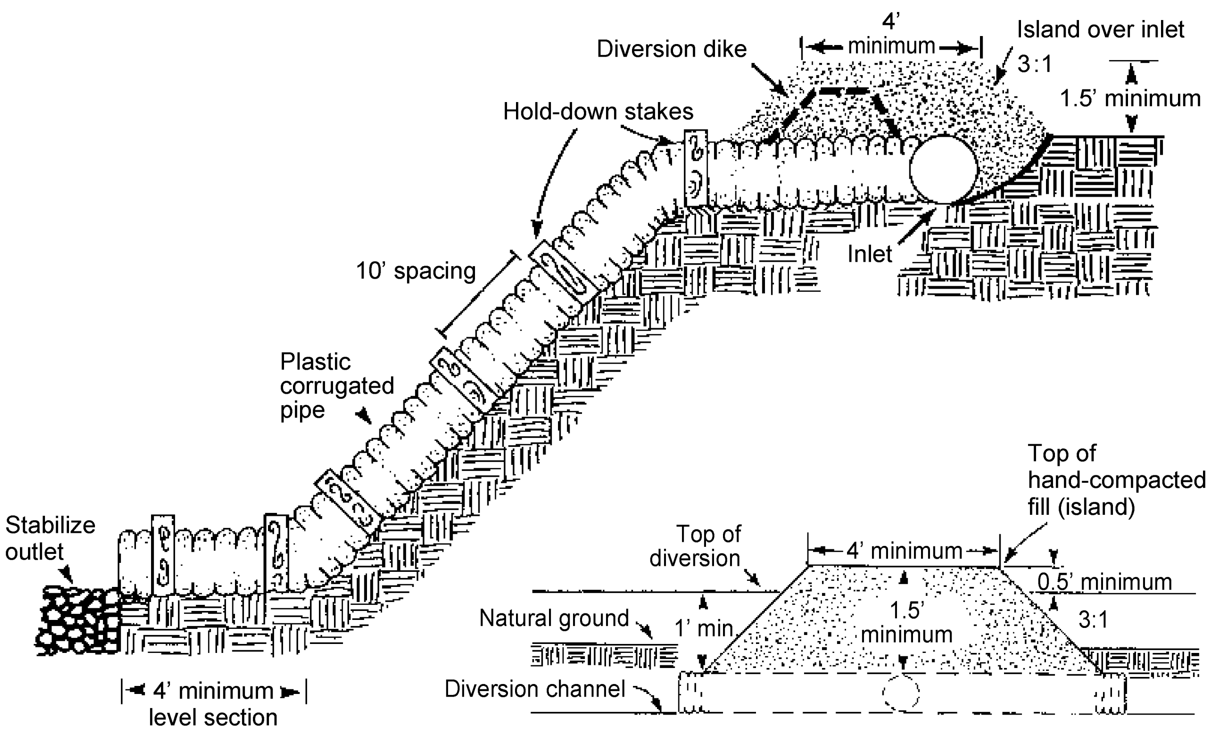


Figure 6.17-1 Cross section of a temporary a slope drain (source: North Carolina, May 1994)

6.18 Flow Control: TEMPORARY OUTLET CONTROLS

DESCRIPTION AND PURPOSE

Temporary outlet controls are protective measures used to prevent erosion at the outlet of temporary pipes or channels. These structures are intended to protect soil from turbulence and high velocities, which can otherwise cause scour erosion.

EFFECTIVENESS

Temporary outlet controls can prevent scour erosion in channels, which will reduce the effects of turbidity and sedimentation downstream.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

High-velocity flows from pipes or channels cause considerable erosion. To prevent erosion, velocities must be reduced to allowable levels before the flow enters an unprotected area.

Outlets should not be discharged onto unstable slopes or steep slopes.

Outlet protection usually consists of a structural apron lining. Apron linings can be made of riprap, concrete, grouted riprap or other structural materials. In some cases, flow velocities may be too high for economical use of an apron. In those cases, a stilling basin or impact basin may be more appropriate. A stilling basin is an excavated pool of water that is lined with riprap and used to dissipate energy from high-velocity flow. An impact basin is a reinforced concrete structure that slows water velocities to an acceptable level before discharging water to an outlet channel. Refer to the following reference for more information on energy dissipaters: *Hydraulic Design of Stilling Basins and Energy Dissipaters*, Engineering Monograph No. 25, U.S. Department of the Interior, Bureau of Reclamation.

DESIGN RECOMMENDATIONS

Outlet protection may or may not require a detailed design, depending upon the scope and complexity of the job. For outlets with very high velocities or very low tailwater conditions, outlet protection should be designed only by a qualified engineer. The following criteria are recommended for the design of structurally lined aprons below pipe outlets:

1. The tailwater depth must be determined immediately downstream of the outlet pipe. The maximum capacity of the pipe should be used when computing tailwater. If the tailwater elevation is less than the elevation halfway up on the pipe outlet, the outlet is classified as a minimum-tailwater-condition outlet. If the tailwater exceeds this level, the outlet is classified as a maximum-tailwater-condition outlet. Pipes that discharge onto broad, flat areas without a defined channel can usually be classified as a minimum-tailwater-condition outlets.

Use Figure 6.18-1 for minimum tailwater conditions and Figure 6.18-2 for maximum tailwater conditions.

2. The most desirable configuration for the outlet is a straight section. This is the only alignment that should be used for the ground design charts here. If a curve is necessary before the end of the apron, a special design should be used.

   The dimensions of the apron should be determined from the appropriate table. Apron-length requirements are computed from Figure 6.18-1 or 6.18-2 as applicable. The apron should be constructed level and at the elevation of the outlet pipe invert.

3. The apron can be constructed of riprap, cable-tied concrete or other suitable material. If riprap is used, the median rock size (d50) can be determined from Figures 6.18-1 or 6.18-2. A geotextile or granular bedding material should be used under the apron if riprap is used. Refer to section 4.50, Riprap, for gradation and thickness recommendations.

MAINTENANCE

Outlet protection should be inspected periodically to check for scour. Any needed repairs should be made promptly to prevent further damage.

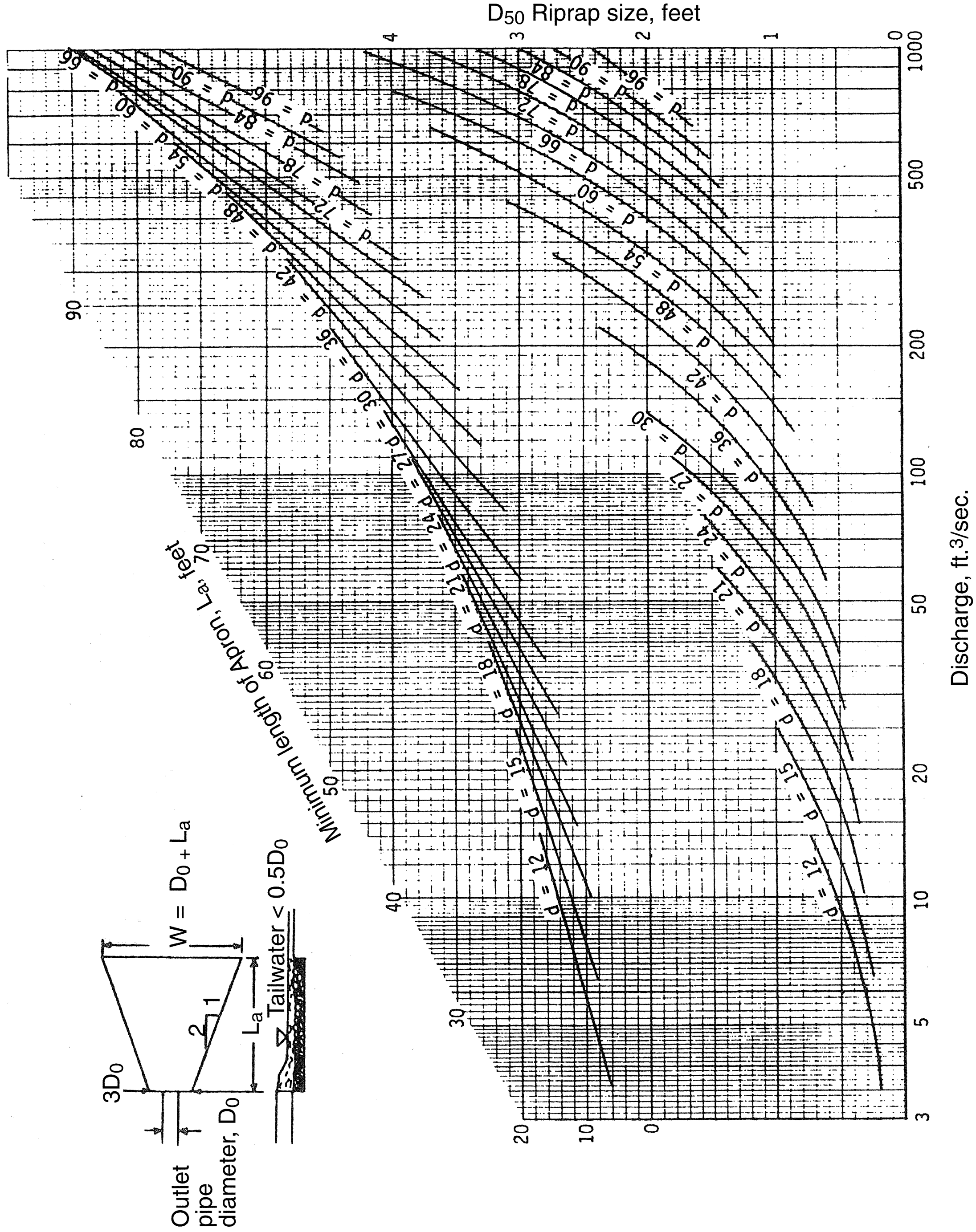


Figure 6.18-1 Design of outlet protection from a round pipe flowing full, minimum tailwater condition (T_W<0.5 diameter)

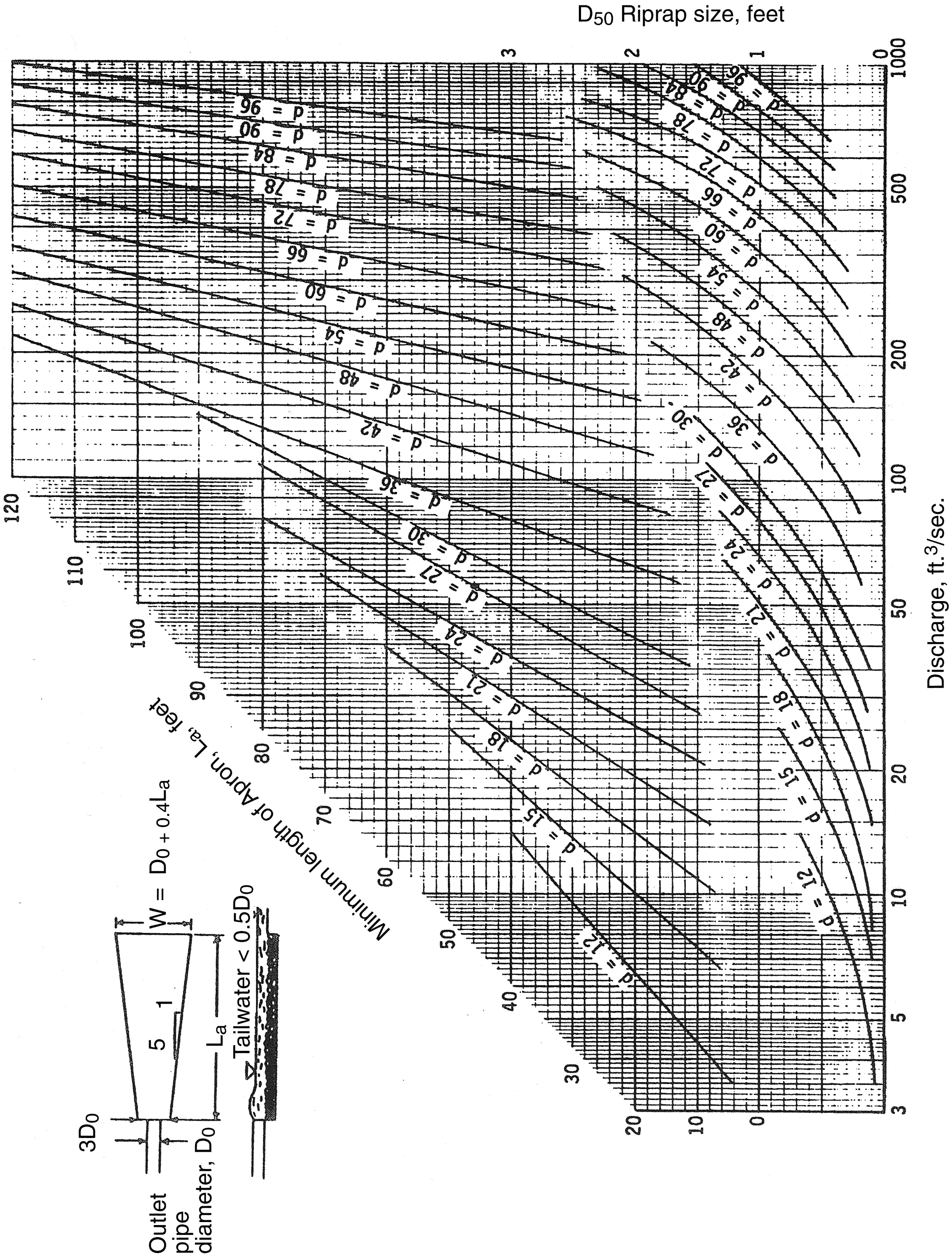


Figure 6.18-2 Design of outlet protection from a round pipe flowing full, maximum tailwater condition ($T_w \geq 0.5$ diameter)

6.19 Flow Control: COFFERDAMS

DESCRIPTION AND PURPOSE

Cofferdams are temporary dams that are used to exclude water from foundations of any type of structure. Cofferdams are used to exclude the water during construction work in water. They include excavation, construction and backfilling for a large number and type of projects. Sheet-pile cofferdams are usually used for larger projects, such as bridge piers. Smaller, easily constructed earth-fill cofferdams are usually used to protect smaller projects. In sensitive areas, portable fabric dams can be used to exclude water while preventing possible downstream siltation from eroding earthfill dams (see Figure 6.19-1).

Cofferdams can function as barriers in a river channel immediately upstream from foundations or earth-fill or rock-fill dams. They keep the water from the foundation, while a diversion tunnel or other structure transmits the water flow back to the channel downstream from the site. The site can be excavated, fill placed, and other activities conducted without being subjected to water flows.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

DESIGN RECOMMENDATIONS

1. Cofferdams should be placed, constructed and operated so as to cause minimum disruption to the aquatic environment especially during fish spawning. The slopes of earth-fill cofferdams may need to be stabilized to prevent erosion in flowing water. Sheet pile or collapsible fabric dams should be considered in sensitive areas, such as spawning areas.

2. Dewatering and treatment of dewatering discharge should be carefully considered in the design of the cofferdam structure (see Dewatering). If no treatment of dewatering discharge is feasible, measures to prevent activities from affecting the discharge should be considered. Measures, such as the placement of a concrete work base by “tremie” tube inside the cofferdam, filtered sump pits, or well-point dewatering, should be considered.

3. Stockpile locations for excavated material should be provided. If backfilling to original contours is required or prudent, care should be taken to avoid turbidity and downstream or off-site siltation. No backfilling with hydraulic dredge or slurry should be used, unless it is designed for in the plans. Note that permits may be required.

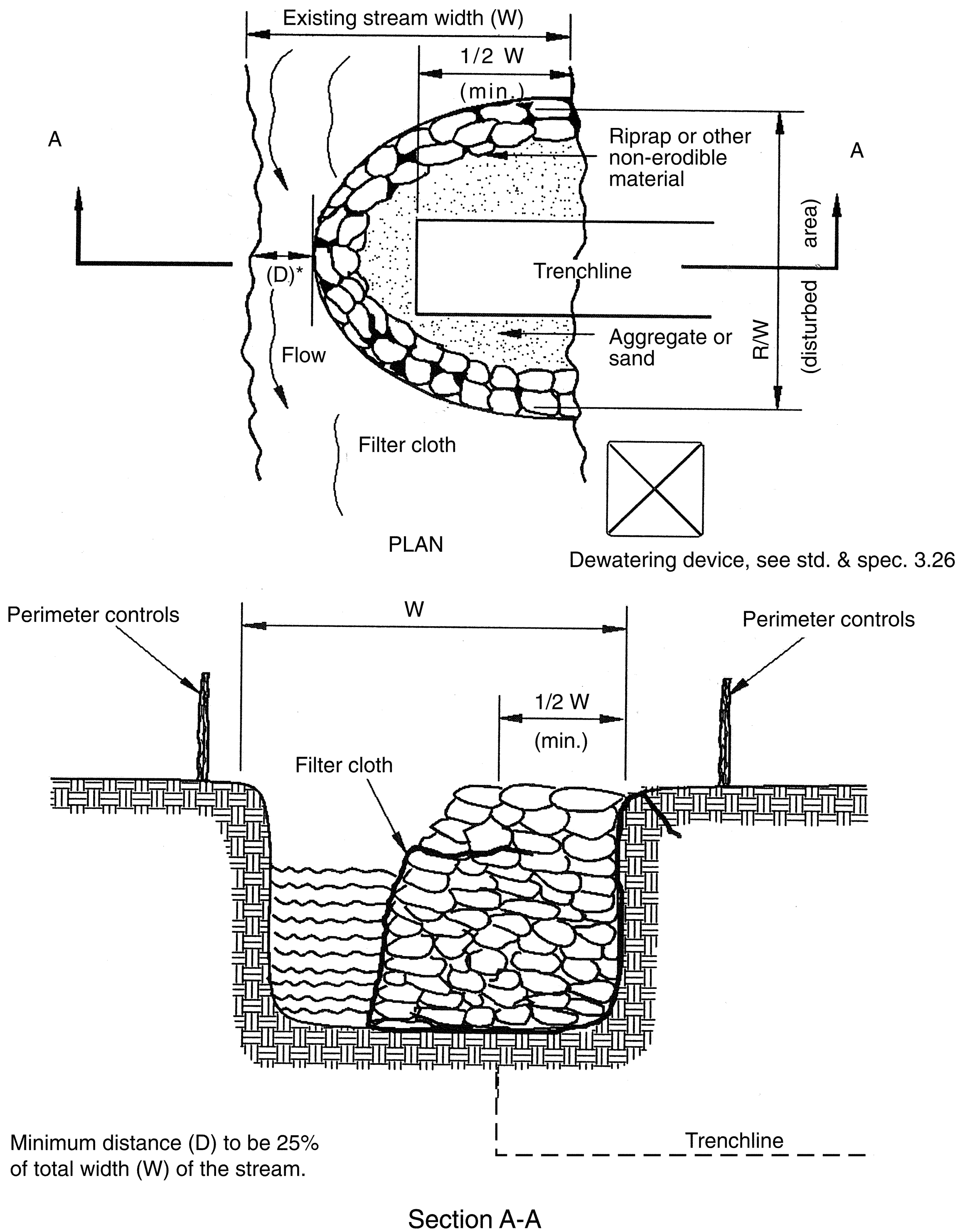


Figure 6.19-1 Cofferdam crossing (source: Virginia Department of Conservation and Recreation)

6.20 Vegetative Stabilization: SOIL EROSION AND SLOPE FAILURE

DEFINITION

Erosion is the removal of soil particles from a surface primarily due to water action. Erosion may also be caused by wind, ice action, boat-induced wave action, uncontrolled runoff or human and animal activities.

Failure is the collapse or slippage of large masses of soil by action of gravity through additional shear stress or decreased shear strength. Slope failure often occurs on the bank of a stream or lake which has been undercut by erosion at the base of the slope. It can also be a problem on steep slopes in upland areas, especially where vegetation has been removed or destroyed. Construction activities can cause slope failure by removing surface cover or the toe of the slope. When a slope fails, it sloughs off either a thin layer or a large mass of soil.

Soil erosion and slope failure are two of the more important impacts of urbanization. While they are natural processes, they are accelerated by urban development.

THE PROCESS

The movement of wind and water tends to erode the natural soils and deposit the resulting sediments elsewhere. This is a natural process that tends to balance over time. Erosion at one location is roughly balanced by deposition at another. However, erosion is often accelerated by human activity, and it becomes a problem when it affects human activities.

In many instances, accelerated failure or erosion is an indication that significant changes have occurred relating to management of land and water resources in the watershed. Any change in land use that removes vegetative cover, increases runoff or changes sediment loads in a stream can cause a soil that was previously stable to become a problem. Examples of such changes include increasing urbanization, intensive farming, or channelization of waterways.

Solving slope failure and erosion problems is difficult because local solutions that do not address the underlying causes in the watershed will likely affect the equilibrium of the system and may negatively impact downslope or downstream areas. Understanding the nature and causes of soil erosion and failure is the first step toward finding appropriate solutions.

Vegetative canopy and root systems help reduce the risk of failure and erosion. In addition, protecting the plant systems can help address the fundamental changes in hydraulics brought about by development or other changes in the management of the watershed system.

6.21 Vegetative Stabilization: FERTILIZER MANAGEMENT

DESCRIPTION

Fertilizer management involves controlling the rate, timing and method of fertilizer application so that plant nutrient needs are met while minimizing the chance of polluting surface or ground water.

TARGET POLLUTANTS

This practice is directed at controlling phosphorus and nitrogen in construction and landscaped areas. Phosphorus is the major surface water concern because it leads to excessive algal growth. Nitrogen is a special concern because of potential ground water contamination by nitrates.

PLANNING CONSIDERATIONS

If the seedbed consists of at least 6 inches of fertile topsoil, fertilizer may not be required. If the topsoil consists of subsoil or blends of several soil horizons and fills, the soil most likely will be deficient in one or more nutrients necessary for plant establishment and growth. In all cases, it is highly recommended that a soil test for available plant macronutrients — nitrogen, phosphorus and potassium (N-P-K) — pH, and cation exchange capacity (CEC) or soluble salts be performed within the season of planting. In addition, suspected problem soils may require micronutrient analysis, especially if the area is, or has been, dominated by annual weeds, such as foxtails and spotted knapweed. The soil must be sampled in accordance with standard sampling procedures. Follow the recommendation of the soil-test laboratory. In general, areas of suspected soil differences (wet areas verses upland) should be sampled separately, but soil may be bulked, mixed and a representative sample sent to a state or federal certified soil-test laboratory (soil kits should generally not be used). The University of Minnesota Extension Service is one of several facilities available for testing soils.

Fertilizer described in this section should be a commercial grade of slow-release fertilizer. Usually the slow-release component is nitrogen, but all components of the fertilizer blend should have a regulated release rate. The rate of release may be regulated by water, temperature or microorganisms. In all cases, loss of phosphorus to the waters of the state should be avoided and should be addressed as part of the erosion-prevention plan. The fertilizer type may vary from liquid to granular forms, and should be appropriate for the method of application (broadcast, banded, hydroseeded, etc.), following the manufacturer's recommendations for application suitability. Care must be exercised not to ruin the coating or process that regulates the release of nutrients. Method and depth of incorporation of the fertilizer must be considered also. For example, banding of slow-release fertilizer at the time of seeding, in general, allows lower levels of nutrients, and will feed the desired plants, not the weeds.

A fertilizer with an N-P-K ratio of approximately 22-5-10, with 0.5% to 8% added iron, magnesium and sulfur, represents a good, all-around blend, but the needed ratio should be based on the soil test for the plant communities that are to be fertilized. It is acceptable to have up to

20% soluble nitrogen, with the remaining 80% in any form of water-insoluble nitrogen, as long as the product has a documented rate and method of dissolution into soil.

In general, the fertilizer should be placed at a rate up to 2 pounds (lb) of actual nitrogen per 1,000 square feet (ft^2) for turf-variety seed communities (MnDOT seed mixes 50B and above) and 1 lb of actual nitrogen per 1,000 ft^2 for native seed communities (MDOT seed mixes 5B to 38A). Matching the fertilizer composition with special soil need conditions on a case-by-case basis will allow soluble forms of nitrogen fertilizer to deal adequately with cellulose-type compost and other soil amendments. Fertilizer application should be restricted to carefully controlled applications within 100 lineal ft of a water of the state.

6.22 Vegetative Stabilization: TEMPORARY SEEDING AND STABILIZATION

DESCRIPTION AND PURPOSE

Temporary seeding is the establishment of temporary vegetative cover on disturbed areas by seeding with suitable fast-growing annual vegetation. This is intended to provide a temporary vegetative cover relatively quickly that will protect the soil from erosion until permanent stabilization.

This practice is normally used to stabilize construction areas that will be inactive for more that 21 days but less than one year. Applicable areas include topsoil stockpiles, rough graded areas, sediment basin dikes, temporary earthen structures and graded areas undergoing settlement.

EFFECTIVENESS

Temporary seeding is only effective for erosion control once vegetation has become established. A good stand of vegetation will protect soil from erosion by raindrop impact and will also slow runoff to prevent rill erosion. The vegetation can also act as a filter, trapping coarse sediment particles carried by runoff. After establishment, temporary seeding can reduce sheet erosion by approximately 90% (USDA, SCS, 1976).

PLANNING CONSIDERATIONS

Preventing erosion is always preferred over sediment control. Often because of the nature of the work, good erosion control is not feasible on construction sites. When a disturbed area will be inactive for a prolonged period, erosion-control measures should be used. Areas that will not be disturbed over the winter should be temporarily seeded and stabilized.

Temporary seeding is an effective erosion-control practice. Annual plants that sprout quickly are used for this practice. Proper seedbed preparation and the use of quality seed is important for good germination and growth. A poor stand (less than 50% cover) will not provide adequate erosion control.

SEEDING RECOMMENDATIONS

1. Select the desired type of vegetation from temporary see mix tables 1, 2 or 3, as appropriate.

2. Proper seedbed preparation is essential for the seed to germinate and grow. The seedbed should be tilled to a depth of about 3 inches. In compacted or hard soils, it may be necessary to use a disc, ripper or other relatively heavy tillage equipment to prepare the seedbed. The seedbed should not be prepared under excessively wet conditions.

3. It is essential that fertilizer be incorporated into the top 2 to 4 inches of soil during seedbed preparation. If the fertilizer is not incorporated, it is more available for loss in runoff and can cause pollution problems. It is best to use a slow-release fertilizer to provide nutrients during the whole establishment cycle and to minimize nutrient flushing.

Fertilizer should only be used after a soil test confirms what should be added.

4. The soil surface must be firm — less than 200 lb per square inch (psi), but not compacted at the time of seeding. When the area is compacted or hardened, it must be loosened by disking, light ripping, chisel plowing, harrowing or other means.

5. Seed should be evenly applied with a cyclone seeder, drill or cultipacker seeder. Small grains and grasses should be planted no more than 0.5 inch deep.

6. If seeding is done during the spring or summer on flat slopes, and these areas have favorable soil and moisture conditions, mulching is optional. At other times of the year, and on steeper slopes or during hot, dry conditions, the temporary seeding should be mulched according to part 6.26, Mulching.

MAINTENANCE

If the seeding fails to grow, it may need to be re-established to provide adequate erosion control. Also, noxious weeds may need to be controlled by mowing or spraying.

Temporary seed mixes (cover crops)

Seeding rates are all expressed in pounds of pure live seed (PLS).

Table 6.22-1 One-year temporary seed mixes for fall or spring applications

Mixture	Plant Species	% of Total	Rate (lb/acre)	Applications
100A	Winter wheat	100	100	Fall (until Oct. 1)
110A	Oats	100	100	Spring
none	Annual rye	100	200	All year

Table 6.22-2 All-season mixes, and/or two- to three-year stabilizing requirements

Mixture	Plant Species	% of Total	Rate (lb/acre)	Applications
120A	ReGreen™	100	25	All year
125A	ReGreen™	88	22	All year
	Alfalfa, Vernal	12	3	All year
	Total:	100	25	

Table 6.22-3 Stabilization mix developed to stabilize erodible areas for three to seven years. Also may be used as a mix that will be tilled back into the soil.

MIXTURE 90A MODIFIED/90B		
Common Name	**Botanical Name**	**% of Mix**
ReGreen™	NA	20.0
Partridge pea	*Chamaecrista fasciculata*	9.0
Wheatgrass, slender	*Elymus trachycaulus*	9.0
Ryegrass, perennial	*Lolium perene*	20.0
Alfalfa, creeping	*Medicago sativa*	7.0
Timothy	*Phleum pratense*	10.0
Dropseed, sand	*Sporobolis cryptandrus*	7.0
Clover, alsike	*Trifolium hybridum*	7.0
Clover, red	*Trifolium pratense*	11.0
	Total	**100.0**
Seeding rate: 50 lb/acre		

6.23 Vegetative Stabilization: PERMANENT SEEDING

DESCRIPTION AND PURPOSE

Permanent seeding is the establishment of perennial vegetation on a disturbed area. It is intended to stabilize disturbed areas in a manner compatible with the intended use and adjacent stakeholders. This practice is used when vegetation is desired to permanently stabilize a site.

EFFECTIVENESS

Once it is established, permanent seeding is very effective for controlling soil erosion. Until the area is stabilized, mulch should be used to provide protection. Permanent seeding protects soil from erosion by raindrop impact and overland flow. Vegetation also maintains the infiltration capacity of soil, thereby reducing the volume of runoff that will occur. Once established, permanent seedings can reduce soil erosion rates by 99% (USDA, SCS, 1976).

PLANNING CONSIDERATIONS

On projects that will take several years before development, longer-lasting cover crops, such as ReGreen™, may be acceptable. It is important to select the proper seed mixture for the intended use of the area, the soil conditions on the site and the climate. Some types of vegetation are well suited to high-intensity use, but they may not be appropriate for a roadside, where low maintenance is desired. With the wide variation in soil types and climate in Minnesota, it is important to select vegetation well suited to the site. The tables provide recommendations for seed mixtures in urban areas based upon intended use, climate by region of the state and soil conditions.

SEEDING RECOMMENDATIONS

1. Fertilizer is helpful to the growth of vegetation, but it can also be a serious pollutant if it is not applied correctly. Fertilizer must be incorporated during seedbed-preparation operations. If fertilizer is incorporated and the seeded area is protected from erosion, fertilizer loss will be minimized. Fertilizer should only be applied in accordance with the results of a soil test. It is best to use a slow-release fertilizer to provide nutrients during the whole establishment cycle and to minimize nutrient flushing.

2. The seedbed should be prepared to a depth of about 3 inches. In compacted or hard soils, it may be necessary to use a disc, ripper or other heavy tillage implement to prepare a seedbed. Seedbeds should not be prepared under excessively wet soil conditions. After seeding, the seedbed should be firmed with a non-smooth drum roller or cultipacker to ensure good seed-to-soil contact.

3. The seed should be drilled or broadcast with equipment that will uniformly distribute. Small grass seeds and legumes should be planted ¼ to ½ inch deep. Large grass seed should not be planted deeper than ¾-inch.

4. The recommended seeding dates given in Table 6.23-3 are the optimum seeding dates for the seed mixtures in Table 6.23-1. These charts should be used as a guide, and consideration should be made for seasonal weather patterns. In general, do not plant during dry periods, when the seed will germinate, but the seedlings will not develop sufficiently to survive until spring. Instead, postpone the seeding and do it later as a dormant seeding. Dormant seedings are used in the fall after soil temperatures are cold enough to prevent germination until spring.

5. Mulching is important for erosion control and moisture conservation on new seedings. (See section 6.50, Mats and Mulches.)

MAINTENANCE

Mowing or spraying may be needed to control weeds during establishment. Spraying should be avoided if it will kill legumes or other dicots in a mixture. If the vegetation is mowed, a blade height of 5 to 6 inches should be used initially to prevent damage to the new seedlings.

The lists below are representative only. Plant species adjustments may be required, depending on intended use. Check with the Minnesota Department of Transportation Environmental Services Section, the Minnesota Department of Natural Resources and the local Soil and Water Conservation District, for additional suggestions based on soil fertility and erosion-prevention requirements.

I. NATIVE MIXES

Native mixes are used in two general groups of seeds: (1) upland mixes and (2) wetland mixes. The subtables provide variations for various parts of the state and woodland edges.

A. Upland Type

Description: Reaches a height of 36-48 inches. Excellent for use on all soil types.
Statewide use, but best for oak savanna and prairie regions.

Table A Seed Mix Tabulation

Mixture 15B

Common Name	**Botanical Name**	**Percent of Mix**
Bluestem, big	*Andropogon gerardi*	5
Grama, sideoats	*Bouteloua curtipendula*	10
Wild rye, Canadian	*Elymus canadensis*	5
Wheatgrass, slender	*Elymus trachycaulus*	5
Ryegrass, annual	*Lolium italicum*	10
ReGreen™	NA	34
Forbs* (see tables below)	NA	5
Switchgrass	*Panicum virgatum*	2
Bluestem, little	*Schizachyrium scoparium*	12
Indiangrass	*Sorghastrum nutans*	12
	Total	**100**

Drill rate: 30 lb/acre.
Broadcast rate: 30 lb/acre & add 10 lb/acre ReGreen™.

***Forb Mixes**

These are broken down into regions of the state or environment conditions and should be added to the seed mix tabulation shown above.

Planting rate is specified in the seed mix tabulation, above. All species should be provided in equal weights.

Table A-1 NW Forb Mix

Description: Native forbs to be added to native grass mixtures in northwestern Minnesota.

Common Name	**Botanical Name**	**Common Name**	**Botanical Name**
Onion, prairie	*Allium stellatum*	Blazingstar, rough	*Liatris aspera*
Aster, heath	*Aster ericoides*	Blazingstar, tall	*Liatris pycnostachya*
Aster, smooth-blue	*Aster laevis*	Bergamot, wild	*Monarda fistulosa*
Milkvetch, Canada	*Astragalus canadensis*	Penstemon, showy	*Penstemon grandiflorum*
Prairie clover, white	*Dalea candidum*	Coneflower, columnar	*Ratibida columnifera*
Prairie clover, purple	*Dalea purpureum*	Black-eyed Susan	*Rudbeckia hirta*
Tick-trefoil, showy	*Desmodium canadense*	Goldenrod, stiff	*Solidago rigida*
Coneflower, narrow-leaved	*Echinacea angustifolia*	Vervain, blue	*Verbena hastata*
Ox-eye, common	*Heliopsis helianthoides*	Vervain, hoary	*Verbena stricta*
Bushclover, round-headed	*Lespedeza capitata*	Alexanders, golden	*Zizia aurea*

Table A-2 SE Forb Mix

Description: Native forbs to be added to native grass mixtures in southeastern Minnesota.

Common Name	Botanical Name	Common Name	Botanical Name
Milkweed, butterfly	*Asclepias tuberosa*	Blazingstar, tall	*Liatris pycnostachya*
Aster, heath	*Aster ericoides*	Bergamot, wild	*Monarda fistulosa*
Aster, smooth-blue	*Aster laevis*	Penstemon, showy	*Penstemon grandiflorum*
Milkvetch, Canada	*Astragalus canadensis*	Coneflower, grey-headed	*Ratibida pinnata*
Partridge pea	*Chamaecrista fasiculata*	Black-eyed susan	*Rudbeckia hirta*
Prairie clover, white	*Dalea candidum*	Goldenrod, stiff	*Solidago rigida*
Prairie clover, purple	*Dalea purpureum*	Spiderwort, Ohio	*Tradescantia ohiensis*
Tick-trefoil. showy	*Desmodium canadense*	Vervain, blue	*Verbena hastata*
Ox-eye, common	*Heliopsis helianthoides*	Vervain, hoary	*Verbena stricta*
Blazingstar, rough	*Liatris aspera*	Alexanders, golden	*Zizia aurea*

Table A-3 SW Forb Mix

Description: Native forbs to be added to native grass mixtures in southwestern Minnesota.

Common Name	Botanical Name	Common Name	Botanical Name
Milkweed, butterfly	*Asclepias tuberosa*	Blazingstar, tall	*Liatris pycnostachya*
Aster, smooth-blue	*Aster laevis*	Bergamot, wild	*Monarda fistulosa*
Milkvetch, Canada	*Astragalus canadensis*	Penstemon, showy	*Penstemon grandiflorum*
Partridge pea	*Chamaecrista fasiculata*	Coneflower, columnar	*Ratibida columnifera*
Prairie clover, white	*Dalea candidum*	Coneflower, grey-headed	*Ratibida pinnata*
Prairie clover, purple	*Dalea purpureum*	Black-eyed susan	*Rudbeckia hirta*
Tick-trefoil. showy	*Desmodium canadense*	Goldenrod, stiff	*Solidago rigida*
Coneflower, narrow-leaved	*Echinacea angustifolia*	Vervain, blue	*Verbena hastata*
Ox-eye, common	*Heliopsis helianthoides*	Vervain, hoary	*Verbena stricta*
Blazingstar, rough	*Liatris aspera*	Alexanders, golden	*Zizia aurea*

Table A-4 Woodland-edge forbs

Description: Native forbs to be added to native grass mixtures in northeastern Minnesota.

Common Name	Botanical Name	Common Name	Botanical Name
Hyssop, fragrant-giant	*Agastache foeniculum*	Lobelia, great-blue	*Lobelia siphilitica*
Anemone Canada	*Anemone canadensis*	Monkey flower	*Mimulus ringens*
Milkweed, marsh	*Asclepias incarnata*	Bergamot, wild	*Monarda fistulosa*
Milkweed, butterfly	*Asclepias tuberosa*	Black-eyed susan	*Rudbeckia hirta*
Aster, heath	*Aster ericoides*	Golden-glow, wild	*Rudbeckia laciniata*
Aster, smooth-blue	*Aster laevis*	Brown-eyed susan	*Rudbeckia triloba*
Aster, large-leaved	*Aster macrophyllus*	Aster, upland-white	*Solidago ptarmicoides*
Milkvetch, Canada	*Astragalus canadensis*	Goldenrod, stiff	*Solidago rigida*
Tic-trefoil, showy	*Desmodium canadense*	Vervain, blue	*Verbena hastata*
Sunflower, early	*Heliopsis helianthoides*	Alexander's, golden	*Zizia aurea*

B. Wetland Types

Description: Native sedge/prairie meadow mix. Reaches a height of 36-48 inches. Developed for use on hydric soils and for wetland restorations. See separate tables for meadow forbs, grasses and sedges.

Installation Note: Sedges, meadow grasses and forbs are best installed by broadcast method, separate from main grass mix, in autumn, if possible.

TABLE B SEED MIX TABULATION

MIXTURE 25A MODIFIED/25B

Common Name	Botanical Name	Percent of Mix
Bluestem, big	*Andropogon gerardi*	10
Wild rye, Canadian	*Elymus canadensis*	8
Wheatgrass, slender	*Elymus trachycaulus*	6
Ryegrass, annual	*Lolium italicum*	6
Switchgrass	*Panicum virgatum*	2
Indiangrass	*Sorghastrum nutans*	18
Meadow Forbs (see table)	NA	4
Meadow Grass Mix (see table)	NA	8
ReGreen™	NA	32
Sedge Mix (see table)	NA	6
Total		**100**

Drill Rate: 30 lb/acre.
Broadcast Rate: 30 lb/acre & add 10 lb/acre ReGreen™

Meadow Grasses, Sedges and Meadow Forbs: for inclusion in mixture 25A Modified/25B.

Table B-1 Meadow Grass Mix (5 of 6 species minimum)

Common Name	Botanical Name	Common Name	Botanical Name
Fringed brome	*Bromus ciliata*	Reed Manna grass	*Glyceria grandis*
Blue-joint grass	*Calamagrostis canadensis*	Fowl Manna grass	*Glyceria striata*
Virginia wild rye	*Elymus virginicus*	Prairie cordgrass	*Spartina pectinata*

Table B-2 Sedge Mix (6 of 7 species minimum)

Common Name	Botanical Name	Common Name	Botanical Name
Bottlebrush sedge	*Carex comosa*	Wool grass	*Scirpus cyperinus*
Lake sedge	*Carex lacustris*	Soft-stem bulrush	*Scirpus vallidus*
Tussock sedge	*Carex stricta*	Green bulrush	*Scripus atrovirens*
Common rush	*Juncus effusus*		

Table B-3 Meadow forbs

Common Name	Botanical Name	Common Name	Botanical Name
Anemone, Canada	*Anemone canadensis*	Blazingstar, tall	*Liatris pycnostachya*
Milkweed, marsh	*Asclepias incarnata*	Lobelia, great-blue	*Lobelia siphilitica*
Aster, New England	*Aster novae-angliae*	Monkey flower	*Mimulus ringens*
Aster, swamp	*Aster puniceus*	Bergamot, wild	*Monarda fistulosa*
Tick-trefoil, showy	*Desmodium canadense*	Black-eyed Susan's	*Rudbeckia hirta*
Joe-pye weed	*Eupatorium maculatum*	Goldenrod, grass-leaved	*Solidago graminifolia*
Boneset	*Eupatorium perfoliatum*	Vervain, blue	*Verbena hastata*
Ox-eye, common	*Heliopsis helianthoides*	Ironweed	*Veronia fasciculata*
Iris, blue-flag	*Iris virginica-shrevii*	Culver's root	*Veronicastrum virginianum*
Blazingstar, meadow	*Liatris ligulistylis*	Alexander's, golden	*Zizea aurea*
Rate: As specified in the seed mix tabulation, above. All species should be provided in equal weights.			

II. General Purpose Mixes/Non-native Mixes

The general-purpose mixes are of two types: (1) forage and hay mixes and (2) low-maintenance turf mixes. The subtables provide alternative seeds to be mixed with the basic seed mixture.

A. Coarse grass type, may be mowed for forage or hay. Can be left unmowed.

Description: Forage and native grass mix. Reaches a height of approximately 24 inches. General purpose seed mix for roadsides.

Table A Non-native mix

MIXTURE 50A MODIFIED/50B		
Common Name	Botanical Name	Percent of Mix
Wheatgrass, slender 'Revenue'	*Agropyron trachycaulum*	8
Bluestem, big 'Bison'	*Andropogon gerardi*	7
Bromegrass, smooth	*Bromus inermis*	15
Ryegrass, perennial	*Lolium perene*	20
Alfalfa, creeping	*Medicago sativa*	4
Legume, native (see table)	NA	1
Switchgrass 'Dakota'	*Panicum virgatum*	8
Timothy	*Phleum praetense*	7
Bluegrass, Kentucky 'Park'	*Poa pratensis*	30
	TOTAL	**100**

Table A-1 Acceptable native legumes

Common Name	Botanical Name
Milkvetch, Canada	*Astragalus canadensis*
Prairie clover, purple	*Dalea purpureum*
Tic-trefoil, showy	*Desmodium canadense*
Bush-clover, round-headed	*Lespedeza capitata*
Vetch, American	*Vicia americana*
Rate: 50 lb/acre	

B. Low-maintenance turf mix. Designed for sod replacements, salted edges, heavy foot traffic and boulevards.

Table B Non-native mix

MIXTURE 60A MODIFIED/60B

DESCRIPTION: Reaches a height of approximately 12 inches

Common Name	Botanical Name	Percent of Mix
Fescue, creeping-red 'Cindy'	*Festuca rubra*	10
Ryegrass, perennial 'Elf'	*Lolium perene*	14
Bluegrass, Canada 'Reubens'	*Poa compressa*	12
Bluegrass, fowl	*Poa palustris*	10
Bluegrass, common '98/85'	*Poa pratensis*	12
Bluegrass, Kentucky 'Park'	*Poa pratensis*	12
Bluegrass, Kentucky 'Caliber'	*Poa pratensis*	10
Alkali grass, 'Salty'	*Puccinella distans*	19
White clover	*Trifolium repens*	1
	Total	**100**
Rate: 100 lb/acre		

6.25 Vegetative Stabilization: SODDING

DESCRIPTION AND PURPOSE

Sodding is the stabilization of a disturbed area with permanent vegetation by laying sod. Sodding provides immediate erosion protection to soil, which is desirable in cases where the erosion potential would be high during vegetative establishment by seeding.

EFFECTIVENESS

Sodding can provide effective protection from erosion immediately after it is laid. The sod protects soil from erosion by raindrop impact and overland flow. It also slows runoff and can trap coarse sediment particles carried by runoff. Sodding can reduce erosion rates by as much as 99% (USDA, NRCS, 1976).

PLANNING CONSIDERATIONS

Before using sod, the planner should be sure that the varieties of grass are compatible with the intended use, soils and desired level of maintenance. The selection of varieties will be much more limited than they are when establishing vegetation from seed. Many of the sods are grown for home lawn use and may prove unsatisfactory if they are used in a location where low maintenance is important.

Sodding is a very good means of establishing vegetation instantly in erosion-prone areas, such as swales, steep slopes and areas adjacent to paved surfaces.

SODDING RECOMMENDATIONS

1. The soil must be prepared as it would be for a seeding. The upper 3 inches must be loosened and be relatively free of clods rocks and debris. The soil surface should be smoothed and firmed prior to sodding to eliminate surface irregularities which would impair good root-to-soil contact.

2. The sod should meet the requirements of MnDOT specification 3878, or equivalent (MnDOT, 1988).

3. Sod should not be cut or laid in excessively wet or dry conditions. During periods of high temperature, the soil should be lightly moistened just before the sod is laid. The joints in the sod should be staggered, and the sod should be laid so that the edges are tightly butted together (see Figure 6.25-1).

4. On slopes of 3:1 or greater, or in areas of concentrated flow, the sod should be pegged down. On steep slopes with sheet flows, the sod should be laid with the length perpendicular to the water flow (see Figure 6.25-2).

5. After the sod is laid, it should be rolled to provide good contact between the sod and the soil.

6. After it is rolled, the sod should be watered so that the soil is moistened to a depth of 4 inches below the sod. Watering should continue as needed until the sod is established. (One inch of water per week is a good rule of thumb.)

7. The first mowing should not be attempted until the sod is firmly rooted, usually two to three weeks after it is laid. Mower blade height should be set at about 3 inches for the first mowing.

8. Sodding should be restricted when you have 30 or fewer growing days to establish roots.

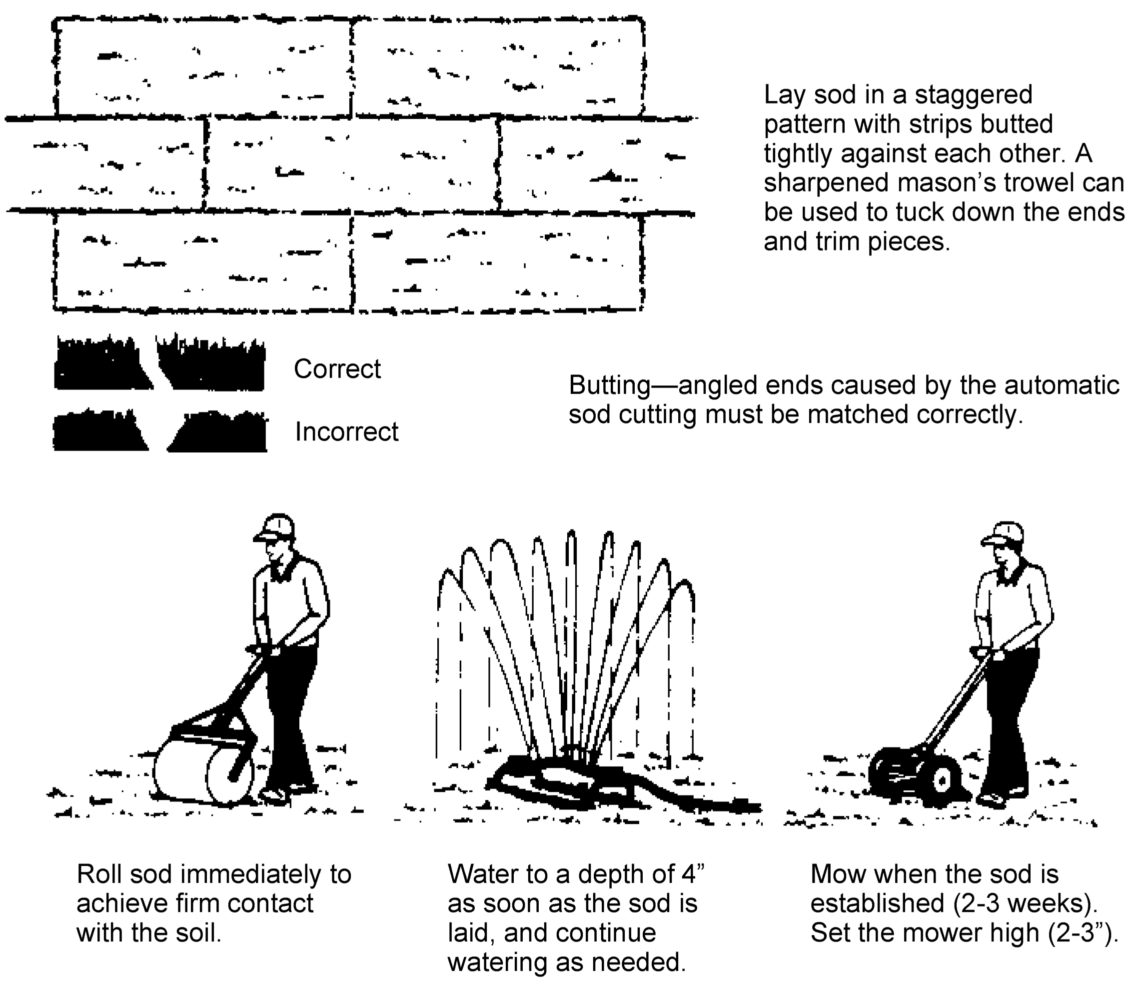


Figure 6.25-1 Proper installation of sod (modified from North Carolina, May 1994)

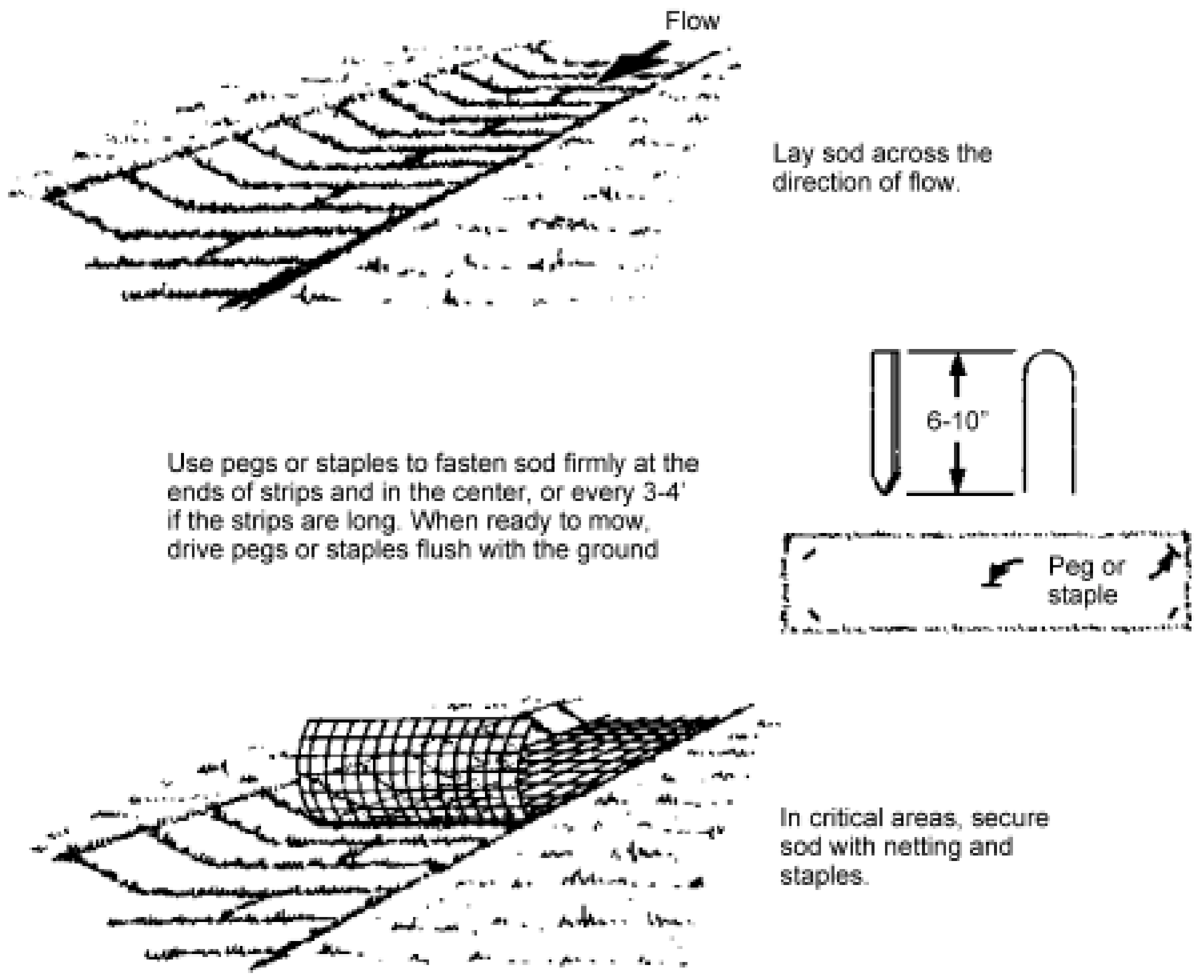


Figure 6.25-2 Installation of sod in waterways (modified from North Carolina, May 1994)

6.30 TREATMENT MEASURES

This part includes measures used to remove sediment from water except for ponds, which are covered in chapter 5 of this manual.

6.31 Treatment Measures: SILT FENCES

DESCRIPTION AND PURPOSE

A silt fence is a temporary sediment barrier consisting of a geotextile, which is attached to supporting posts trenched into the ground. Sediment-laden runoff ponds uphill from the silt fence and runoff is filtered as it passes through the geotextile (see Figure 6.31-1 for a typical installation of a silt fence).

Silt fences are intended to intercept and detain small amounts of sediment from disturbed areas in order to keep the sediment from leaving the site. Silt fences can also prevent sheet erosion by decreasing the velocity of runoff. In some instances, straw or hay bales could be used; however, their failure rate is high (see Figure 6.31-2 for a detail of silt fences on a slope).

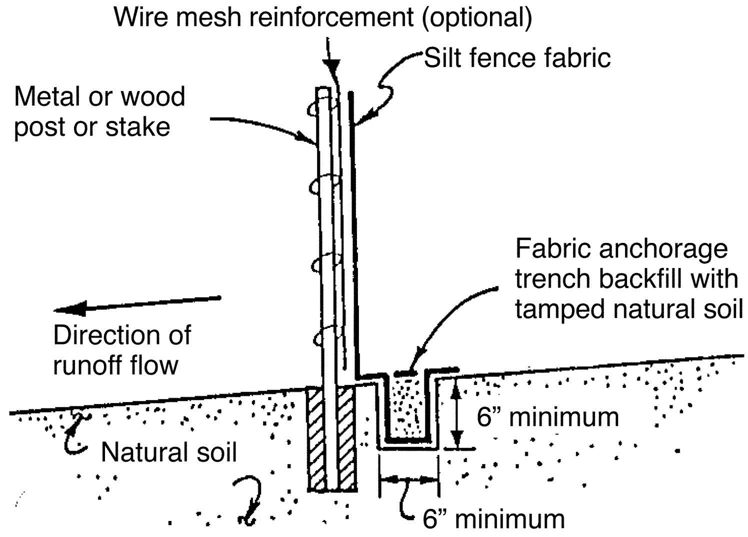
The use of silt fences as a sediment barrier is not recommended in areas of concentrated flow, such as ditches; in those cases, soil berms, silt dikes, straw waddles and excelsior logs, or rock check dams should be used.

PLANNING CONSIDERATIONS

A silt fence is a permeable barrier that should be planned as a system to retain sediment on the construction site. The fence retains sediment primarily by retarding flow and promoting deposition behind the fence. In operation, the fence generally becomes clogged with fine particles, which in turn reduces the flow rate. This causes a pond to develop more quickly behind the fence. The designer should anticipate ponding and provide sufficient storage areas and overflow outlets to prevent flows from overtopping the fence. Since silt fences are not designed to withstand high standing water, locate them so that only shallow pools can form. Tie the ends of a silt fence into the landscape to prevent flow around the end of the fence before the pool reaches design level. Often a crescent shape will perform better than the traditional straight line. Provide stabilized outlets to protect the fence system and release storm flows that exceed the design storm.

Deposition occurs as the storage pool forms behind the fence. The designer can direct flows to specified deposition areas through appropriate positioning of the fence or by providing an excavated area behind the fence. Plan deposition areas at accessible points to facilitate routine cleanout and maintenance. Show deposition areas in the erosion-and-sedimentation-control plan. A silt fence acts as a diversion if placed slightly off the contour. This may be used by the designer to control shallow, uniform flows from small, disturbed areas and to deliver sediment-laden water to deposition areas.

Silt fences serve no function along ridges or near drainage divides where there is little movement of water. Confining or diverting runoff unnecessarily with a silt fence may create erosion and sedimentation problems that would not otherwise occur.



(Note: Depending upon configuration, attach fabric to wire mesh with hog rings, steel posts with tie wires, or wood posts with staples.

Figure 6.31-1 Typical installation for silt fence

DESIGN RECOMMENDATIONS

1. Silt fences should be installed on the contour (as opposed to up and down a hill) and constructed so that flow cannot bypass the ends.

2. Ensure that the drainage area is no greater than 1/4 acre per 100 ft of fence.

3. Make the fence stable for the 10-year peak storm runoff.

4. Where all runoff is to be stored behind the silt fence, ensure that the maximum slope length behind the fence does not exceed the specifications shown in Table 6.31-1.

5. By design, ensure that the depth of impounded water does not exceed 2 ft at any point along the fence.

Table 6.31-1 Maximum slope length and slope for which silt fence is applicable

		By Calculation	**By Calculation**	**By Accepted Design Practices**
Slope H:V	**Percent**	**Silt fence storage equals 2 ft for a 100-year event**	**Silt fence storage equals 2 ft for a 2-year event or 3 ft for a 100-year event**	
100:1	1%	400 ft	900 ft	100 ft
50:1	2%	200 ft	450 ft	75 ft
25:1	4%	100 ft	225 ft	75 ft
20:1	5%	80 ft	180 ft	75-50 ft
17:1	6%	67 ft	150 ft	50 ft
12.5:1	8%	50 ft	112 ft	50 ft
10:1	10%	40 ft	90 ft	50-25 ft
5:1	20%	20 ft	45 ft	25-15 ft
4:1	25%	16 ft	36 ft	15 ft
2:1	50%	8 ft	18 ft	15 ft

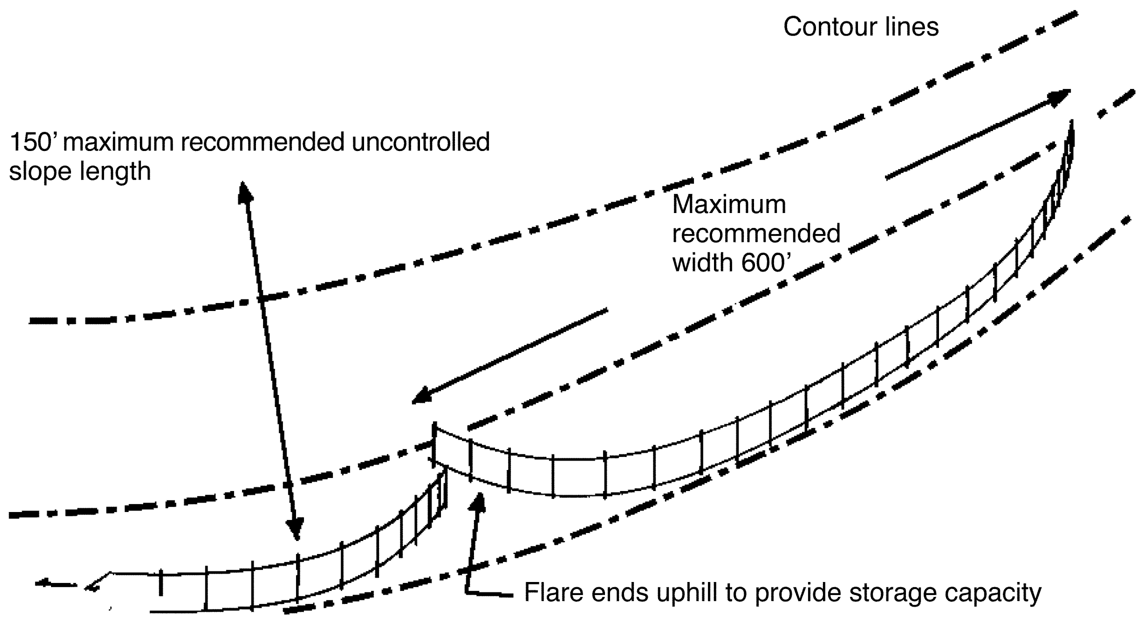


Figure 6.31-2 Typical silt fence layout

CONSTRUCTION SPECIFICATIONS

SILT FENCE

This description covers silt fence for use in retaining sediment and preventing off-site sedimentation. The following types are provided for specific uses:

Heavy Duty	General use during site grading, to protect critical areas and bodies of water. This type has metal posts and woven wire fence material as backing for the geotextile material.
Standard	Light-duty applications, to protect temporary construction or to supplement the other types of silt fence. This type is installed with plow type equipment with stakes spread at 8 ft intervals.
Preassembled	Light-duty applications, to protect temporary construction or to supplement the other types of silt fence. This type often has posts pre-attached to the silt fence geotextile.
Machine-sliced Installation	For most applications

The following describes the components of the silt fence which consists of a geotextile, which may have wire backing, and posts. (See Table 6.31-2 for further specifications)

GEOTEXTILE

Geotextile should be uniform in texture and appearance and have no defects, flaws or tears that would affect its physical properties. It should contain sufficient ultraviolet (UV) ray inhibitor and stabilizers to provide a minimum two-year service life outdoors.

Backing

Wire mesh backing is required with heavy duty silt fence. Use three vertically placed wire fasteners ("hog rings") to fasten the geotextile woven wire fence material at a minimum spacing of 2 ft.

Posts

Steel posts are used for heavy duty silt fence and machine sliced method of installation. Standard applications may use wooden posts, which should have a sharpened end and should be set in the ground at least 1.5 ft deep. Each post should be securely fastened to the geotextile and net backing by ties or staples suitable for such purpose.

FIELD ASSEMBLY

The geotextile should be attached to the upstream side of the post and any backing. The bottom edge of the geotextile should be buried at least 6 inches deep in a vertical slot or trench, with the soil pressed firmly against the embedded geotextile.

MACHINE SLICE INSTALLATION

A geotextile fabric should be inserted in a slit in the soil (6-12 inches deep) so that no flow can pass under the silt fence. The slit should be created such that a horizontal chisel point, at the base of a soil-slicing blade, slightly disrupts soil upward as the blade slices through the soil. This upward disruption minimizes horizontal compaction and creates an optimal soil condition for mechanical compaction against the geotextile. The geotextile should be mechanically inserted directly behind the soil-slicing blade in a simultaneous operation, achieving consistent placement and depth. No turning over (plowing) of soil is allowed for the slicing method.

The contractor should compact the soil immediately next to the silt fence fabric with the wheels of a tractor, skid steer or roller. Drive over each side of the silt fence two to four times.

Each post should be tied in three places with 50 lb plastic zip ties. Position the post with the projections, or nipples, facing away from the silt fence fabric. Place all three ties within the top 8 inches of fabric, puncturing holes vertically a minimum of 1 inch apart. Position each tie diagonally through the fabric so that it rests on top of a post nipple and tighten.

MATERIALS

General

Use a synthetic geotextile fabric which is certified by the manufacturer or supplier as conforming to the requirements shown in Table 6.31-2.

Table 6.31-2 Specifications for 3 types of silt fence

Description	Heavy Duty	Standard	Machine Slice
Geotextile			
Type	Woven	Woven	Monofilament
Width	48 inches	36 inches	36 inches
Grab Tensile Strength ASTM D 4632	100 lb Min.	100 lb Min.	130 lb
Apparent Opening Size AOS ASTM D 4751	20-70 Sieve	20-70 Sieve	30-40 Sieve
UV Stability ASTM D 4355 500 hr.	70% Min.	70% Min.	70% Min.
Top-fastening Component	Overlap Around Woven-wire Backing	Sewn-in Cord	
Net Backing			
Material	Woven Wire		
Min. Weight	14-1/2 gauge		
Min. Mesh Opening	2 inches		
Max. Mesh Opening	6 inches		
Min. Width	30 inches		
Tensile Strength ASTM D 4595	100 lb/ft		
UV Stability ASTM D 4355 500 h	70% Min.		
Posts	(E)		
Material	Metal	Wood	Metal
Min. Size	1.25 lb/ft	1.5 inch by 1.5 inch	1.25 lb/ft
Min. Length	5 ft	4 ft	5 ft
Min. Embedment	2 ft	1.5 ft	2 ft
Max. Spacing	8 ft	8 ft	6 ft
Type of Post Fasteners	U-shaped clips No. 16 gauge wire	Gun staples 0.5 inch long	Plastic zip ties (50-lb tensile strength)
Min. Fasteners Per Post	3	5	3

Geotextile fabric should contain UV ray inhibitors and stabilizers to provide a minimum of two years of expected usable construction life at a temperature range of 0 to 120° F.

Ensure that posts for silt fences are either 1.5-inch hardwood with a minimum length of 4 ft or 1.25 lb/linear ft steel, with a minimum length of 5 ft. Make sure that steel posts have projections to facilitate fastening the fabric. Post spacing will be site specific, but under all condition 6-8 ft. on center is a standard maximum.

INSTALLATION

1. Silt fence that is inadequately embeded in the ground will blow out, releasing water and sediment under the fence. Failure to properly install, inspect and maintain are the primary causes of this failure.

2. Silt fences can also be overtopped by sediment build up over several storm events. The silt fence must be maintained when sediment reaches 1/3 the height of the silt fence. For a 3 ft silt fence, cleaning should be conducted whenever there is on 1 ft of silt build up.

3. Another primary area of failure is for silt fences to be overtopped in a concentrated flow area. The silt fence is not meant to be placed in concentrated flow areas, and slope length calculations of Table 6.31-1 do not apply to concentrated flows.

4. Silt fences are not terraces; they cannot be put in sequence to extend the slope length allowable. Other methods must be used if the allowable distance is exceeded.

5. Another area of failure is for the silt fence to be eroded around the ends. The fence must be tied into the slope so that the base of the fence is above the design storage depth.

6. Construct the silt fence from a continuous roll of geotextile if possible. Cut to the length of the barrier to avoid joints. When joints are necessary, securely fasten the geotextile fabric. It is preferred that the material be overlapped to the next post or geotextile may be wrapped together around posts.

7. For heavy duty use support standard strength silt fence by woven wire mesh fastened securely to the upslope side of the posts using hog rings and tie wires. Extend the wire mesh support to the bottom of the trench. Woven wire is not required with the standard silt fence or slicing method of installation.

8. When a wire-mesh support fence is used, space posts no more than 8 ft apart. Support posts should be driven securely into the ground to a minimum of 2 ft.

9. Unless machine-slice methods are used, excavate a trench approximately 6 inches wide and 6 inches deep along the proposed line of posts and upslope from the barrier.

10. Backfill the trench with compacted soil or gravel placed over the geotextile.

11. Never attach silt fence to trees.

MAINTENANCE

1. Inspect silt fences at least once a week and after each rainfall, or as required by permits. Make any required repairs immediately. Repair scoured areas on the back side of fence at this time to prevent future problems.

2. Should the fabric of a silt fence collapse, tear, decompose or otherwise become ineffective, replace it within 24 hours of discovery.

3. Remove silt deposits once they reach one-third the height of the fence to provide adequate storage volume for the next rain and to reduce pressure on the fence. Take care to avoid undermining the fence during cleanout.

4. Remove all fencing materials and unstable sediment deposits and bring the area to grade and stabilize it after the contributing drainage area has been properly stabilized.

Note: Other specifications are acceptable, make sure your project specifications are appropriate for your project

6.32 Treatment Measures: FLOTATION SILT CURTAINS

DESCRIPTION AND PURPOSE

A flotation silt curtain is a silt barrier for use within a lake or pond, stream or other water. The flotation silt curtain consists of a geotextile curtain weighted at the bottom and attached to a flotation device, or carrier, at the top (See figure 6.32-1). This structure is used to isolate an active construction area within a waterbody to prevent silt-laden water from migrating out of the construction zone. A moving water silt curtain can be used in rivers and streams, while a still-water-type curtain is used in lakes and ponds.

EFFECTIVENESS

Flotation silt curtains are effective for limiting the migration of suspended sediment within a lake or pond. They will not reduce the amount of disturbance from work performed in water, but they will minimize the area that is impacted.

PLANNING CONSIDERATIONS

Flotation silt curtains are to be used as a last resort and should be used in conjunction with other protection measures. In some cases, it may not be practical or possible to avoid construction within a lake or stream. A flotation silt curtain can be used to isolate the water-quality effects from this type of work. The silt curtain should be located so that the amount of water included in the construction zone is minimized.

DESIGN RECOMMENDATIONS

1. The curtain should be constructed of a nylon fabric with a minimum tensile strength of 300 lb per inch of fabric.

2. The top of the curtain should have a flotation carrier consisting of high quality polyethylene foam. The flotation carrier should also have a high quality cable in it to carry loads imposed upon the curtain.

3. The bottom edge should be weighted by cable or chain with an adequate weight for the situation. Anchors must also be used to keep the curtain in place. The weight and spacing of anchors will be site-specific.

4. Where the curtain is made up of sections, the sections should be joined so that silt cannot permeate through the connection (grommets and laces for still water and mechanically for moving water).

MAINTENANCE

The silt curtain should be maintained until the construction area is stabilized and turbidity is reduced to acceptable background levels.

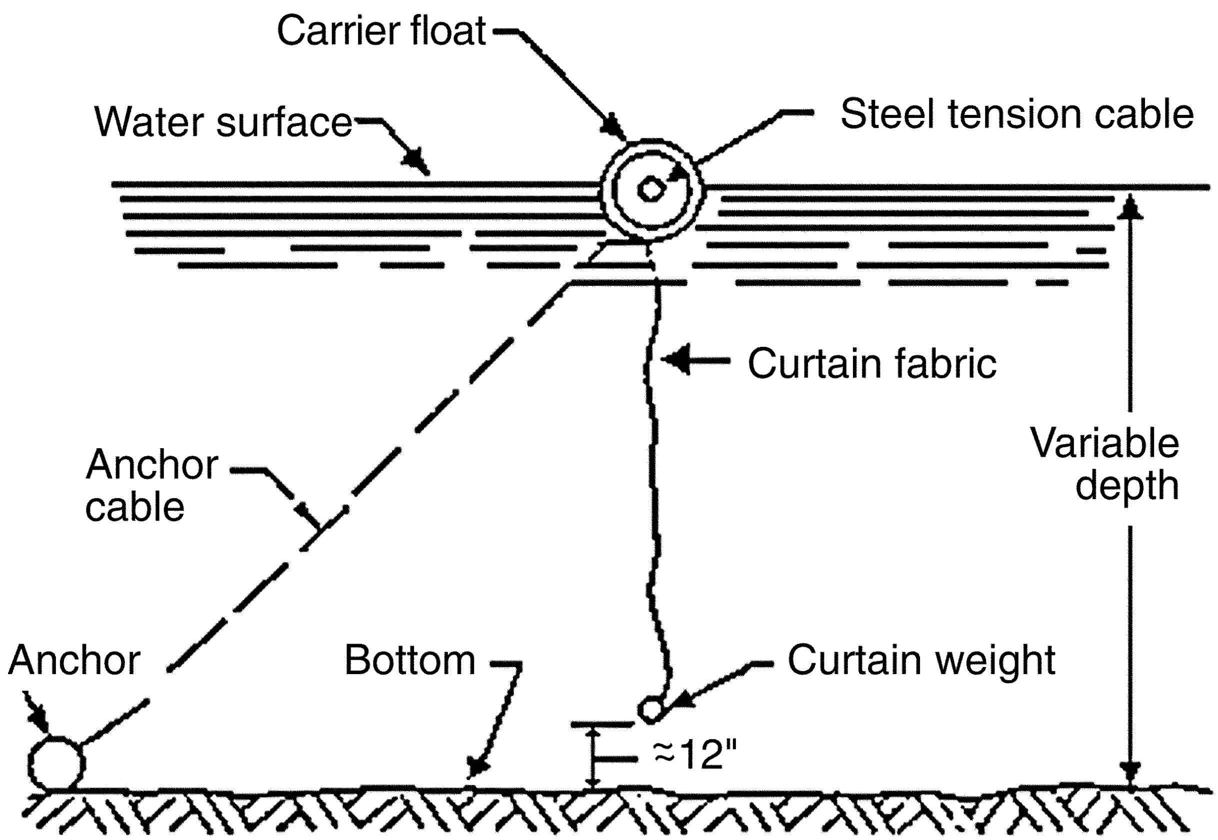


Figure 6.32-1 Flotation silt curtain

6.33 Treatment Measures: CHECK DAMS

DESCRIPTION AND PURPOSE

Check dams are generally used in concentrated-flow areas, such as ditches and swales. The use of rock check dams has been well established, while the use of silt dikes, waddles and fiber logs is a relatively new but growing technology. Check dams can either be permanent or temporary barriers to slow flow velocities and/or to filter concentrated flows. Ditch check dams tend to pond water. Under low-flow situations, water ponds behind the structure and then seeps slowly through, infiltrates or evaporates. Under high-flow situations, water flows over and/or through the structure. Check dams do not include staked hay bales or silt fence placed in a concentrated-flow area.

EFFECTIVENESS

Check dams provide relatively good removal of coarse and medium-size sediment from runoff. However, most fine silt and clay particles will pass though the voids on these structures. Check dams provide several advantages over staked hay bales: they require less maintenance, are effective in medium- to heavy-flow situations, and can be a permanent erosion-control measure. In the case of waddles and fiber logs, many times these will become a permanent part of vegetation establishment.

PLANNING CONSIDERATIONS

Slopes should not exceed 10%; a drop structure should be considered if the slope is greater than 10%. The maximum drainage area should be less than five acres, and flow velocities should not exceed 12 fps for a 10-year, 24-hour storm frequency.

DESIGN RECOMMENDATIONS

Rock check dams should consist of well-graded stone consisting of a mixture of rock sizes. For example: Class IV riprap with the percent less than the specified rock diameter.

100% < 24 inches
75% < 15 inches
50% < 9 inches
10% < 4 inches

Other options include 1.5-inch clean gravel and river rock. When riprap is provided on a project, the riprap can be temporarily used for rock checks, removed, and then reused for the permanent riprap installation. In a series of check dams, the top center of the downstream check dam should be at the bottom of the upstream check dam (see Figure 6.33-1).

A triangular silt dike is a triangular-shaped foam block covered with geotextile fabric. When laid in the channel, it will form a check dam. Triangular silt dikes are light-weight and easy to install and maintain.

Straw waddles and excelsior logs are straw and wood-fiber cores wrapped with synthetic netting. They can be partially buried in a channel to create mini dams. They are available in many diameters to meet site requirements. They can be helpful in establishing permanent vegetation in a channel.

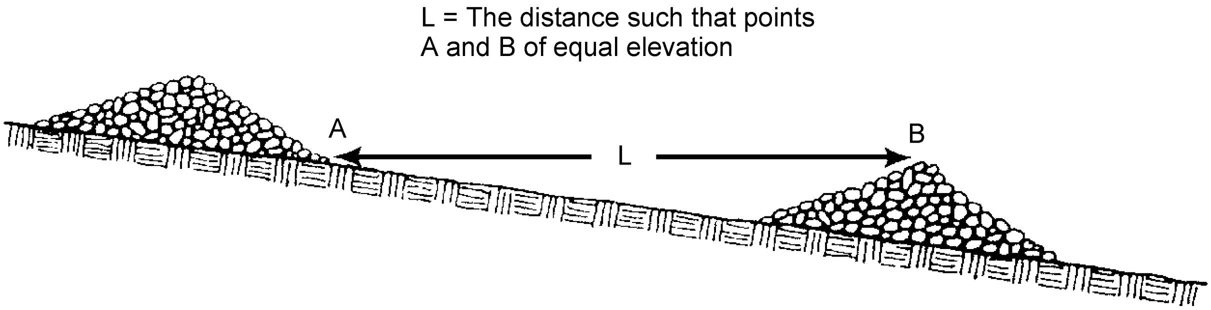


Figure 6.33-1 Space check dams in a channel so that the crest of the downstream dam is at the elevation of the toe of the upstream dam. (Source: Virginia Department of Conservation and Recreation, 1992.)

The spacing between ditch checks should be such that the bottom of the upstream check should be at the same elevation as the top of the downstream check. The spacing can be calculated by multiplying the height of the check dam by the slope H:V or by dividing by the slope in %. For a 2 ft size check dam the V indicates the spacing:

Table 6.33-1

Ditch grade (%)	Spacing (feet)
1	200
2	100
4	50
6	33
Above 6% ditch grade, you may need to flatten the slope	
8	25
10	20

To increase the effectiveness of rock check dams, a shallow pool upstream of the check is recommended. The pool allows additional sediment storage.

CONSTRUCTION SPECIFICATIONS

Install all structural check dams as recommended by the manufacturer. When stone dams are used, generally follow the following procedures:

1. Place stone to the lines and dimensions shown in the plan over a nonwoven geotextile fabric foundation.

2. Keep the center stone section at least 9 inches below natural ground level where the dam abuts the channel banks.

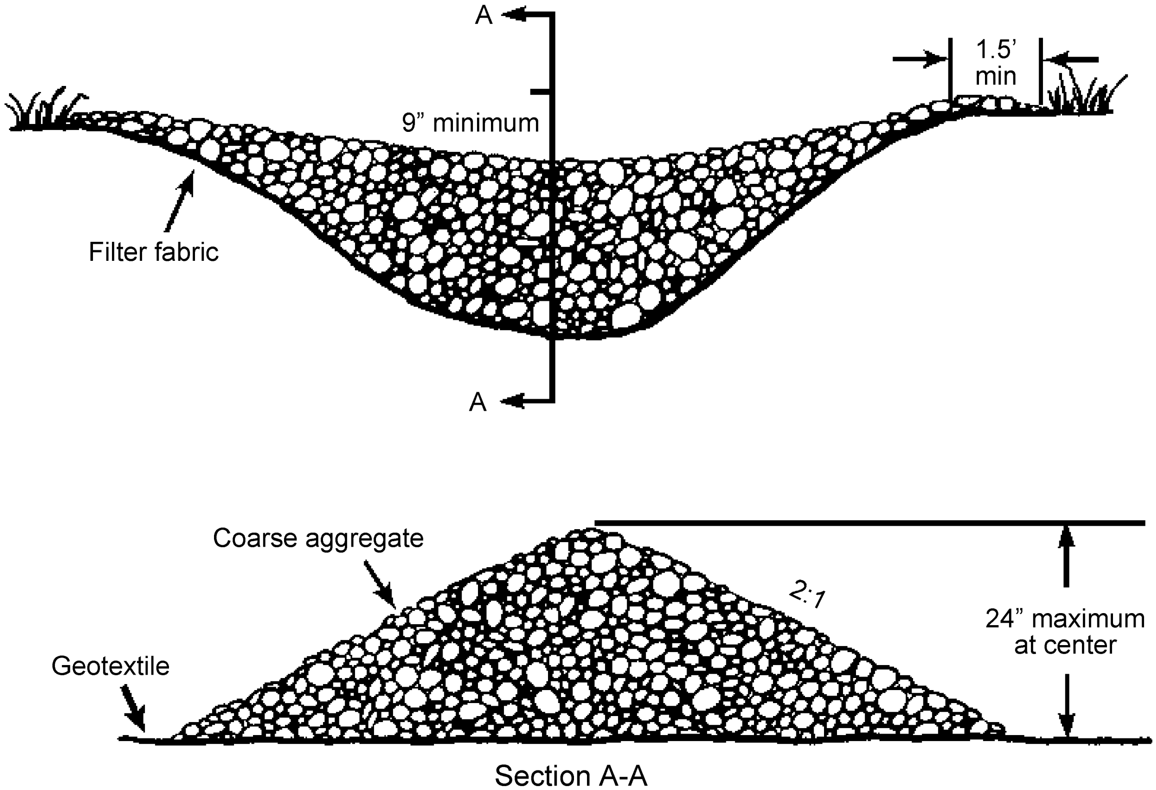


Figure 6.33-2 Stone check dam: stone should be placed over the channel banks to keep water from cutting around the dam. (Source: Virginia Department of Conservation and Recreation, 1992.)

3. Extend stone at least 1.5 ft beyond the ditch banks (Figure 6.33-2) to keep overflow water from undercutting the dam as it re-enters the channel.

4. Set spacing between dams to assure that the elevation at the top of the lower dam is the same as the toe elevation of the upper dam.

5. Protect the channel downstream from the lowest check dam, since water will flow over and around the dam.

6. Make sure that the channel reach above the most-upstream dam is stable.

7. Ensure that channel appurtenances, such as culvert entrances below check dams, are not subject to damage or blockage from displaced stones.

MAINTENANCE

Inspect check dams and channels for damage after each runoff event.

Anticipate submergence and deposition above the check dam and erosion from high flows around the edges of the dam. Correct all damage immediately. If significant erosion occurs between dams, install a protective riprap liner in that portion of the channel (See section 4.50, Riprap.).

Remove sediment accumulated behind the dams as needed to prevent damage to channel vegetation, allow the channel to drain through the stone check dam, and prevent large flows from carrying sediment over the dam. Add stones to dams as needed to maintain design height and cross section.

6.34 Treatment Measures: STRAW (OR HAY) BALE SEDIMENT BARRIERS

Note: Straw (or hay) bale sediment barriers are effective sediment-control practices only when they are used in appropriate locations and properly installed and maintained. Generally, alternatives, such as stone check dams, or silt fences should be used, especially in areas of concentrated flow. In many cases, installation or maintenance conditions are not met and the practice fails.

This practice is only recommended when proper planning is used and adequate construction supervision is available to ensure that the structure is installed and maintained correctly. Check dams (see part 6.3.) are more reliable and should be used if possible

DESCRIPTION AND PURPOSE

A straw (or hay) bale sediment trap is a row of entrenched and anchored bales, which are installed so that they detain and filter sediment-laden runoff.

This type of sediment trap is intended to remove coarse sediment from small amounts of runoff before it leaves the site.

The use of straw bales for a sediment trap is not recommended in areas of concentrated flow, such as ditches; instead, rock check dams should be used.

EFFECTIVENESS

Straw bales are moderately effective for trapping medium and coarse-grained sediment particles. They are generally not effective for trapping fine silt or clay particles in runoff. And, if straw bales are improperly installed, they can actually increase the amount of erosion by concentrating runoff and causing gully erosion.

PLANNING CONSIDERATIONS

Straw bale sediment traps are generally used in locations where silt fences could be used. Silt fences are almost always preferable to straw bales because they have a lower failure rate, are more effective and have a longer life. Because straw bale sediment traps have been widely used in the past, their proper use and installation is presented here for the planner’s consideration.

DESIGN RECOMMENDATIONS

1. The slope length above the bales should be 100 ft or less.

2. The bales should be installed on the contour with their ends flared upslope, as shown in Figure 6.34-1.

3. The bales should be composed of clean straw or hay.

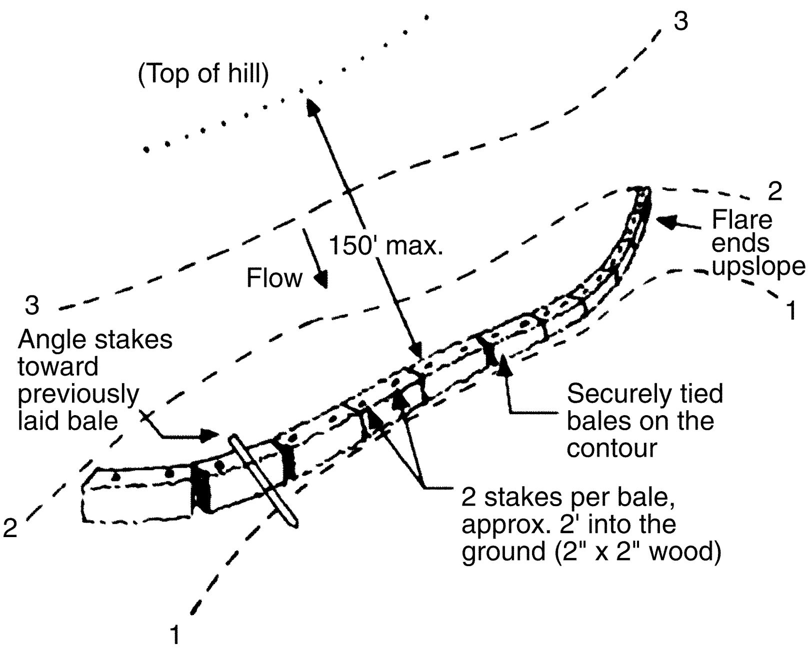


Figure 6.34-1 Placement and anchoring detail for straw bale sediment trap

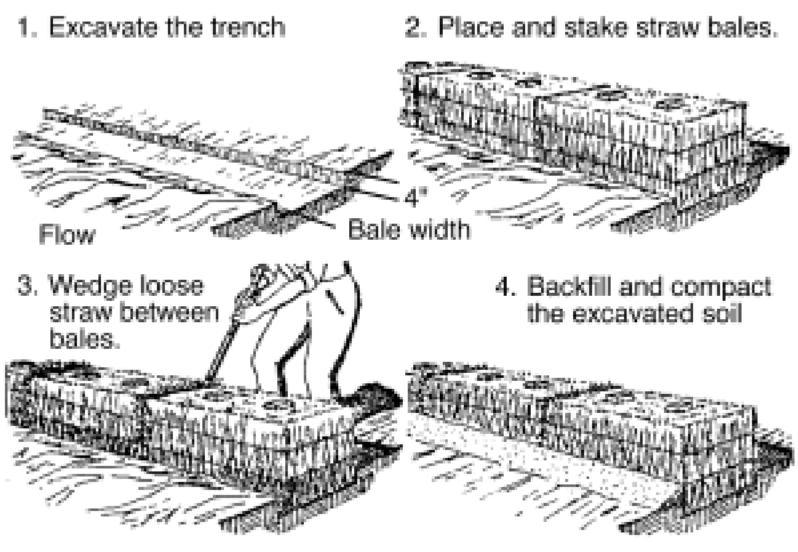


Figure 6.34-2 Construction of a straw bale barrier (adapted from *Installation of Straw and Fabric Filter Barriers for Sediment Control*, Sherwood and Wyant)

4. The bales should be trenched 4 inches into the ground and should be staked with steel fence posts or 2" x 2" wood stakes. The stakes should be angled toward the previously laid bale.

5. Soil should be compacted on the upslope side of bales as shown in Figures 6.34-2 and 6.34-3. Loose straw should be wedged between the bales.

MAINTENANCE

Straw bale sediment traps should be inspected after every significant runoff event. Sediment deposits should be removed from behind the barrier as needed. Sediment should not be allowed to accumulate to a depth of more than one-half the height of the bales. Damaged, destroyed or rotted bales should be replaced immediately.

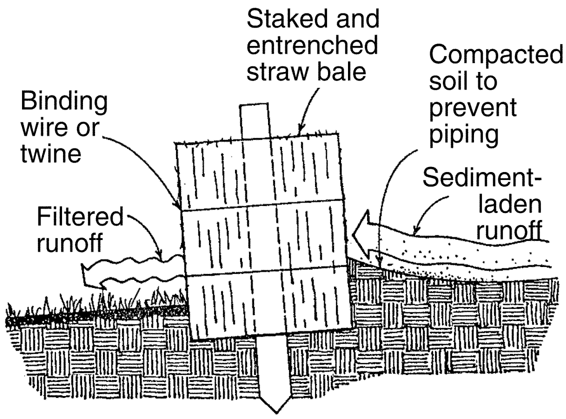


Figure 6.34-3 Cross section of a properly installed straw bale (source: *Michigan Soil Erosion and Sedimentation Control Guidebook*, 1975)

6.35 Treatment Measures: STORM DRAIN INLET PROTECTION

DESCRIPTION AND PURPOSE

Storm drain inlet protection is a sediment barrier placed around a storm drain drop inlet. This structure is used to trap sediment before it enters a storm sewer. This will keep sediment from being transported to lakes or streams and can also prevent clogging of the storm sewer caused by heavy sediment loads.

EFFECTIVENESS

Storm drain inlet protection provides relatively good removal of coarse and medium-size sediment from runoff. However, most fine silt and clay particles will pass though gravel filters on these structures. The Type A sediment barrier will do a better job of removing fine silt and clay from runoff.

PLANNING CONSIDERATIONS

It is critical that the storm sewer inlet not be completely blocked by inlet protection when public safety is a concern. Blocking an inlet has caused streets to flood and sediment to build up, creating a safety hazard. Erosion-control practices should be used in addition to this practice to limit sediment movement from disturbed areas. The inlet protection should be left in place until the drainage area is stabilized.

DESIGN RECOMMENDATIONS

Inlet protection should only be used in locations where sediment can be removed and temporary ponding will not create a safety hazard or cause property damage. Various designs have been adapted for different conditions. These individual types are described beginning on page 6.35-2.

NEW TECHNOLOGIES

Filter baskets and socks (bags) inserted under and around the catch basin grill are applicable where the inlet drains a relatively flat area and concentrated flows are not expected. Inlet drains with filtering devices have also been developed and may be useful in some applications. These devises must be installed, operated and maintained in accordance with manufacturer specifications.

MAINTENANCE

After any significant rainfall, storm sewer inlet protection must be inspected. Sediment should be removed as needed. Excavated sediment should be placed where it will not create an erosion problem, and inlet protection should be removed as soon as the contributing drainage area is stabilized.

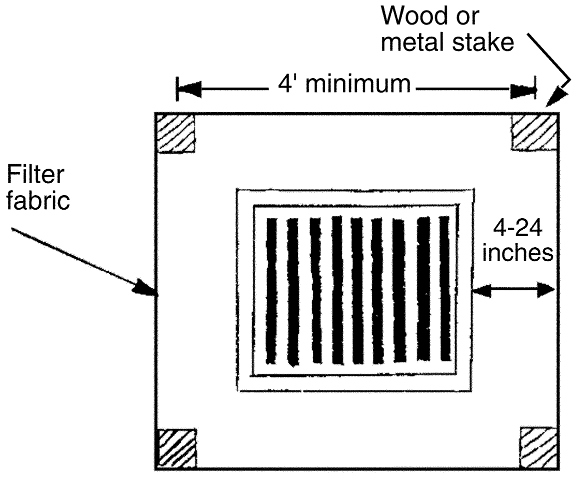


Figure 6.35-1 Type A silt-fence inlet sediment barrier

TYPE A-SILT-FENCE INLET SEDIMENT BARRIER

1. This method is applicable where the inlet drains a relatively flat area (slopes of less than 3%) where sheet flow is typical. This method is not recommended for inlets receiving concentrated flows, such as in road ditches.

2. The silt fence should be constructed in accordance with Practice 6.31, Silt Fence, except that the posts should be no more than 4 ft apart.

3. Each side of the inlet protection should be at least 4 ft long.

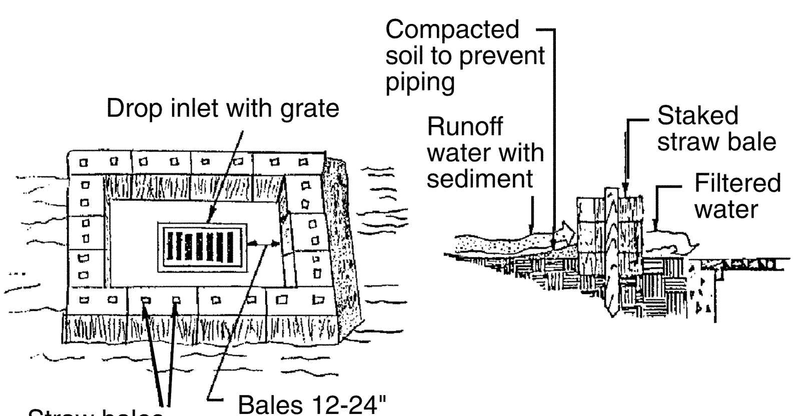


Figure 6.35-2 Type B straw-bale inlet sediment barrier (source: *Michigan Soil Erosion and Sedimentation Control Guidebook*)

TYPE B - STRAW BALE INLET SEDIMENT BARRIER

1. This method is applicable for the same conditions as Type A. Type A is preferred. Type B should only be used when Type A cannot be readily used, flow velocities are low, and the practice would be of temporary or limited duration.

2. The bales should be installed in accordance part 6.41, Sediment Traps. As mentioned in that practice, proper installation is imperative.

3. Straw bales should be set back 12 to 24 inches from the inlet.

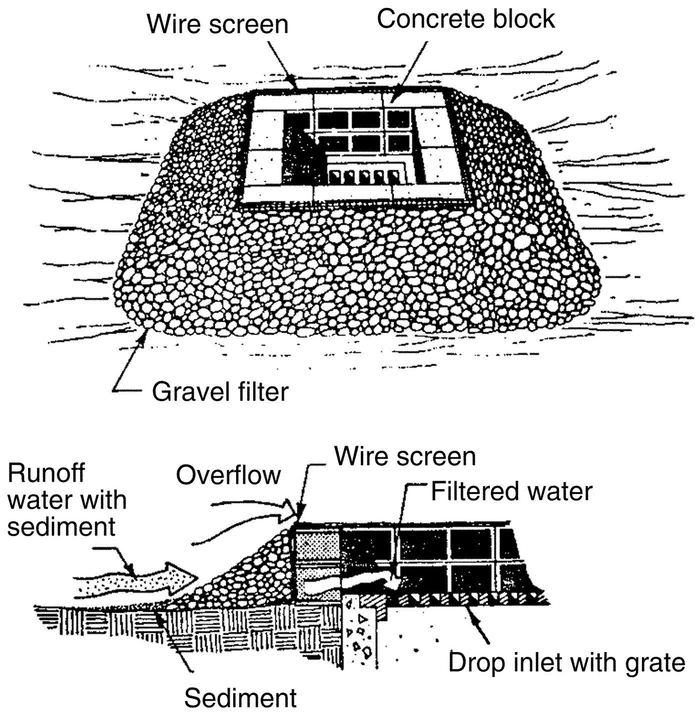


Figure 6.35-3 Type C block-and-gravel inlet sediment filter (source: Virginia Department of Conservation and Recreation)

TYPE C – BLOCK-AND-GRAVEL DRAIN INLET SEDIMENT FILTER

1. This method of inlet protection is applicable if heavy flows are expected and when an overflow capacity is needed to prevent excessive ponding around the structure.

2. Place concrete blocks lengthwise on their sides around the inlet as shown in Figure 6.35-3. The height of the barrier can be varied, depending upon needs, by stacking various sizes of block. The blocks should be between 12 and 24 inches high.

3. Wire mesh should be placed over the edges of the block before the rock is placed to prevent rocks from being washed through the block. Hardware cloth with ½-inch mesh should be used.

4. Stone should be placed against the wire mesh to the top of the block. The stone should be 1- to 3-inch washed gravel.

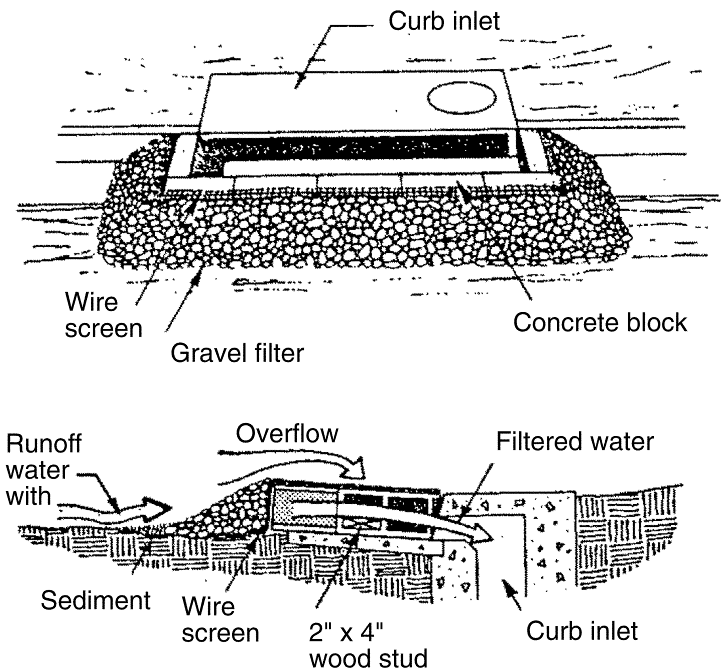


Figure 6.35-4 Type D block-and-gravel curb inlet sediment filter (source: Virginia Department of Conservation and Recreation)

TYPE D – BLOCK-AND-GRAVEL CURB INLET SEDIMENT FILTER

1. This method of inlet protection is applicable at curb inlets where an overflow capability is necessary to prevent excessive ponding in front of the structure. Public safety should be considered when using this practice.

2. Concrete blocks should be placed on the side around the inlet as shown in Figure 6.35-4. A 2x4 should be placed through the outer hole of the two spacer blocks to support the front row of blocks.

3. Wire mesh with 2-inch openings should be placed over the openings in the blocks to prevent gravel from being washed through the blocks.

4. Stone should be placed against the wire mesh to the top of the block. The stone should be 1- to 3-inch washed gravel.

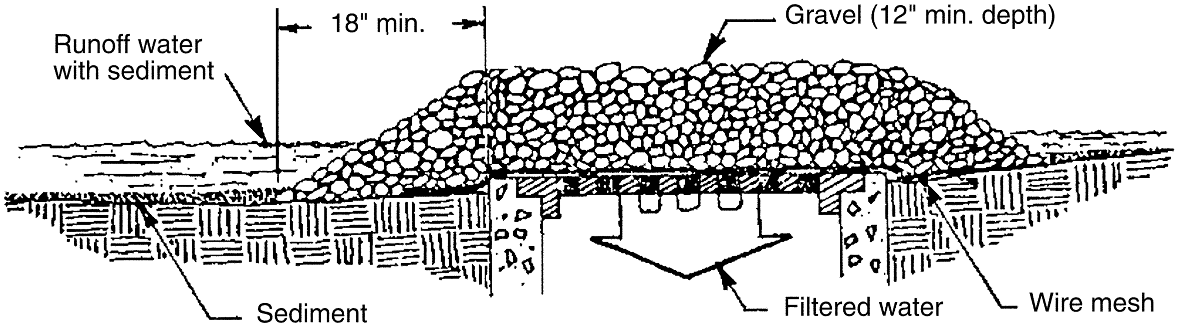


Figure 6.35-5 Type E gravel-and-wire-mesh drop inlet sediment filter

TYPE E – GRAVEL-AND-WIRE-MESH DROP INLET SEDIMENT FILTER

1. This method is applicable where heavy concentrated flows are expected and where ponding around the structure will not be inconvenient or cause damage to adjacent structures.

2. Wire mesh should be placed over the grating as shown in Figure 6.35-5 to prevent gravel from being washed into the storm drain. The wire mesh should have 1/2-inch openings and extend one foot beyond the grating.

3. The stone should be 1-3-inch washed gravel. The stone should be at least 12 inches deep and extend at least 18 inches beyond the grating.

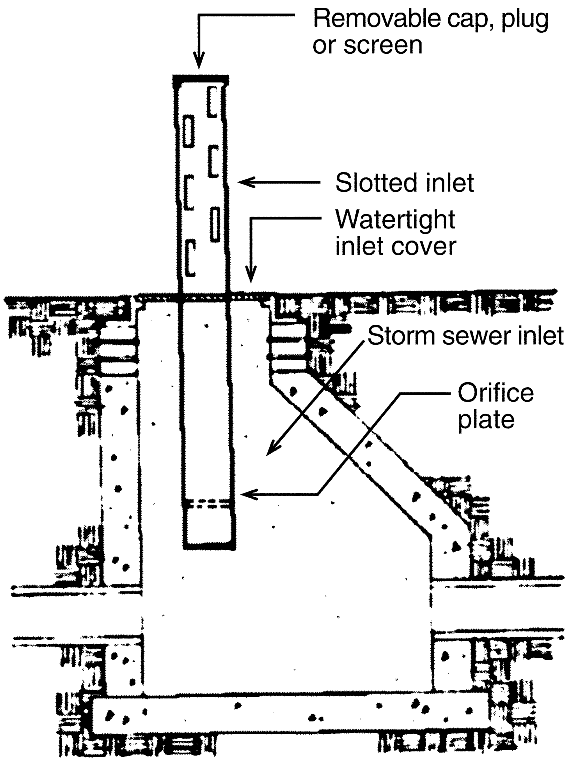


Figure 6.35-6 Type F slotted-riser storm sewer inlet (source: *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois*, 1981)

TYPE F – SLOTTED-RISER STORM SEWER INLET

1. This method is applicable where heavy concentrated flows are expected and where ponding around the structure will not cause excessive inconvenience or damage to adjacent structures.

2. The riser may be made of corrugated metal, smooth metal or polyvinyl chloride (PVC) pipe. An orifice plate should be used to restrict flow. A flow velocity through the slots of 2 fps or less is suggested. Inlets constructed according to the standard dimensions table in Figure 6.35-6 will meet this criterion.

3. A prefilter consisting of geotextile or rock should be placed around the slotted riser.

6.40 Miscellaneous Measures: DEWATERING

DESCRIPTION

Dewatering encompasses various methods used to remove and discharge excess water from a construction site. The most common method is to pump water out of areas where it does not otherwise drain off, such as excavated areas, sediment basins and sediment traps. Dewatering may also include methods, such as sand point wells, used to lower the ground water table to provide a stabilized area for construction. Cofferdams and diversion structures may be used to keep water from a dewatered area or a site.

PURPOSE

Dewatering may be used during construction to remove accumulated water and sediments from sediment traps and basins to ensure their effectiveness throughout the project. At the end of the project, dewatering of sediment traps and basins is appropriate prior to removing the last sediment-control measures. Water remaining in excavated areas may be eliminated by dewatering so that construction can proceed on schedule.

PLANNING CONSIDERATIONS

These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

Water pumped out of cofferdams, excavations, footings and other areas where water can accumulate may contain high concentrations of suspended solids. The solids are sometimes already suspended in the water, or the pumping process can mix the solids into the water. Water that is pumped from a sand point for dewatering operations can also contain high levels of sediment, especially at first. In either case, adequate sediment control must be provided before the pumped water is discharged. If the pumped water is running clear or begins to run clear, the sediment-control devices may be bypassed as long as sediment is not re-introduced into the system.

Discharging pumped water that contains suspended sediment can cause substantial amounts of pollutants to enter Minnesota’s surface waters. Sediment smothers aquatic organisms, covers habitat and provides nutrients that cause excessive weed and algal growth. It can be related to processes that raise the water temperature, reduce the amount of dissolved oxygen, and hinder successful fish spawning.

Sediment-laden water affected by construction or other activity must be treated by temporary sedimentation traps, basins, geotextile filters or other appropriate BMPs. These guidelines include several suggested types of dewatering structures, which have different applications, depending on site conditions and types of operation.

DESIGN RECOMMENDATIONS

Water not affected by construction activity can be diverted around a construction site or removed by well points and discharged to a stable outlet without treatment. However, treatment of waters affected by construction activity must be provided. We recommend the following measures be considered diversion structures, well points, filtered sump pits, sediment traps, treatment ponds, and other dewatering systems that are appropriate for the discharge and effectiveness of the system. The appropriation and discharge of water may require additional local, state or federal permits.

OPERATIONS

A dewatering structure must be sized (and operated) to allow pumped water to flow through the device at the appropriate rate, without exceeding the design criteria for the treatment system.

Design criteria specific to each particular dewatering device should be developed.

MAINTENANCE

1. The dewatering system must be inspected frequently and repaired or replaced if sediment buildup recurs or if the structure does not function as designed.

2. The accumulated sediment that is removed from a dewatering device must be spread onsite and stabilized, used as fill or disposed of at an approved disposal site.

Examples of construction-site dewatering practices that are <u>not</u> acceptable include:

1. straight pipe pumping sediment-laden water directly to a lake, pond, river, stream, brook, wetland or marsh;

2. straight pipe pumping sediment-laden water directly to a storm drain inlet or catch basin; and

3. discharging water in a manner that causes erosion of the site or receiving channels.

6.41 Miscellaneous Measures: SEDIMENT TRAPS

DESCRIPTION AND PURPOSE

A temporary sediment trap is a small, temporary ponding area formed by constructing an earthen embankment with an outlet across a swale. Temporary sediment traps are intended to detain sediment-laden runoff from small, disturbed areas long enough to allow the majority (at least 75%) of the sediment to settle out.

EFFECTIVENESS

Temporary sediment traps provide good control of coarse sediment and are moderately effective for trapping medium-size sediment particles. However, they have a relatively low trapping efficiency for fine silt and clay particles suspended in runoff. If a higher trapping efficiency is desired, a temporary sediment basin with a larger storage volume and longer detention time should be used.

PLANNING CONSIDERATIONS

For maximum effectiveness, sediment traps should be located as close as possible to the disturbed area. Temporary diversions can be used to direct sediment-laden runoff to the sediment trap. Every effort should be made to exclude runoff from undisturbed areas. Sediment traps and other sediment-control measures should be installed before work is begun in the contributing drainage area.

DESIGN RECOMMENDATIONS

1. A temporary sediment trap should only be used in a location with a drainage area of five acres or less and where it will be used for two years or less.

2. Sediment traps must have an outlet to carry runoff through the structure. The outlet can be a pipe outlet, gravel outlet or other suitable device. The outlet must be capable of handling the runoff from a 10-year-frequency, 24-hour-duration storm without failure or significant erosion.

3. For pipe outlets, see Practice 6.37, Temporary Sediment Basins, for design requirements.

4. If a gravel outlet is used, it should be located in the low point of the embankment. The minimum length in feet of a gravel outlet should be four times the number of acres in the drainage area. The crest of the gravel outlet should be level and ft below the top of the embankment. See Figure 6.41-1.

The gravel used for the outlet should be 1- to 2-inch size, such as MnDOT CA-1 or CA-2 coarse aggregate. Geotextile can be installed inside the gravel filter to improve the sediment-trapping efficiency of the structure. However, this increases the probability that the outlet will become clogged.

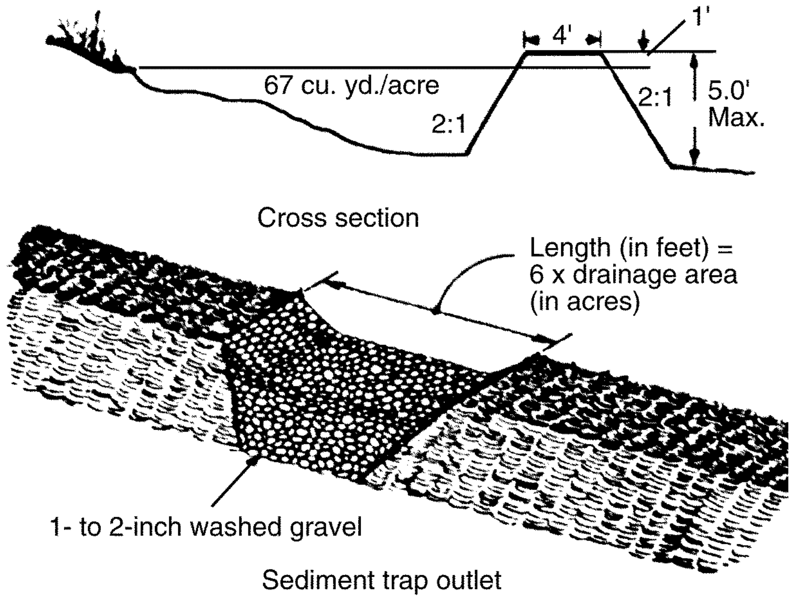


Figure 6.41-1 Temporary sediment trap with gravel outlet (source: Virginia Department of Conservation and Recreation)

MAINTENANCE

As previously mentioned, the sediment should be removed when it fills half of the capacity of the sediment trap. If the outlet becomes clogged with sediment, it should be cleaned to restore its flow capacity.

The structure should be inspected after significant runoff events to check for damage or operational problems. Once the contributing drainage area has been stabilized, the structure should be removed.

6.42 Miscellaneous Measures: SUMP PITS

DESCRIPTION AND PURPOSE

A sump pit is a temporary hole or pit placed so that it can collect water so that the water can be discharged relatively unaffected by construction or other activity. Other uses may be to dewater sediment traps and basins or excavations. A perforated standpipe wrapped in an appropriate geotextile designed to minimize plugging is placed in the center of the pit. Then the area is backfilled with filter stone. Water that collects in the pit flows through the gravel into the standpipe and is pumped out to a filtering device or, in some cases, directly to a receiving water. The sump-pit discharge may be pumped directly to a receiving water only if the perforated portion of the standpipe has been properly wrapped in geotextile and the discharge water is clear.

PLANNING CONSIDERATIONS

A sump pit may be used to dewater a cofferdam, sediment trap or basin, or it may be used during construction when water collects in an excavation. A sump pit may be used for dewatering where space is limited, such as in urban areas. It should generally be used only for small flows and volumes.

DESIGN RECOMMENDATIONS

1. The number of sump pits and their locations will depend on the site and any state or local requirements. A detailed design is not required, but construction should conform to the general criteria outlined in Figure 6.42-1.

2. The standpipe should have perforations to allow water to flow in and it should be extended at least 1 ft over the top of the pit.

3. If the sump pit is to discharge directly into a receiving water or storm-drainage system, the standpipe must be wrapped in geotextile before the pit is backfilled with stone.

4. Pit dimensions must be sight specific.

5. The standpipe should be constructed by perforating a 12- to 24-inch-diameter corrugated metal or PVC pipe.

6. A base of 2-inch aggregate should be placed in the pit to a depth of 12 inches. After the standpipe is installed, the pit surrounding it should be backfilled with 2-inch aggregate.

7. The standpipe should extend 12-18 inches above the lip of the pit.

8. If the discharge will be pumped directly to a storm-drainage system, the standpipe must be wrapped with geotextile filter cloth meeting the property values in Table 6.42-1, before it is installed.

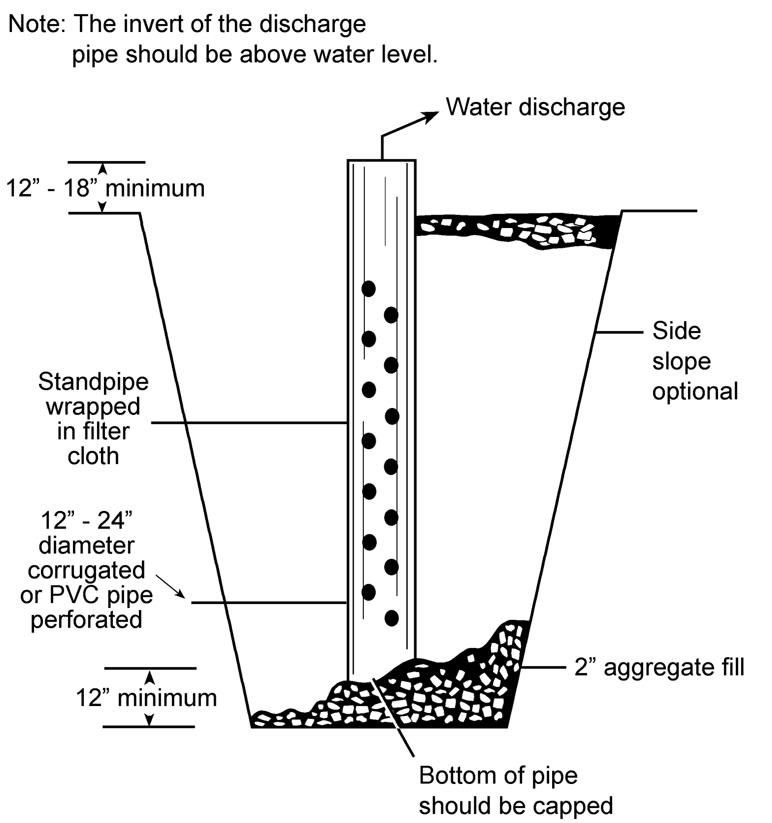


Figure 6.42-1 Sump pit dewatering (source: USEPA, April 1992)

9. If desired, hardware cloth, a three-dimensional synthetic material or chicken wire may be placed around the standpipe before attaching the filter cloth. This will increase the rate of water seepage into the pipe and prevent plugging.

Table 6.42-1 Geotextile filter fabric requirements for temporary sedimentation basin outlet design for dewatering

Property	Test Method	Unit	Minimum Avg. Roll Value	
			Machine Direction	Cross Direction
Grab tensile strength	ASTM D 4632	kN (lb)	1.62 (365)	0.89 (200)
Grab tensile elongation	ASTM D 4632	%	24	10
Mullen burst strength	ASTM D 3786	kPa (psi)	3445 (500)	
Puncture strength	ASTM D 4833	kN (lb)	0.51 (115)	
Trapezoid tear strength	ASTM D 4533	kN (lb)	0.51 (115)	0.33 (75)
Apparent opening size	ASTM D 4751	U.S. Std. Sieve	40 (0.420mm)	
Percent open area	COE-02215-896	%	10	
Permitivity	ASTM D 4491	ft/sec^{-1}	1.36	
Permeability	ASTM D 4491	cm/sec	0.092	
Flow rate	ASTM D 4491	l/min/m^2 (gpm/ft^2)	4074 (100)	
UV resistance after 500 hours	ASTM D 4355	% strength retained	90	

6.43 Miscellaneous Measures: SMALL FLOW-TREATMENT DEVICES

DESCRIPTION AND PURPOSE

This design is for the treatment of small dewatering flows that are affected by contractor activity using a filter box. A filter box is a structure that can be made of steel, sturdy wood or other materials suitable to handle the pressure requirements imposed by the volume of water. Fifty-five-gallon drums welded top to bottom are normally readily available and, in most cases, will suffice. These devices are not normally recommended but may be used on a site specific basis.

PLANNING CONSIDERATIONS

A filter box allows only minimal settling time for sediment particles. Therefore, filter boxes should only be used when site conditions restrict the use of other methods.

DESIGN RECOMMENDATIONS

1. The bottom of the box should be made porous by drilling holes (or some other method).

2. One- to 3-inch coarse aggregate meeting the gradations requirements in Figure 6.40-1 should be placed over the holes to a minimum depth of 12 inches (metal hardware cloth may need to be placed between the aggregate and the holes if holes larger than the majority of the stone have been made in the bottom of the box).

3. Geotextile should be placed on top of the coarse aggregate.

4. Six inches of washed sand should be placed on top of the geotextile.

5. Because of the fast flow of sediment-laden water through the aggregate, the effluent must be directed over a well-vegetated strip of at least 75 ft after leaving the base of the filter box.

6. Once the water level nears the top of the box, the pump must be shut off while the box drains and additional capacity is made available.

7. The box should be designed and constructed to allow for emergency flow over the top of the box.

8. Clean-out of the box is required once one-third of the original capacity is depleted due to sediment accumulation. The clean-out point should be clearly marked on the tank.

9. If the stone filter becomes clogged with sediment so that it no longer adequately functions, the stones must be pulled away from the inlet, cleaned, and replaced.

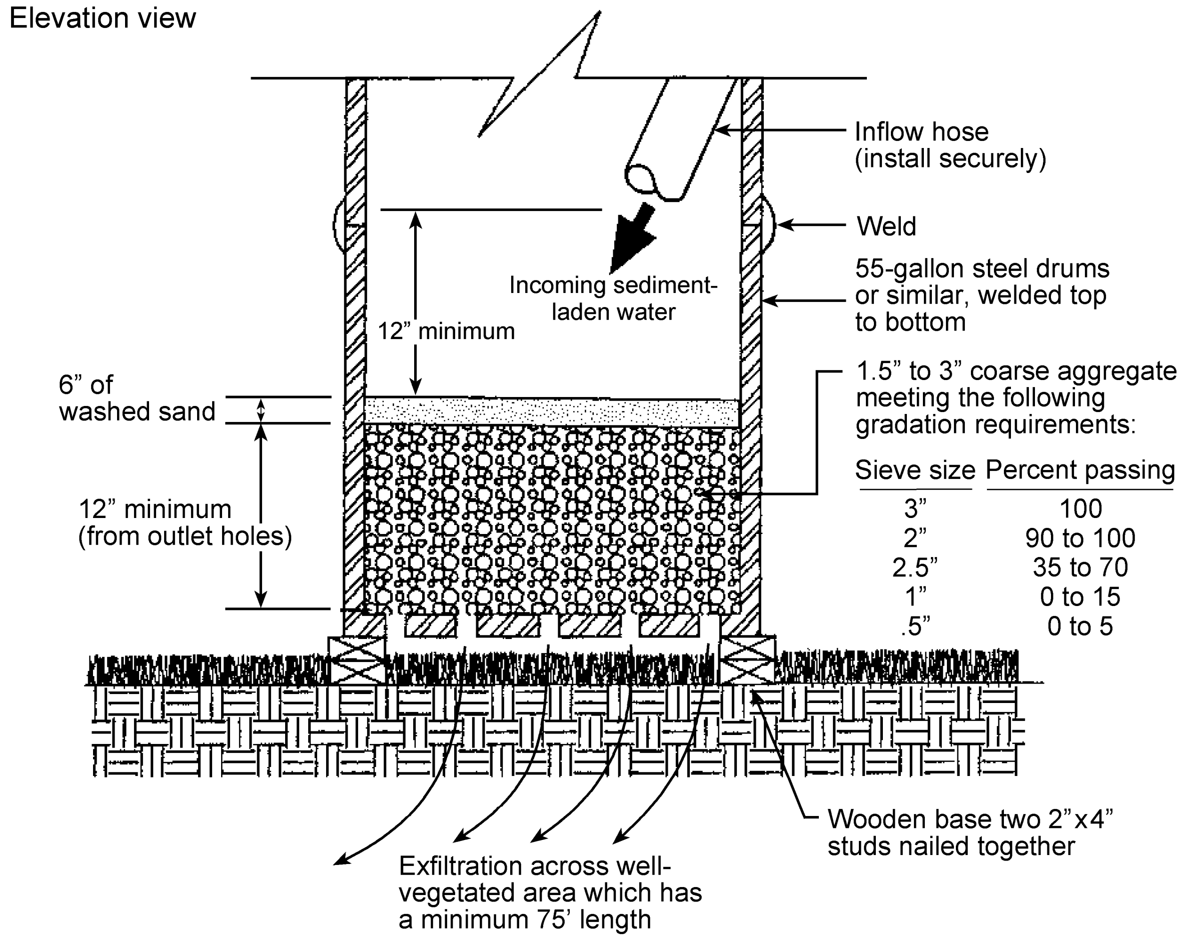


Figure 6.43-1 Cross section of a filter box (source: USEPA, April 1992)

6.44 Miscellaneous Measures: STRAW BALE/SILT FENCE TRAPS

DESCRIPTION AND PURPOSE

A straw bale/silt fence sediment trap is a temporary settling/filtering device for water that is discharged from dewatering activities. This structure should consist of straw bales or a silt fence, a stone outlet (a combination of riprap and aggregate) and an excavated wet-storage pit oriented as shown in Figure 6.44-1.

PLANNING CONSIDERATIONS

A straw bale/silt fence sediment trap can be used whenever sediment-laden water must be removed from a construction site by pumping.

DESIGN RECOMMENDATIONS

1. The structure must have a surface area which is dictated by the following formula:

   $$[\text{Pump discharge (gpm)}] \times \left(\frac{2.23 \times 10^{-3}\ \text{cfs}}{1\ \text{gpm}}\right) / (0.02\ \text{ft/sec}^{*}) = \text{required surface area (ft}^2)$$

2. The excavated area should be at least 3 ft below the base of the perimeter measures (the straw bales or silt fence).

3. The perimeter measures must be installed in accordance with the guidelines found in part 6.31, Silt Fence.

4. Once the water level nears the crest of the stone weir (emergency overflow), the pump must be shut off while the structure drains down to the elevation of the wet storage.

5. The excavated wet-storage pit may be dewatered only after a minimum of six hours of sediment-settling time. This effluent should be pumped across a well-vegetated area or through a silt fence before it is allowed to enter a surface water.

6. Once the wet-storage area becomes filled with sediment to one-half the excavated depth, accumulated sediment should be removed.

7. Once the device has been removed, ground contours must be returned to their original condition.

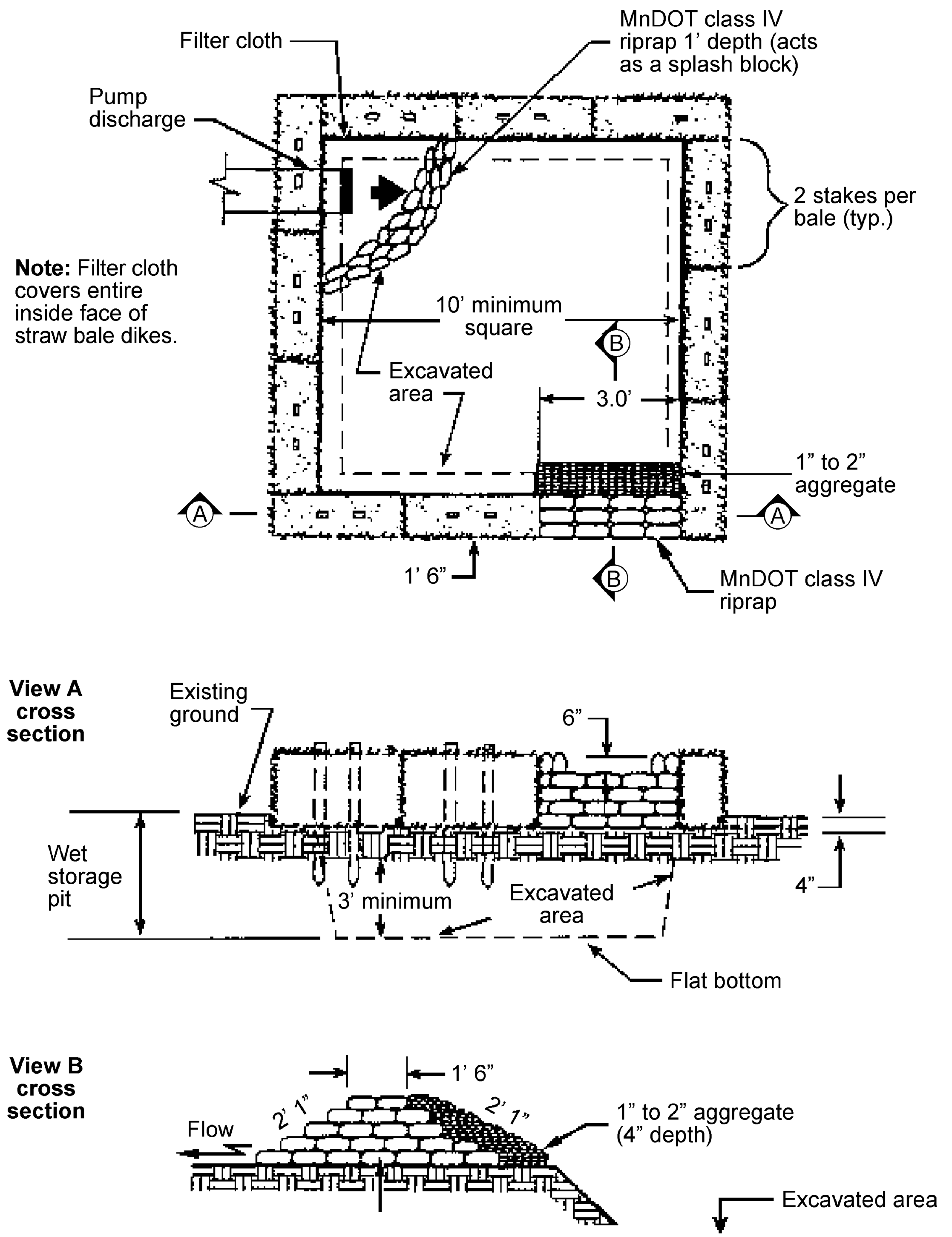


Figure 6.44-1 Combination straw bale/silt fence trap (source: USEPA, April 1992)

6.50 MATS AND MULCHES

This part describes methods of enhancing vegetation and protect soils before vegetation becomes established by reinforcing soils on a temporary or permanent basis.

6.51 Mats and Mulches: MULCHES

DEFINITION

This practice involves the application of straw or other organic materials to form a temporary, protective soil cover. The mulch material may be disc-anchored into the soil, hydraulically bonded, or covered with netting and stapled. Erosion control by hydraulically applied mulches, erosion control blankets, and turf-reinforcement mats are discussed in the following sections. Note: Decorative mulches such as wood and rock mulches, frequently used as permanent cover to accent landscape plantings, are not included in this part.

PURPOSE

A mulch protects the soil surface from the forces of raindrop impact and overland flow. Organic mulches foster the growth of vegetation, reduce evaporation, insulate the soil, and suppress weed growth.

CONDITIONS WHERE PRACTICE APPLIES

Mulch temporary or permanent seed installations immediately. Areas where vegetation cannot be established because of the season should be mulched to temporarily protect the soil surface. Use an organic mulch, and seed the area as soon as conditions are favorable for germination and seedling growth.

PLANNING CONSIDERATIONS

A surface mulch is the most effective, practical means of controlling runoff and erosion on disturbed land prior to vegetation establishment. Mulch reduces soil moisture loss by evaporation, prevents crusting and sealing of the soil surface, moderates soil temperatures, provides a suitable microclimate for seed germination, and may increase the infiltration rate of the soil.

Organic mulches, such as straw, have been found to be the most effective. Do not use materials that may contain competing weed and grass seeds. Decomposition of some wood products can tie up significant amounts of soil nitrogen, making it necessary to modify fertilization rates or to add fertilizer with the mulch.

Additional methods, such as erosion-control blankets and turf-reinforcement mats, may be needed in critical areas, such as waterways and channels and slopes steeper than 3:1.

Tackifiers, or chemical soil stabilizers or soil binders, are useful for tacking organic mulches. Various types of netting materials are also available to anchor organic mulches.

The choice of materials and anchoring of mulches should be based on slope steepness and length, soil conditions, season, type of vegetation, and size of the area. A properly applied and stabilized mulch is always beneficial for site stabilization. Mulching is especially important when conditions for germination are not optimum, such as midsummer and early winter, and on difficult areas, such as cut slopes and slopes with southern exposures.

CONSTRUCTION SPECIFICATIONS

Straw is the mulch most commonly used in conjunction with seeding. The straw should generally come from wheat or oats ("small grains"), but other sources may be specified.

Mulch may be spread by hand or with a mulch blower. Straw may be lost to wind and must be chemically or mechanically anchored to the soil immediately after it is spread. The following methods of anchoring mulch may be used:

A mulch-anchoring tool: is a tractor-drawn implement designed to punch mulch into the soil. A mulch-anchoring tool provides maximum erosion control with straw. A regular farm disc, weighted and set nearly straight, may be used instead, but it will not do a job comparable to the mulch-anchoring tool. The disk should not be sharp enough to cut through the straw. These methods are limited to slopes no steeper than 3:1, where equipment can operate safely. Operate machinery on the contour.

A tackifier is a chemical binder that secures mulch to soil. Application of tackifier should be heaviest at the edges of areas and at crests of ridges and banks, to resist wind. The tackifier should be applied uniformly to the rest of the area. A tackifier may be applied after the mulch has been spread or it may be sprayed into the mulch as the mulch is being blown onto the soil. Applying straw and a tackifier together is the most effective method. Liquid binders include latex, guar gum, proteins and an array of commercially available synthetic binders. Environmentally incompatible products, such as toxic materials, should not be used. Asphalt-based products are not allowed in some states.

A netting is often used to keep straw mulch in place until vegetation becomes established. Synthetic net is most commonly used, but jute nets are useful in channel and critical-area stabilization. Nets should be biodegradable, and degrade within six months. Nets are not designed to provide moisture-conservation benefits or erosion protection. Therefore, they are used in conjunction with organic mulches, such as straw.

In critical areas, netting should always be installed over the mulch. Hydraulic mulches, such as wood fiber, may be sprayed on top of an installed net. Install netting and matting in accordance with the manufacturer's instructions.

MAINTENANCE

Inspect all mulches periodically, and after rainstorms to check for rill erosion, dislocation or failure. Where erosion is observed, apply additional mulch. If washout occurs, repair the slope grade, reseed and reinstall mulch. Continue inspections until vegetation is firmly established.

6.52 Mats and Mulches: HYDRAULIC MULCH AND TACKIFIERS

DESCRIPTION

A hydraulic mulch is a processed material that, when mixed with water, can be applied in a continuous stream. Hydraulic mulches vary in type, composition and additives, and range from light- to heavy-duty. They are intended to form a thick, heavy-bodied crust or mat-like barrier that controls water- and wind-induced erosion. Although an infinite number of application rates could be used, one or two rates are generally specified. One rate is the blanket equivalent rate required for erosion control, usually between 3,000 and 4,000 pounds per acre, depending on manufacture recommendation for percent slope and length. The other rate, generally half the erosion blanket control rate, is especially useful for enhancing seed germination and soil stabilization on 6:1 or flatter slopes. The ratios of wood fiber and recycled newsprint that make up light-duty hydraulic mulch may vary.

MULCH MATERIALS

Bonded Fiber Matrix: A bonded fiber matrix refers to a continuous layer of elongated wood fiber strands that are held together by a water-resistant bonding agent to form a water-absorbing crust. When properly dried, this acts as an erosion-control blanket. This mulch is applied with a mechanically agitated pumping machine (hydroseeder). Bonded fibers work in a wide range of applications, but are particularly suited for more difficult sites. Properly applied, bonded fiber matrices can provide excellent erosion protection and revegetative support.

Wood Fiber Mulch: When sprayed on the soil, the virgin wood fibers and tackifier that comprise this biodegradable mulch form a blotter-like cover that readily absorbs water and allows infiltration to the underlying soil. Wood fiber mulch should be made entirely from whole wood chips, and not contain recycled materials, such as sawdust or pulverized newspaper, or any substances that inhibit germination or growth. The fibers should be colored with a dye to aid in visual metering when the mulch is applied hydraulically.

Blended Mulch: This mulch consists of specially prepared, biodegradable, shredded paper particles, wood fibers and tackifier. The blend should contain a wetting agent, deforming agent, and nontoxic dyestuff that will impart a bright green or blue color to aid in visual metering during application. Blended mulches are available in several wood-fiber-to-paper ratios; most common is 70:30 or 50:50.

Currently, manufacturers are working on a vast array of additions to these basic mulches. The use of compost, peat, and shredded soybean or other legume biomass as additives is gaining. These should be considered as soil types and site conditions warrant.

TACKIFIERS

GENERAL SPECIFICATIONS

1. *Latex-Base:* The components for the latex-base adhesive should meet the following requirements. The composition, by weight, of the latex emulsion polymer should be 48% styrene, 50% butadiene, and 2% additive; 42-46% solids; and a pH, as shipped, of 8.5 to 10.0. The emulsion should not be allowed to freeze or be exposed to sunlight for a prolonged period.

2. *Guar Gum*: Guar gum tackifiers should consist of a minimum of 95% guar gum by weight; the remainder should consist of dispersing and cross-linking additives.

3. *Other Tackifiers*: Other tackifiers include, but are not limited to: water-soluble natural vegetable gums blended with gelling and hardening agents, or a water-soluble blend of hydrophilic polymers, viscosifiers, sticking aids and other gums.

MULCH ANCHORING

Anchoring of straw mulch can be accomplished by spraying a hydromulch with tackifier immediately after the straw mulch has been placed.

CONSTRUCTION CONSIDERATIONS

Spraying of hydraulic mulch should not be performed during windy conditions, which would prevent the proper placement. The contractor should protect all traffic, signs, structures and other objects from being marked or disfigured by the mulch/tackifier material. The tackifiers specified should be applied at the manufacturer's recommended rate.

MULCH APPLICATION

Wood fiber mulch should be applied with hydraulic spray equipment in a water slurry at a minimum of 2,000 lb per acre for flatter slopes, and up to 3,500-4,000 lb per acre in critical areas where the potential for erosion exists. The tackifier can be premixed by the manufacturer, or can be added in the field. The tackifier should comprise 2-5% by weight.

Blended mulches are normally not intended for use on critical areas with high erosion potential. They are an excellent germination medium, and should be considered on flatter slopes and hard-to-reach areas. Tackifier can be premixed by the manufacturer at 2-5% by weight or can be added in the field.

The use of wood fiber mulch in combination with straw has been found to be very effective. Typically the straw mulch is blown onto the surface at a rate of 1.5 tons per acre and immediately oversprayed with wood fiber mulch at 500 lb per acre. The wood fiber mulch should have tackifier added at 2.5-5% by weight. Seeding and fertilizing should be done prior to mulching. Disk-anchoring is not required with this practice, which makes this an ideal alternative for hard-to-reach areas where disk-anchoring is not possible.

6.53 Mats and Mulches: LANDSCAPE MULCHES

DESCRIPTION AND PURPOSE

Landscape mulch is a product that prevents erosion but often is placed to prevent vegetation from growing at a site. Bark chips and shredded bark byproducts of timber processing often are used as landscape mulches. They may be applied by hand or with a mulch blower. Small stones (aggregate) are another type of landscape mulch.

SPECIFICATIONS

Wood landscape mulch should consist of raw hard or soft timber that has been run through a mechanical chipper, hammermill or tub grinder. The wood should be substantially free of mold, dirt, sawdust and foreign material and not be in an advanced state of decomposition. Wood landscape mulch should not contain chipped manufactured boards or chemically treated wood, such as waferboard, particleboard and chromated copper arsenate (CCA) or penta-treated wood. This mulch, when air dried, should all pass a 4-inch screen and not more than 20% by weight of the material should pass a No. 8 sieve (3/32 inch). Free bark or green leaf composition, either singly or combined, should not exceed 20% by weight. Individual pieces should generally not exceed 6 inches in length. The engineer usually determines the suitability of the material by visual inspection.

Aggregate mulch consists of small stones, often about 3/8-inch to 2-inch, with 5% allowable passing a 3/8-inch sieve. Crushing is allowable, but not required. Color and hardness may also be a consideration in the specifications. Aggregate mulch often results in higher soil temperatures that are detrimental to the growth of planted vegetation.

6.54 Mats and Mulches: SOIL STABILIZERS

DESCRIPTION AND PURPOSE

Soil stabilizers normally consist of calcium solution and polyacrylamide (PAM). However, wide range of synthetic compounds is available to stabilize and protect the soil surface. These include emulsions or dispersions of vinyl and other compounds, mixed with water. They may be used alone or in conjunction with wood fiber hydromulches and tackifiers. Due to their being proprietary products, little is known of the content of these products. However, they must be toxic free and have available a "*material safety data sheet*."

CONDITION WHERE PRACTICE APPLIES

Soil stabilizers are designed to reduce the erodibility of bare soils during construction activities or to enhance the performance of mulching on permanent slopes. Soil stabilizers should have proven ability to reduce the movement of soil through chemical bonding. They increase the particle size, thus making silt fence more effective, and increase the water-absorption capability of the soil.

PLANNING CONSIDERATIONS

Only the anionic form of PAM may be used. Cationic PAM is toxic. PAM and PAM mixtures and additives should be environmentally compatible and harmless to fish, wildlife and plants. They should also be noncombustible. Detailed information on performance of additives should be provided by the manufacturer.

Anionic PAM, in pure form, should have no more than 0.05% acrylic monomer (cationic) by weight, as established by the Food and Drug Administration and the U.S. Environmental Protection Agency. To maintain the ≤0.05% acrylic monomer content, the application rate for PAM, in its pure form, on slopes and channels, should not exceed 200 lb per acre (224 kg/ha). In all cases, follow manufacturer recommendations.

When used alone, chemical stabilizers do not insulate the soil or retain moisture. Therefore, they do little to aid seedling establishment. They are easily damaged by traffic and lose their effectiveness more rapidly than organic mulches. They decompose with varying times, some within 60 to 90 days.

Check labels on chemical mulches and binders for environmental concerns. Take precautions to avoid damage to fish, wildlife and water resources.

CONSTRUCTION METHODS

1. Application of soil stabilizer is intended to be conducted with conventional hydraulic seeding equipment. Soil stabilizer may also be placed by dry spreading. When dry spreading is used, the contractor must ensure that the material is applied uniformly and remains in place during subsequent wind events. The manufacturer should provide detailed instructions on the

storage, mixing and application procedures to insure proper safety and effectiveness of the product.

2. Seeding must be done in a manner that ensures direct contact with the soil. When using soil stabilizer, seed must be sown separately the soil stabilizer is applied.

3. Application rates should be as recommended by the manufacturer.

4. When soil stabilizer is used on permanent slopes, an approved mulch should be applied as well to protect and facilitate germination of new seed.

6.55 Mats and Mulches: EROSION-CONTROL BLANKETS

DESCRIPTION

Erosion-control blankets are biodegradable, open-weave blankets used for establishing and reinforcing vegetation on slopes, ditch bottoms and shorelines. Several categories are provided with different service application and specific uses as follows:

Table 6.55-1

Category	Service Application	Use	Acceptable Types
1	Very Temporary	Flat areas, shoulder drain outlets, roadway shoulders, lawns, mowed areas.	Straw, wood fiber, rapidly degradable netting on one side
2	One Season	Slopes 1:3 and steeper less than 50 ft long, ditches with gradients 2% or less, flow velocities less than 5.0 fps.	Straw, wood fiber, netting on one side
3	One Season	Slopes 1 vertical:3 horizontal and steeper, more than 50 ft long, ditches with gradients 3% or less, flow velocities less than 6.5 fps.	Straw, wood fiber, netting on two sides
4	Semipermanent	Ditches with gradients 4% or less, flow velocities less than 8.0 fps, flow depth 6 inches or less.	Straw/coconut, wood fiber, netting on two sides
5	Semipermanent	Ditches with gradients 8% or less, flow velocities less than 15.0 fps and flow depth less than 8 inches, watercourse banks within the normal flow elevation.	Coconut fiber, netting on two sides

Physical Requirements

Fiber Material: Erosion-control blankets should consist of a uniform web of interlocking fibers with net backing. The blanket should be of uniform thickness, with the material fibers being evenly distributed over the area of the blanket. The blankets should be porous enough to promote plant growth yet shield the underlying soil surface from erosion. All material should have been properly cured to achieve curled and barbed fibers. All blankets should be smolder resistant.

Net Backing: The net backing on each blanket should consist of polypropylene mesh. For Category 1 blankets, the net backing should start to decompose after one month with 80% breakdown occurring within three months. For Category 2 and 3 blankets, the netting should contain sufficient UV stabilization for breakdown to occur within a normal growing season. For Category 4 and 5 blankets, the netting should be UV stabilized to provide a service life of two to three years.

For blankets designated as “netting on two sides,” the fiber material should be sandwiched between a top and a bottom layer of net backing.

Stitching: The fiber material in each blanket should be securely attached to the net backing to prevent movement of the fiber. For blankets consisting of 3-inch material fibers, the blanket should be fastened together at a spacing not to exceed 2 inches. For blankets consisting of 6-inch material fibers, the blanket should be fastened together at a spacing not to exceed 4 inches.

Staples

The staples used to anchor Category 1 and 2 blankets should be U shaped, 11 gauge or heavier steel wire having a span width of 1 inch and a length of 6 inches or more from top to bottom after bending. Staples used to anchor Category 3 and 4 and 5 blankets should have a minimum length of 8 inches.

Table 6.55-2 Blanket and staple specifications

	Straw RD 1S	Straw 2S	Straw Coconut 2S	Coconut 2S	Wood Fiber RD 1S	Wood Fiber 1S	Wood Fiber 2S	Wood Fiber HV 2S
Min. weight per Square Yard	0.50 lb	0.50 lb	0.50 lb	0.50 lb	0.64 lb	0.64 lb	0.64 lb	1.20 lb
Fiber Length: 80% Must Be Greater Than	3"	3"	3"	6"	6"	6"	6"	6"
Material	100% Straw Cuttings	100% Straw Cuttings	70% Straw plus 30% Coconut Fibers	100% Coconut Fibers	100% Excelsior Fibers	100% Excelsior Fibers	100% Excelsior Fibers	100% Excelsior Fibers
Net Backing Service Life	1-3 Months	6-9 Months	6-9 Months	24-36 Months	1-3 Months	6-9 Months	6-9 Months	24-36 Months
Net Backing Type	Rapid Photodegradable Polypropylene	Polypropylene	Polypropylene	Black UV-stabilized Polypropylene	Rapid Photodegradable Polypropylene	Polypropylene	Polypropylene	Black UV-stabilized Polypropylene
Netting Opening, Min.	0.5" x 0.5"	0.5" x 0.5"	0.5" x 0.5"	0.6" x 0.6"	0.75" x 0.75"	0.75" x 0.75"	0.75" x 0.75"	0.75" x 0.75"
Netting Weight per 1,000 Yd^2 Min. Top	14.75 lb	14.75 lb	27.65 lb	27.65 lb	14.75 lb	14.75 lb	14.75 lb	27.65 lb
Netting Weight per 1,000 Yd^2 Min. Bottom	--	14.75 lb	14.75 lb	27.65 lb	--	--	14.75 lb	27.65 lb
Staple Length	6"	6"	8"	8"	6"	6"	8"	8"
Number of Staples per Square Yard	1.5	1.5	2		1.5	1.5	2	2
Staple Diameter	0.122"	0.122"	0.15"	0.15"	0.122"	0.122"	0.15"	0.15"
RD means rapidly degradable, 1S means netting on 1 side, 2S means netting on 2 sides, HV = High Velocity								

6.56 Mats and Mulches: TURF-REINFORCEMENT MATS

DEFINITION AND PURPOSE

Turf-reinforcement mats (TRMs) are synthetic, nondegradable mats that are usually buried to add stability to soils. They come in a wide range of designs and have been proven to be valuable on slopes and in channel-lining applications. TRMs are designed to be permanent and often are filled with soil and vegetated when installed.

Turf-reinforcement matting consisting of nondegrading, three-dimensional matrix materials should be used with expected velocities of 15 fps and shear stress of 8 lb/ft^2. Beyond these velocities and shears, vegetated structures such as articulated block, cable concrete and cribwalls, should be considered. A TRM may have a biodegradable component intermixed with the synthetic portion to aid plant establishment

Mats should be appropriate for the expected velocity and shear stress. Check the manufacturer' specifications. Required minimum thickness and area holding capacity of the TRM should be defined by the manufacturer.

SPECIFICATION

Once finish grade is established, the area should be seeded, the TRM installed and, if appropriate, immediately filled with topsoil. The finish surface is normally seeded and covered with an erosion-control blanket or hydraulically applied mulch to keep the soil from eroding and aid in germination of a permanent stand of vegetation. However, TRMs are installed in a variety of ways. Follow the manufacturer's recommendations for specific applications.

6.57 Mats and Mulches: ANCHORING DEVICES

Wire Staples

Wire staples should be U-shaped, No. 11 gauge or heavier wire. They should have a span of 1 inch and a length of 6 inches or more from top to bottom after they are bent. An 8-inch staple may be required with certain blanket and soil types (see part 6.55, Erosion-control Blankets).

Biodegradable Anchoring Devices

These devices are normally used in areas that will be mowed soon after vegetation is established. All materials should be environmentally safe, and should have no potential for soil and/or water contamination. Petroleum-based plastics or composites containing petroleum-based plastics should generally not be used. The anchoring devices should maintain their mechanical anchoring ability for at least two months and degrade within four months under warm soil conditions. The below-ground portion of the anchoring devices should be shaped, using barbs, twists, bends or other methods, to provide additional mechanical pull resistance when the devices are installed in the soil.

Installation

The installation pattern and spacing of anchoring devices should vary according to the specified product, slope, and soil type. As a minimum, anchor devices should be installed according to manufacturer's recommendation and increased based on site conditions.

6.60 MISCELLANEOUS MEASURES

6.61 Miscellaneous Measures: SAND, WIND FENCES

DEFINITION

A sand or wind fence is an artificial barrier of evenly spaced wooden slats or approved fabric erected perpendicular to the prevailing wind and supported by posts. Much research has been done recently on the use of vegetation to reduce snow drifting, and it would seem that some of this research would be applicable to sand blowing.

PURPOSE

Sand or wind fence are used to reduce wind velocity at the ground surface and trap blowing materials.

CONDITIONS WHERE PRACTICE APPLIES

Sand or wind fences are used across open, bare areas subject to frequent winds, where the trapping of blowing sand (or snow) is desired. Wind fences are used primarily to prevent sand from blowing off disturbed areas onto roads or adjacent property.

PLANNING CONSIDERATIONS

Soil movement by wind depends on the physical character and condition of the soil. Normally only dry soils are moved by wind. The structure of soil in an air-dry state is the index to its erodibility. Loose, fine-textured soils are the most readily blown.

Three types of soil movement operate simultaneously in the process of wind erosion:

- suspension — fine dust particles are carried and suspended in air,
- saltation — movement of particles in short bounces on the ground, and
- surface creep — movement of large particles on the ground by both direct wind and bombardment by smaller particles.

A sand fence catches and holds blowing sand in much the same way as a snow fence prevents snow drift. The fence consists of evenly spaced wooden slats. The spaces between the slats allow wind and sand to pass through the fence, but the wind velocity is reduced, causing sand deposition along the fence and between rows of fence (Figure 6.61-1).

Sand fences can trap large amounts of sand. Their effectiveness depends on the source of sand and the frequency and velocity of wind. Use sand fences at construction sites to prevent off-site damage to roads, streams and adjacent property. Generally, locate them perpendicular to the prevailing wind and as near to parallel as possible on the leeward side of the area to be protected. Sand or wind fences have been found to be effective up to 22.5 degrees from perpendicular to the wind.

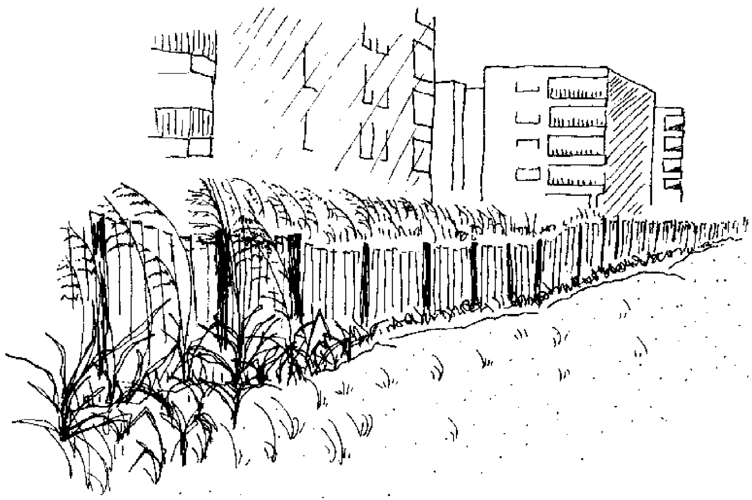


Figure 6.61-1 Sand fences trap blowing sand and debris. (Source: North Carolina, May 1994.)

DESIGN CRITERIA

No formal design criteria have been developed for sand or wind fences. Construction specifications below describe typical wind fence installation.

CONSTRUCTION SPECIFICATIONS

1. Normally, locate sand fences perpendicular to the direction of the prevailing wind. However, they may be as much as 22.5 degrees from perpendicular and still be very effective.

2. Commercial sand fences usually consist of wooden slats wired together with spaces between the slats. The distance between slats is approximately equal to the slat width (about 1.5 inches). Other materials can be used to capture sand, but they must be securely fastened in place and not spaced too far apart.

3. Erect sand fences in parallel rows 20 to 40 ft apart and 2 to 4 ft high. The number of rows installed depends on the degree of protection needed. When fences are approximately two-thirds full, erect another series of fences.

MAINTENANCE

Maintain sand fences and erect additional fences as needed until the eroding area has been permanently stabilized or, in the case of dune building, until the dune has reached the desired height and is properly vegetated.

6.62 Miscellaneous Measures: TOPSOIL APPLICATION

DEFINITION

Preserving and using topsoil to enhance final site stabilization with vegetation.

PURPOSE

Topsoil is applied to provide a suitable medium for vegetative growth.

CONDITIONS WHERE PRACTICE APPLIES

Topsoil may be applied to a site:

- where a sufficient supply of quality topsoil is available.
- where the subsoil or areas of existing surface soil present the following problems:
- the structure, pH, or nutrient balance of the available soil cannot be amended by reasonable means to provide an adequate growth medium for the desired vegetation.
- the soil is too shallow to provide adequate rooting depth or will not supply necessary moisture and nutrients for growth of desired vegetation.
- the soil contains substances toxic to the desired vegetation.
- where high-quality turf or ornamental plants are desired.
- where slopes are 2:1 or flatter.

PLANNING CONSIDERATIONS

Topsoil is the surface layer of the soil profile, generally characterized as darker than the subsoil due to enrichment with organic matter. It is the major zone of root development and biological activity. Microorganisms that enhance plant growth thrive in this layer. Topsoil can usually be differentiated from subsoil its texture as well as its color. Clay content usually increases in the subsoil. Where subsoils are often high in clay, the topsoil layer may be significantly coarser in texture. The depth of topsoil may be quite variable. On severely eroded sites, the topsoil may be gone entirely.

Advantages of topsoil include its high organic-matter content and friable consistency (soil aggregates can be crushed with only moderate pressure), and its available water-holding capacity and nutrient content. Most often topsoil is superior to subsoil in these characteristics. The texture and friability of topsoil are usually much more conducive to seedling emergence and root growth.

In addition to being a better growth medium, topsoil is often less erodible than subsoils, and the coarser texture of topsoil increases infiltration capacity and reduces runoff.

Although topsoil may provide an improved growth medium, there may be disadvantages, too. Stripping, stockpiling, hauling and spreading topsoil, or importing topsoil, may not be cost-effective. Handling may be difficult if large amounts of branches or rocks are present, or if the terrain is too rough. Most topsoil contains the seeds of weeds, which compete with desirable species.

In site planning, compare the options of topsoiling with preparing a seedbed in the available subsoil. The clay portion of many subsoils retains moisture. When properly limed and fertilized, subsoils may provide a satisfactory growth medium, which is generally free of weed seeds.

If topsoil and subsoil are not properly bonded, water will not infiltrate the soil profile evenly, and it will be difficult to establish vegetation.

Do not apply topsoil to slopes steeper than 2:1 to avoid slippage, nor to a subsoil of highly contrasting texture. Sandy topsoil over clay subsoil is a particularly poor combination especially on steep slopes. Water may creep along the junction between the soil layers and cause the topsoil to slough.

Do not apply topsoil to areas of existing trees. The additional soil depth reduces air infiltration into the root zone of trees. This causes stress to the tree and a decline in tree health. Since most spreading is done with machines, there is the additional factor of soil compaction. While its overall weight is less, the common skid steer loader has some of the highest ground pressures of all construction equipment.

Stripping

Strip topsoil only from those areas that will be disturbed by excavation, filling, road building or compaction by equipment. A 4- to 6-inch stripping depth is common, but depth varies depending on the site. Determine stripping depth by taking soil cores at several locations within each area that will be stripped. Topsoil depth generally varies along a gradient from hilltop to toe of the slope. Put sediment basins, diversions and other controls into place before stripping.

Stockpiling

Select stockpile location to avoid slopes and natural drainageways, avoiding traffic routes. On large sites, respreading is easier and more economical when topsoil is stockpiled in small piles located near areas where they will be used.

Sediment barriers: Use sediment fences or other barriers where necessary to retain sediment.

Temporary seeding: Protect topsoil stockpiles by temporarily seeding as soon as possible, no more than 30 working days or 120 calendar days after the formation of the stockpile (see practice 6.22, Temporary Seeding).

Permanent vegetation: If stockpiles will not be used within 12 months, they must be stabilized with permanent vegetation to control erosion and weed growth (see part 6.23, Permanent Seeding).

Site Preparation

Before spreading topsoil, establish erosion- and sedimentation-control practices, such as diversions, berms, dikes, waterways and sediment basins.
Maintain grades on the areas to be topsoiled according to the approved plan and do not alter them by adding topsoil.

Immediately before spreading the topsoil, loosen the subgrade by disking or scarifying to a depth of at least 4 inches, to ensure bonding of the topsoil and subsoil. If no amendments have been incorporated, loosen the soil to a depth of at least 6 inches before spreading the topsoil.

Spreading Topsoil

Uniformly distribute topsoil to a minimum compacted depth of 2 inches on 3:1 slopes and 4 inches on flatter slopes. To determine the volume of topsoil required for application to various depths, use Table 6.62-1. Do not spread topsoil while it is frozen or muddy or when the subgrade is wet or frozen. Correct any irregularities in the surface that result from topsoiling or other operations to prevent the formation of depressions or water pockets.

Compact the topsoil enough to ensure good contact with the underlying soil, but avoid excessive compaction, as it increases runoff and inhibits seed germination. Light packing with a roller is recommended where high-maintenance turf is to be established.

Table 6.62-1 Cubic yards of topsoil required for application to various depths

Depth (inches)	Per 1,000 Square Feet	Per Acre
1	3.1	134
2	6.2	268
3	9.3	403
4	12.4	536
5	15.5	670
6	18.6	804

On slopes and areas that will not be mowed, the surface may be left rough after topsoil is spread. A disk may be used to promote bonding at the interface between the topsoil and subsoil.

After topsoil application, follow procedures for seedbed preparation, taking care to avoid excessive mixing of topsoil into the subsoil.

6.63 Miscellaneous Measures: SURFACE ROUGHENING

DEFINITION

This practice involves the roughening of a bare soil surface with horizontal grooves running across the slope, by tracking, stair-stepping, or tracking with construction equipment.

PURPOSE

The soil surface is roughened on sites to aid the establishment of vegetative cover from seed, to reduce runoff velocity, to increase infiltration, to reduce erosion and to provide for sediment trapping.

CONDITIONS WHERE PRACTICE APPLIES

There are different methods for achieving a roughened soil surface on a slope, and the selection of an appropriate method depends upon the type of slope. Roughening methods include tracking (Figure 6.63-1), stair-step grading (Figure 6.63-2), or ripping and grooving (Figure 6.63-3a, b and c). Factors to be considered in choosing a method are slope steepness, mowing requirement and whether the slope is formed by cutting or filling.

PLANNING CONSIDERATIONS

All construction slopes require surface roughening but some may require subsurface mixing to prevent soil stratification and to facilitate stabilization with vegetation. Note that roughening equipment will be limited by the slopes on which it can work.

Rough slope surfaces are preferred because they aid the establishment of vegetation, improve water infiltration and decrease runoff velocity. Graded areas with smooth, hard surfaces may be attractive, but such surfaces increase the potential for erosion. A rough, loose soil surface gives a mulching effect that protects lime, fertilizer and seed. Nicks in the surface are cooler and provide more favorable moisture conditions than hard, smooth surfaces; this aids seed germination and establishment.

Limit roughening with tracked machinery to sandy soils to avoid undue compaction of the soil surface. Tracking is generally not as effective as the other roughening methods described in this manual.

Operate tracked machinery up and down the slope to leave horizontal depressions in the soil. Do not back-blade during the final grading operation.

CONSTRUCTION SPECIFICATIONS

Cut Slope Roughening for Areas Not To Be Mowed

Stair-step grade or groove cut slopes with a gradient steeper than 3:1.

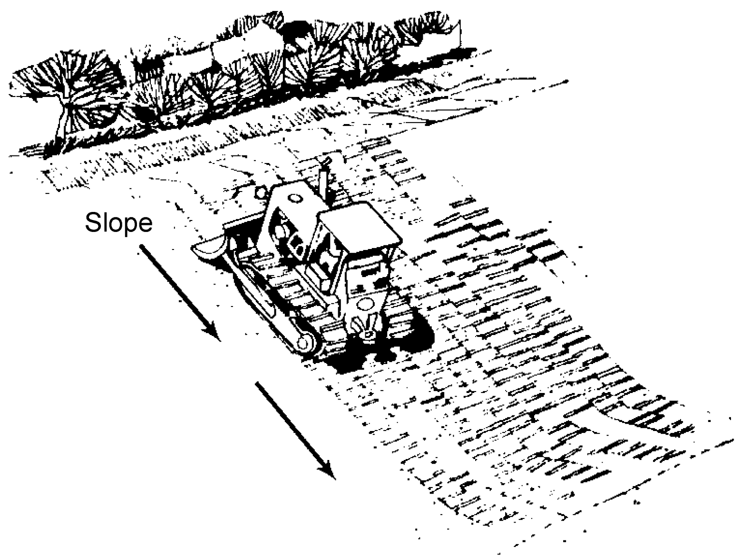


Figure 6.63-1 Bulldozer treads create grooves perpendicular to the slope. The slope should not be back-bladed during the final grading. (Source: Virginia Department of Conservation and Recreation, 1992.)

Use stair-step grading on any erodible material soft enough to be ripped with a bulldozer. Slopes consisting of soft rock with some subsoil are particularly suited to stair-step grading.

Make the vertical cut distance less than the horizontal distance, and slightly slope the horizontal position of the “step” in toward the vertical wall.

Do not make vertical cuts more than 2 ft deep in soft materials or more than 3 ft deep in rocky materials.

Grooving uses machinery to create a series of ridges and depressions that run across the slope (on the contour).

Groove using any appropriate implement that can be safely operated on the slope, such as bulldozer ripper teeth, root rippers, chisel plows, disks, tillers, spring harrows, or the teeth on a front-end loader bucket. Do not make such grooves less than twice the thickness of the topsoil or more than 15 inches apart.

Place fill slopes with a gradient steeper than 3:1 in lifts not to exceed 9 inches, and make sure that each lift is properly compacted. Ensure that the face of the slope consists of loose, uncompacted topsoil 4 to 6 inches deep. Use grooving, as described above, to scarify the subsurface soil and to roughen the face of the slopes, if necessary.

Do not blade or scrape the final slope face.

Cuts, Fills and Graded Areas That Will Be Mowed

Make mowed slopes no steeper than 3:1.

Roughen these areas to create shallow grooves perpendicular to the slope by normal tilling, chisel-plowing or disking. Make the final pass on the contour.

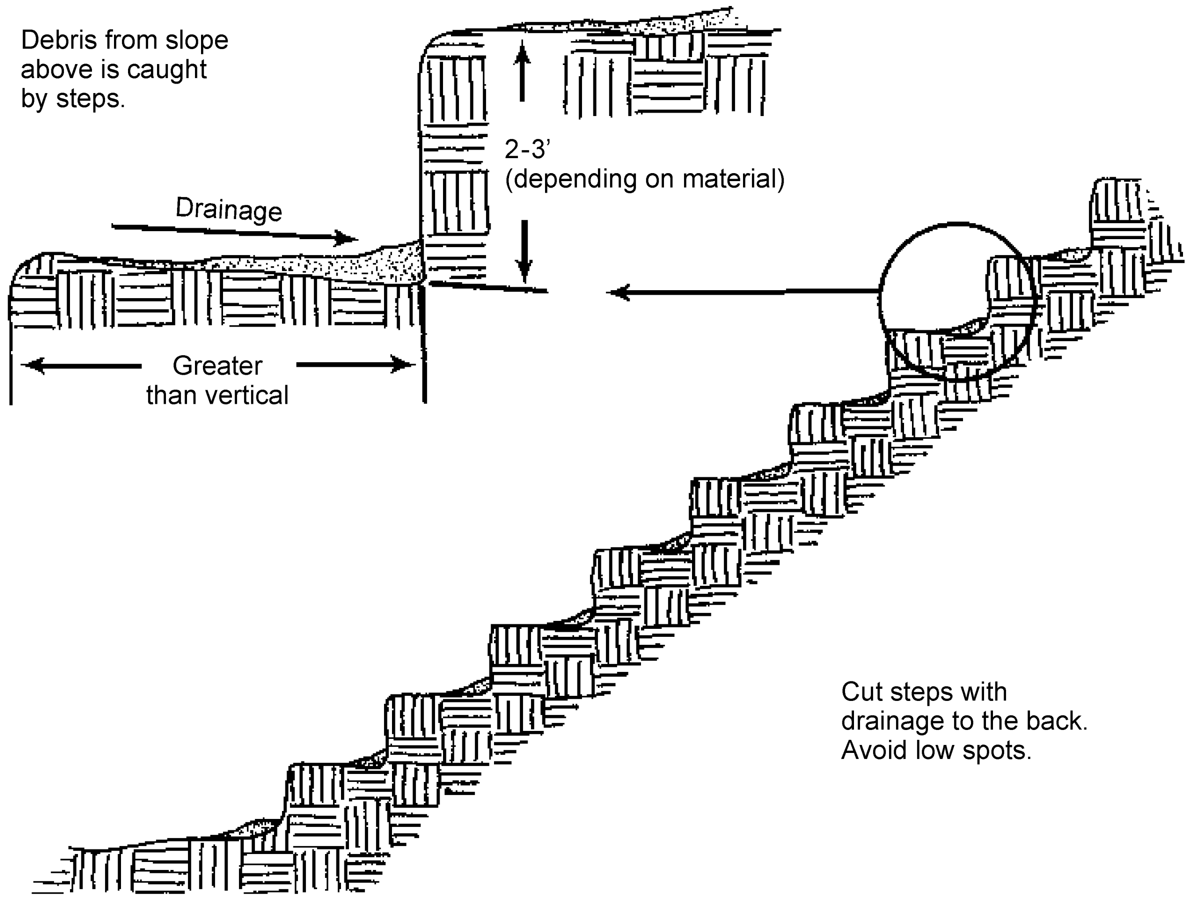


Figure 6.63-2 Stair-stepping-cut slopes (modified from Virginia Department of Conservation and Recreation, 1992)

Make grooves formed by implements close together (less than 10 inches) and not less than 1 inch deep.

Excessive roughness (clods larger than 6 inches, 3 inches for tractor mowing, 1 inch for roughening with tracked machinery) is undesirable where mowing is planned.

MAINTENANCE

Immediately seed and mulch roughened areas to obtain optimum seed germination and seedling growth. Establish good seed-to-soil contact.

Periodically check the seeded slopes for rills and washes. Fill these areas slightly above the original grade, then reseed and mulch as soon as possible.

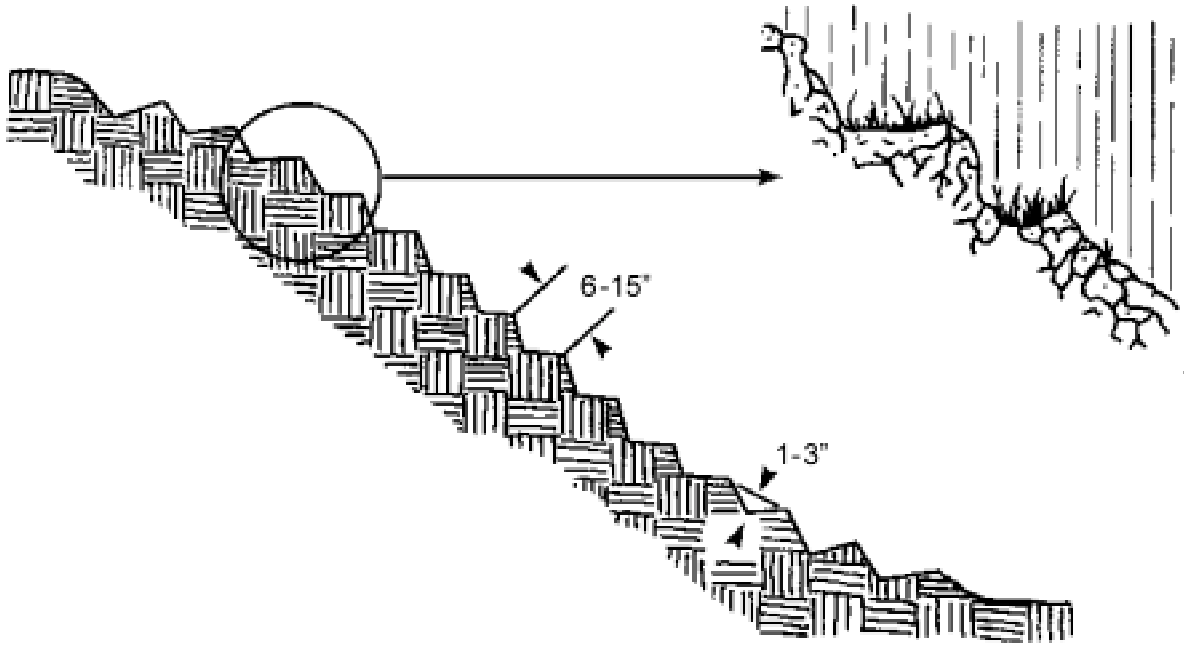


Figure 6.63-3a Groove by cutting furrows along the contour. Irregularities in the soil surface catch rainwater and retain lime, fertilizer and seed (modified from Virginia Department of Conservation and Recreation, 1992).

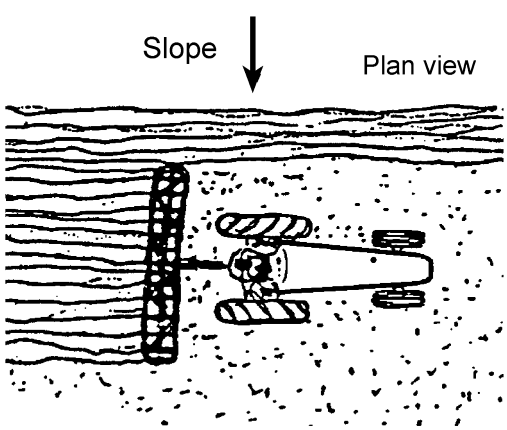


Figure 6.63-3b Roughen soil surfaces on slopes, leaving about 3-inch-high ridges for erosion resistance. Protect slopes of 3:1 or greater with mulch or erosion-control blankets.

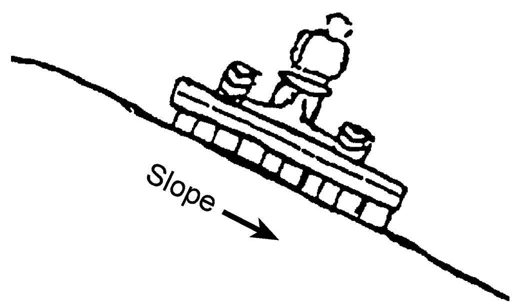


Figure 6.63-3c Operate equipment across the slope, or perpendicular to the direction of water flow, to prevent rill erosion. Immediately repair ruts.

6.64 Miscellaneous Measures: DUST CONTROL

DEFINITION AND PURPOSE

This practice involves controlling dust that results from land-disturbing activities.

Its purpose is to prevent surface and air movement of dust from disturbed soil surfaces that may cause off-site damage, health hazards and traffic problems.

CONDITIONS WHERE PRACTICE APPLIES

Use this practice on construction sites and other disturbed areas subject to surface dust movement and dust blowing where off-site damage may occur if dust is not controlled.

PLANNING CONSIDERATIONS

Construction activities that disturb soil can be a significant source of air pollution. Large quantities of dust can be generated, especially in "heavy" construction activities, such as grading for road construction and commercial, industrial or subdivision development.

In planning for dust control, it is important to schedule construction operations so that the smallest area is disturbed at one time.

Leave undisturbed buffer areas between graded areas wherever possible.

The greatest dust problems occur when the probability of rainfall erosion is least. Therefore, avoid exposing large areas of soil anytime, but for dust control especially during drought conditions.

Install temporary or permanent surface-stabilization measures immediately after completing land grading.

DESIGN CRITERIA

No formal design procedure is given for dust control. See Construction Specifications below for the most common dust-control methods.

CONSTRUCTION SPECIFICATIONS

Vegetative Cover: For disturbed areas not subject to traffic, vegetation provides the most practical method of dust control (See section 6.20, Vegetative Stabilization.).

Mulch (Including Gravel Mulch): When properly applied, mulch offers a fast, effective means of controlling dust (See section 6.50.).

Spray-on Adhesive: Examples of spray-on adhesives for use on mineral soils (See part 6.52, Hydraulic Mulch and Tackifiers) (use manufacturer's specifications when applicable);

Table 6.64-1

Type of Adhesive	Water Dilution	Type of Nozzle	Application Rate (gallons/acre)
Anionic asphalt emulsion	7:1	Coarse spray	1,200
Latex emulsion	12.5:1	Fine spray	235
Resin in water	4:1	Fine spray	300

Calcium chloride may be applied by mechanical spreader as loose, dry granules or flakes at a rate that keeps the surface moist but not so high to cause water pollution or plant damage.

Sprinkling: The site may be sprinkled until the surface is wet. Sprinkling is especially effective for dust control on haul roads and other traffic routes. This method can be costly and must be performed during dry periods.

Stone used to stabilize construction roads can also be effective for dust control (see part 6.53, Landscape Mulches).

Barriers: A board fence, wind fence, sediment fence or similar barrier can control air currents and blowing soil. Place barriers perpendicular to prevailing air currents at intervals about 15 times the barrier height. Where dust is a known problem, preserve windbreak vegetation (see part 6.64, Dust Control).

Tillage: Deep plow large open disturbed areas and bring clods to the surface. This is a temporary emergency measure that can be used as soon as soil blowing starts. Begin plowing on the windward edge of the site (see also part 6.63, Surface Roughening).

MAINTENANCE

Maintain dust control measures through dry-weather periods until all disturbed areas have been stabilized.

For additional dust-control measures and discussion, part 7.25, Dust Control.

6.65 Miscellaneous Measures: HAZARDOUS WASTE DISPOSAL FOR CONTRACTORS

PURPOSE

This section is adapted from MPCA Hazardous Waste Fact Sheet #3.11, July 1997.

This fact sheet provides guidance for contractors to improve hazardous-waste management at job sites.

BACKGROUND

Contractors typically work at various remote client-owned sites. The purpose of this guidance is to improve the way construction remodeling and maintenance contractors manage hazardous waste generated at these sites.

We want to assist contractors to properly manage hazardous waste generated at job sites. This guidance does not affect whether a contractor needs a U.S. Environmental Protection Agency (USEPA) ID number or a license. Contractors may transport waste they generate at contract job sites back to their business location on their Minnesota hazardous waste license. The business will remain responsible for proper management and disposal of any consolidated hazardous waste. This guidance does not prevent the contractor from hiring a registered hazardous waste transporter to manage their hazardous waste.

See Table 6.65-1 for a list of types of contractor businesses to which this guidance applies.

Management Options

When contractors generate hazardous waste at job sites, it can be managed in one of the following ways:

- Contractors may leave hazardous wastes at job sites for proper management and disposal by the site owner.
- Contractors may transport hazardous wastes via a registered hazardous waste transporter directly to a disposal facility.
- Contractors may transport waste to a very-small-quantity generator (VSQG) collection site.
- Contractors may transport wastes to their main business location for proper storage or disposal.

Guidance Conditions

If an eligible contractor wants to transport the waste to a VSQG collection site or to their place of business, the contractor must meet the following conditions:

1. The contractor must have a valid Hazardous Waste Generator License for his or her business location. The contractor must obtain a license from the county if the business is located in Anoka, Carver, Dakota, Hennepin, Ramsey, Scott or Washington counties, or from the

MPCA if his or her business is located elsewhere in Minnesota (local zoning may control the ability to license residential business sites).

2. The contractor is the generator of the waste.

3. The waste is generated in Minnesota at a site that is not owned by the contractor.

4. The waste is generated as a result of construction, remodeling or maintenance.

5. The contractor must generate less than 2,640 lb annually at the remote job site (defined in VSQG standards Minn. R. 7045.0206, subp. 4.)

6. The waste must be stored and managed properly, as provided in Minnesota rules, both at the job site and at the contractor's business location.

7. The amount of hazardous waste transported in any load may not exceed 1,000 lb.

8. The contractor must remove any hazardous waste from the job site and deliver it to the main business location or a licensed collection site within five days of completing work, or within 24 hours of loading the waste onto the contractor's vehicle.

9. The waste must be transported in a vehicle owned and operated by the contracting business and in accordance with Minnesota Department of Transportation (MnDOT) hazardous material shipping requirements.

10. Manifesting is not required for the contractor to transport waste from the remote job site to the main business location.

11. The contractor must transport hazardous waste generated at a remote job site directly to his or her main location or to a licensed VSQG collection site.

12. Once the waste reaches the contractor's licensed business location, the business must manage the waste in accordance with applicable hazardous waste rules.

Table 6.65-1: Standard industrial codes (SICs) for contractor waste

SIC	Description of Industry Type
1521	General - Contractors-Single-Family Homes
1522	General - Contractors-Residential Buildings
1531	Operative Builders
1541	General Contractors-Industrial Buildings
1542	General Contractors-Nonresidential, other than 1541
1611	Highway & Street Construction
1622	Bridge, Tunnel, Elevated Highway Construction
1623	Water, Sewer, Pipeline, Communications, Power Construction
1629	Heavy Construction
1711	Plumbing, Heating & Air-Conditioning
1721	Painting & Paper Hanging
1731	Electrical Work
1741	Masonry, Stone Setting, Stone Work
1742	Plastering, Drywall, Acoustical Insulation Work
1743	Terrazzo, Tile, Marble, & Mosaic Work
1751	Carpentry Work
1752	Floor Laying & Floor Work
1761	Roofing, Siding & Sheet Metal Work
1771	Concrete Work
1781	Water Well Drilling
1791	Structural Steel Erection
1793	Glass & Glazing Work
1794	Excavation Work
1795	Wrecking & Demolition Work
1796	Installation or Erection of Building Equipment
1799	Special Trade Contractors
2951	Asphalt Paving Mixtures and Blocks

CHAPTER 7

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7.00 POLLUTION PREVENTION

DESCRIPTION

Individuals, industries and local government should develop and implement a Pollution Prevention Plan (Plan), which could be part of a local water-management plan, to address the specific conditions for various sites, facilities or activities. The goal of the Plan is to avoid, minimize or mitigate pollution. If pollutants cannot be eliminated**,** they should be properly treated or removed for disposal.

ENVIRONMENTAL CONCERNS

Storm water is an environmental concern because, depending upon its source and its path, it can contain or pick up contaminants which are then transferred to the surface or ground water to which it drains. Certain contaminants can degrade the quality of the surface water so much that the health of plants and animals within and surrounding the water body are affected. For this reason, the 1987 amendments to the Clean Water Act required the U.S. Environmental Protection Agency (EPA) to develop regulations for stormwater discharges associated with municipal and industrial activity.

PLANNING CONSIDERATIONS

The EPA regulations require some stormwater discharges to be authorized under a National Pollutant Discharge Elimination System (NPDES) permit. In 1992, the EPA delegated authority to the Minnesota Pollution Control Agency (MPCA) to administer the storm water NPDES program.

The MPCA currently regulates the stormwater runoff from a variety of activities, including construction activities, municipal separate storm sewer systems (MS4s) in populated areas and certain industrial stormwater discharges. Phase I of the NPDES stormwater program already covers large and medium MS4s, 10 industrial categories and construction activity that disturbs five or more acres. The final Storm Water Phase II rule, signed on October 29, 1999, and published in the *Federal Register* on December 8, 1999 (63 FR 1536), expanded the NPDES program to cover all small MS4s within urbanized areas as well as construction sites that disturb one to five acres. Cities may also be required to obtain permits for some industrial, construction and other activities. Contact the MPCA for the latest requirements.

IMPLEMENTATION

Most management of stormwater runoff can be accomplished through the use of best management practices (BMPs), which, for the purposes of this manual, have been classified in two groups: nonstructural and structural.

Nonstructural BMPs focus on changing behavior and management. These measures can be described as “good common sense” and can include such practices as moving materials inside to reduce exposure, prohibiting certain practices, training, and employing spill-prevention plans.

Table 7.00-1

Mandatory Facilities

Mining, Oil & Gas Operations

1011	1041	1081	1221	1231	1311	1382	1411	1442	1474	1481
1021	1044	1094	1222	1241	1321	1389	1422	1446	1475	1499
1031	1061	1099			1381		1423	1455	1479	
							1429	1459		

Manufacturing

2411	2449	2812	2843	2891	3111	3261	3281	3313	3339	3365
2421	2451	2813	2844	2892		3262	3291	3315	3341	3366
2426	2452	2816	2851	2893	3211	3263	3292	3316	3351	3369
2429	2491	2819	2861	2895	3221	3264	3295	3317	3353	3398
2431	2493	2821	2865	2899	3229	3269	3296	3321	3354	3399
2435	2499	2822	2869	2911	3241	3271	3297	3322	3355	
2436		2823	2873	2951	3251	3272	3299	3324	3356	3441
2439	2611	2824	2874	2952	3253	3273		3325	3357	
2441	2621	2841	2875	2992	3255	3274	3312	3331	3363	3731
2448	2631	2842	2879	2999	3259	3275		3334	3364	3732

Automobile Recycling

5015	5093

Discretionary Facilities

Manufacturing

2011	2079	2281	2394	2678	3087	3452	3542	3592	3676	3827
2013	2082	2282	2395	2679	3088	3462	3543	3593	3677	3829
2015	2083	2284	2396		3089	3463	3544	3594	3678	3841
2021	2084	2295	2397	2711		3465	3545	3596	3679	3842
2022	2085	2296	2399	2721	3131	3466	3546	3599	3691	3843
2023	2086	2297		2731	3142	3469	3547		3692	3844
2024	2087	2298	2434	2732	3143	3471	3548	3612	3694	3845
2026	2091	2299		2741	3144	3479	3549	3613	3695	3851
2032	2092		2511	2752	3149	3482	3552	3621	3699	3861
2033	2095	2311	2512	2754	3151	3483	3553	3624		3873
2034	2096	2321	2514	2759	3161	3484	3554	3625	3711	
2035	2097	2322	2515	2761	3171	3489	3555	3629	3713	3911
2037	2098	2323	2517	2771	3172	3491	3556	3631	3714	3914
2038	2099	2325	2519	2782	3199	3492	3559	3632	3715	3915
2041		2326	2521	2789		3493	3561	3633	3716	3931
2043	2111	2329	2522	2791	3231	3494	3562	3634	3721	3942
2044	2121	2331	2531	2796		3495	3563	3635	3724	3944
2045	2131	2335	2541		3411	3496	3564	3639	3728	3949
2046	2141	2337	2542	2833	3412	3497	3565	3641	3743	3951
2047		2339	2591	2834	3421	3498	3566	3643	3751	3952
2048	2211	2341	2599	2835	3423	3499	3567	3644	3761	3953
2051	2221	2342		2836	3425		3568	3645	3764	3955
2052	2231	2353	2652		3429	3511	3569	3646	3769	3961
2053	2241	2361	2653	3011	3431	3519	3571	3647	3792	3965
2061	2251	2369	2655	3021	3432	3523	3572	3648	3795	3991
2062	2252	2371	2656	3052	3433	3524	3575	3651	3799	3993
2063	2253	2381	2657	3061	3442	3531	3577	3652		3996
2064	2254	2384	2671	3069	3443	3532	3578	3661	3812	3999
2066	2257	2385	2672	3081	3444	3533	3579	3663	3821	
2067	2258	2386	2673	3082	3446	3534	3581	3669	3822	
2068	2259	2387	2674	3083	3448	3535	3582	3671	3823	
2074	2261	2389	2675	3084	3449	3536	3585	3672	3824	
2075	2262	2391	2676	3085	3451	3537	3586	3674	3825	
2076	2269	2392	2677	3086		3541	3589	3675	3826	
2077	2273	2393								

Transportation and Warehousing

4011	4111	4141	4212	4221	4231	4412	4481	4492	4512	5171
4013	4119	4142	4213	4222		4424	4482	4493	4513	
	4121	4151	4214	4225	4311	4432	4489	4499	4522	
	4131	4173	4215	4226		4449	4491		4581	

Structural BMPs are measures that control or manage stormwater runoff and drainage. Examples of structural BMPs include enclosures used for covering exposed significant materials, swales, dikes or stormwater-treatment basins.

One of the highest priorities of stormwater regulations and BMPs is to improve the quality of surface waters by reducing or eliminating the contact of pollutants with storm water. Whenever significant materials are exposed to storm water, there is a potential for the pollutant stormwater runoff to degrade water quality. Significant materials can be any type of raw or finished items that are stored, handled, used, processed or generated at a site. (For a description of significant materials, see page 20 of the general permit for industrial activities, available from the MPCA.)

Previous regulations required certain industries to obtain permits on a mandatory or discretionary basis based on Standard Industrial Codes (SICs). See Table 7.00-1 for a list of mandatory and discretionary facilities. The Phase II rule conditionally exempts industrial facilities in all 10 categories that have "no exposure" of significant materials to storm water, thereby reducing application of the program to many industrial activities that had been previously required to get permits.

FOR MORE INFORMATION

The MPCA also has many regulatory and pollution-prevention programs that can affect storm water, such as the hazardous waste program, the above-ground and underground tanks programs, spills-response programs and even air quality rules. This manual cannot be all-inclusive. This chapter presents pollution-prevention principles and examples of how these issues can be handled. Many fact sheets have been developed to help individuals, industries and local governments to develop their pollution-prevention programs. Contact the MPCA for information related to your specific program.

The MPCA has fact sheets and staff to answer your questions about the programs affecting stormwater runoff, including the stormwater permit program for industrial activity, construction activities and municipalities. Hazardous waste, tanks or other programs also have significant resources and information available that may be applicable. For more information on how these programs may be helpful for your facilities, contact the MPCA office closest to your county (see Table 7.00-2).

Table 7.00-2 MPCA offices and phone numbers

Toll-free (all MPCA offices)	(800) 657-3864
Brainerd	(218) 828-2492
Detroit Lakes	(218) 847-1519
Duluth	(218) 723-4660
Marshall	(507) 537-7146
Rochester	(507) 285-7343
St. Paul	(651) 296-6300
Willmar	(320) 214-3791
MPCA web site: http://www.pca.state.mn.us	

7.01 Nonstructural Practices: PLAN DEVELOPMENT

When preparing a Stormwater Pollution Prevention Plan and making recommendations for BMPs, the following factors should be taken into account: implementability, cost effectiveness, and contaminant/pollutant removal effectiveness.

The Plan will only be valuable if it is effective, workable and affordable (*i.e.*, if it can and will be implemented).

The steps involved in the development of the plan, as well as the interaction between various phases, should be carefully spelled out. For example, observations made during the monitoring phase may indicate it is necessary to reconduct the site reconnaissance for a specific activity or material or to re-evaluate the BMPs originally selected. This "continuous loop" evaluation process will improve the Plan concepts and implementation

PLANNING AND ORGANIZATION

The planning and organization phase starts with designating a person to lay out the organization of the Plan. For larger projects or complex issues, the individual may want to form a pollution prevention team to research existing conditions, gather maps and drawings, develop procedures for spill and response plans, or gather materials safety data sheets and other documents that will be used to assist in preparing and implementing the Plan.

The Plan must specify roles and responsibility for the individual or each team member. Each responsibility indicated in the Plan must have an individual assigned to manage it. Whether required by Minnesota's general stormwater permit regulations or not, the permit conditions can be a guide to development of a pollution-prevention plan.

A simple way to organize the pollution prevention team is to work from duty to responsible person. First, list all the responsibilities. Next, assign a title/position that is compatible with the responsibility. Then assign an individual to manage each task. Link the assignments to skills and abilities. This procedure will identify the pollution prevention team members and their respective responsibilities. All team members should have a title associated with their positions. The responsibility/title correlation makes it easier to re-assign team members as employees are promoted or leave the organization. The responsibilities assigned to a title can be used to define job descriptions for new employees.

Team responsibilities/tasks that should be assigned to titles/individuals include (if applicable):

- storm water manager (individual or director of the team),
- owner's representative,
- individual to perform detailed site reconnaissance/assessment,
- personnel to maintain material inventory and to evaluate handling and storage practices,
- maintenance supervisor,
- director of housekeeping practices (litter control, lawn management and erosion control),

- fueling facility manager,
- de-icing practices manager,
- manager/coordinator of aerial spraying operations,
- spill/release coordinator,
- training/education program director,
- secretary for documentation of meetings and records, and
- Water quality monitoring coordinator.

The pollution prevention team will meet as often as required (daily, monthly, quarterly, semiannually or otherwise) to review the plan, discuss plan-implementation results and make revisions, as required, to meet the plan's goals and objectives. Discussions, meeting notes and revisions must be documented in stormwater-management files.

The following are general requirements of a plan:

1. Complete a drainage map. The map should indicate the following items at or adjacent to the facility:
   a. drainage areas and directions of runoff (indicated by arrows);
   b. discharge outfalls from the site (structures, such as ditches or storm sewers, that carry runoff from the facility);
   c. the name and location of waters of the state that receive facility runoff (If waters of the state are too distant from the facility to be indicated on the site map, indicate the name, direction and shortest distance to the lake, river, stream or wetland that receives runoff from your site.);
   d. areas where materials or waste produces (which may include solid waste or air emissions) are exposed;
   e. locations of storm sewer inlets and an indication of which, if any, structures have floor drains or loading dock drains that are connected to storm sewers;
   f. locations and types of BMPs currently installed at the facility to reduce or eliminate pollutants; and
   g. location of water quality monitoring point(s), if needed.

2. Complete an inventory of exposed materials. Indicate the types of materials handled or stored at the site. The following are examples of materials that, if exposed, must be included in the inventory:
   a. raw materials, such as fuels, solvents, petroleum products, detergents, plastic pellets, materials used in food processing or production, stockpiled sand, salt or coal;
   b. by-products or intermediate products, such as wood dust, chips or bark, screened limestone, taconite or gravel by-product, recycled blacktop;
   c. finished materials, such as metallic products, including scrap metal and recycled or scrap motor vehicle parts, old process equipment/machinery, taconite pellets;
   d. waste products, such as ashes, sludge, solid and liquid waste, slag;
   e. hazardous substances designated under section 101(14) of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA);

f. any chemical the facility is required to report under section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA).

3. Evaluate facility areas for exposure of materials. In creating the inventory of exposed materials, the person or team developing the plan must, at a minimum, evaluate the following areas at the industrial site (as well as other areas where appropriate) to determine whether or not materials are exposed in these areas:
   a. vehicle and equipment maintenance, parking and storage areas, including fueling and washing/cleaning areas, to determine whether there is discolored soil in these areas as a result of fuel or lubricant leaks or spills;
   b. liquid storage tanks and other bulk material stockpile areas;
   c. loading and unloading areas;
   d. outdoor manufacturing, processing or storage areas and industrial plant yards, to determine whether there is discolored soil in these areas as a result of leaked or spilled solvents, fuels or lubricants;
   e. dust- or particulate-generating areas, including dust-collection devices that may release dust;
   f. rooftops contaminated by industrial activity or operation of a pollution-control device;
   g. on-site waste disposal areas, such as waste ponds, dumpsters, solid waste storage or management areas; and
   h. exposed (nonvegetated) soil areas where there is a potential for erosion to occur.

4. Describe appropriate BMPs, including structural and nonstructural BMPs, that will be used at the facility to minimize, eliminate or control pollution at the site. The description must include an objective for each BMP, as well as a description of how to evaluate proper functioning of the BMP and any maintenance requirements of the BMP. BMPs should target materials and areas identified in the site plan. The following general categories of BMPs shall be considered and one or more shall be incorporated into the facility's Plan if materials are exposed to storm water on site:
   a. Source reduction: Reduce or eliminate the materials that are exposed. Materials-management practices should be evaluated to determine whether inventories of exposed materials can be reduced or eliminated. This can include cleanup of old equipment yards, periodic checking of dust-control equipment to ensure there is no accumulation of dust in the area around the control equipment, removal and treatment of petroleum-contaminated soil, consolidation of materials from many areas into one area, and training employees regarding proper handling and disposal of materials. Materials may also be moved indoors or covered with a tarp or structure to eliminate contact with precipitation.
   b. Diversion: Divert drainage away from exposed materials through the use of curbing, berms, sewers or other forms of drainage control or elevate exposed material above surrounding drainage.
   c. Treatment: Where contact of materials is unavoidable, use treatment devices to reduce the concentration and amount of pollutants in the discharge. Such devices include oil/water separators, detention/retention ponds and vegetated swales.

5. Evaluate all discharge conveyances from the site (storm sewers, pipes, tile lines, ditches, etc.) to determine whether liquids other than uncontaminated storm water are being discharged from

these devices. This should be done during dry weather when stormwater discharge is not occurring. The evaluation should cover sewer inlets and floor drains to determine which inlets/drains are connected to sanitary sewer lines, storm sewer lines, or septic tanks/drainage fields. Appropriate methods, such as dye or smoke testing or video imaging, should be used to determine the source of discharges. The Plan must certify that discharges from the site have been evaluated for the presence of non-stormwater discharges. The certification shall indicate the date of testing, location of testing, the methods used to determine the source of discharges and the results of testing. Discharge of non-storm water (such as sanitary sewer or floor drain connections to storm sewers) is *not* authorized. Before such discharge may continue, authorization under an appropriate NPDES permit must be obtained.

6. Develop a preventive maintenance program. The program must require regular inspection and maintenance of management devices (*e.g.*, cleaning oil/water separators and catch basins), as well as inspecting and testing plant equipment and systems to uncover conditions that could cause breakdowns or failures resulting in discharges of pollutants (*e.g.*, hydraulic leaks, torn baghouse filters) to surface waters.

7. Develop a spill-prevention-and-response procedure. In order to develop this procedure, the person or team developing the Plan should evaluate where spills have occurred and where they have the potential to occur. Determine drainage points for potential spill areas and develop appropriate spill-prevention-and-containment measures. Detailed procedures for cleaning up spills shall be identified and made available to appropriate personnel. If the facility has any other spill contingency plan that satisfies the above requirements, that plan may be incorporated by reference into this Plan to satisfy this requirement.

8. Develop and implement an employee training program to inform appropriate personnel of the components and goals of the Plan. Training shall address spill response, good housekeeping and materials-management practices. The Plan shall identify periodic dates for such training.

9. Identify personnel responsible for managing and implementing the Plan as well as those responsible for the reporting requirements of the permit. This should include the facility contact person as indicated on the permit application. Identified personnel must be available at reasonable times of operation.

Table 7.01-1 indicates recommended BMPs that would eliminate, reduce contact, or would treat pollutants with potential to discharge. Other appropriate methods that will eliminate or reduce contact or treat pollutants are acceptable. Facilities must collect and dispose of wastes in accordance with appropriate federal, state and local requirements.

See - Minnesota General Storm Water Permit, Industrial Activity (page 8 of 20).

Table 7.01-1

Material, Area, or Activity	**Synopsis of Recommended BMPs to Reduce or Eliminate Contact or Treat Runoff**
Storage Areas/Stockpiled Materials (for Materials Including Raw, Intermediate and Finished Product)	• See Section 7.50 and following • Cover and/or enclose stored materials to prevent contact. • Divert around storage areas. • Stack/pile material to minimize surface area exposed to precipitation. • Practice good housekeeping measures such as frequent removal of debris. • Install treatment measures to remove pollutants from runoff prior to **discharge** from the site.
Waste Storage Areas	• See Section 7.21 • Minimize waste generated at the site. • Store indoors or in covered dumpsters or under other types of cover. • Divert around areas. • Install treatment devices to remove pollutants from runoff prior to **discharge** from the site.
Loading/Unloading and Other Material Handling Areas	• See Section 7.44 • Cover loading and unloading areas. • Divert around areas. • Where dust is likely to be generated during material handling, install equipment or change methods of handling to minimize or eliminate dust generation. • If liquid materials are being loaded or unloaded and if loading/unloading areas drain to storm sewer inlets, prevent material from getting into the storm sewer inlets. • Install treatment measures to remove pollutants from runoff prior to **discharge** from the site.
Outdoor Storage Tanks or Drums of Fuel, Lubricants, Solvents.	• See section 7.60 and following • Store drums inside (if allowed by Fire Marshall or insurer). • Prepare and train appropriate employees in dealing with spills and leaks properly, use dry clean-up methods when possible. • Install impervious surface underneath drums. • Prevent run-on to and runoff from tank and drum storage areas, provide adequate containment to hold spills and leaks.

Table 7.01-1 *(cont.)*

Obsolete Equipment Stored Outside	• See section 7.43 • When possible, dispose of unused equipment properly, or move indoors. • Drain and recycle fluids from equipment. • Cover equipment. • Divert around equipment.
Floor, Sink, or Process Wastewater Connected to a Storm Sewer	• See Section 7.30 and following • Inspect and test floor, sink and process wastewater drains for proper connections and remove any connections to storm sewers or **waters of the state**.
Exterior Vehicle and Equipment Washing	• See Section 7.42 • Conduct washing indoors or in a covered area. • Contain and recycle wash waters. • **Discharge** wash waters to sanitary sewer with permission of the receiving wastewater treatment authority. • Do not allow off-site **discharge** of wastewater. • Evaluate wastewater from steam cleaning of parts contaminated with oils, greases or solvents that is not recycled to determine if it is hazardous. Dispose of hazardous sludge and wastewater appropriately.
Fueling Areas	• See Section 7.44 • Minimize run-on into the fueling area. • Use dry clean-up methods for fuel area rather than hosing down the fuel area. • Train appropriate employees on proper fueling practices. • Install treatment devices to remove pollutants from runoff before it discharges from the site.
Vehicle and Equipment Dismantling and Maintenance	• Promptly transfer used fluids to the proper closed container for recycling; empty drip pans when they fill.
Spills of Liquid Material	• See Section 7.22 • Stop the source of the spill immediately. • Contain the liquid until cleanup is complete. • Deploy oil containment booms if the spill may reach waters of the state or drainageways to waters of the state. • Cover the spill with absorbent material. • Dispose of cleanup materials properly. • Report the spill to the Duty Officer, when appropriate.

Table 7.01-1 *(cont.)*

Areas of the Facility with Unstabilized Soils Subject to Erosion.	• See Chapter 6.00 and following • Minimize run-on from adjacent areas. • Seed and mulch or sod low traffic areas. • Stabilize high traffic areas including vehicle entrances, exits, loading, unloading and vehicle storage areas. • Prevent sediment from unstabilized areas from leaving the site. • Install treatment devices to remove pollutants from the runoff prior to **discharge** from the site.
Surface Preparation, Paint Removal and Paint Spraying	• See Section 7.45 • Enclose, cover, or contain blasting, sanding, and spray painting activities to the extent practical. • Collect spent abrasives routinely and store under a cover to await proper disposal. Evaluate spent abrasives and removed paint to determine if it is hazardous. Test waste material for lead content and dispose of waste material properly.

7.02 Nonstructural Practices: EMPLOYEE TRAINING

Successful waste-reduction activities need support from all employees, including top management and production personnel.

Less waste is generated if employees are trained to operate equipment and handle materials safely and correctly. Occupational and safety hazards are reduced as well.

ISSUES

Employees should be made aware of the costs and environmental issues related to hazardous waste generation and disposal. One way to do this is to post these costs and any waste-reduction savings on bulletin boards throughout the company.

Waste reduction usually happens in production processes. Explain how waste is generated by each process so employees understand that they share the responsibility for waste generation. Employees that are well informed can make valuable waste-reduction suggestions.

Incentive programs can be useful in encouraging employees to participate in waste-reduction activities.

IMPLEMENTATION

Employees should be trained to look for practices which:

- generate less waste by making existing processes more efficient.
- are common-sense measures that apply to the human side of business rather than to the technological side; therefore, they can be used in all areas of production.
- are easy and inexpensive to implement, and practical for your operations.
- have health and safety benefits for employees, the general public and the environment.

Good operating practices include:

- improved inventory management;
- waste segregation;
- improved production scheduling;
- preventive maintenance;
- spill and leak prevention;
- employee training and education;
- employee participation in planning;
- materials usage, handling and storage; and
- clear labeling.

7.03 Nonstructural Practices: INSPECTIONS AND MAINTENANCE

1. Site inspections should be conducted at least once every two months by an appropriately trained person. The purpose of these inspections is to (1) determine whether structural and nonstructural BMPs require maintenance or changes, and (2) to evaluate the completeness and accuracy of the Plan. Inspections should be documented using an inspection form provided by the owner. The following compliance items should be inspected, and documented where appropriate:
   a. Evaluate the facility to determine that the Plan accurately reflects site conditions as described in Part II.A. of the permit, documenting any inaccuracies;
   b. evaluate the facility to determine whether new exposed materials have been added to the site since completion of the Plan, documenting any new materials;
   c. during the inspection conducted during the runoff event, observe the runoff to determine whether it is discolored or otherwise visibly contaminated, documenting observations; and
   d. determine whether the nonstructural and structural BMPs as indicated in the Plan are installed and functioning properly in accordance with the implementation schedule.

2. On the inspection form, indicate the date and time of the inspection as well as the name of the inspector.

3. If conditions are observed at the site that require changes in the Plan, the changes should be made as soon as possible

4. If the findings of a site inspection indicate that BMPs are not meeting the objectives, corrective actions must be initiated within 30 days and the BMP restored to full operation as soon as field conditions allow.

RECORDS

A copy of the Plan should be retained on the site, and be available upon request. The following records should be maintained:

- dates of inspections;
- findings of inspections;
- corrective actions taken;
- documentation of all changes to the Plan; and
- a copy of annual reports.

NOTIFICATION

If a spill, bypass or release occurs, it must be reported to the appropriate authority. The spill plan must specify who shall report and where the report shall be made.

7.04 Nonstructural Practices: MONITORING AND EVALUATION

The monitoring phase involves conducting periodic site observations, stormwater characterization and voluntary stormwater sampling and analytical data. Based on the results of the monitoring program, the effectiveness of the BMPs can be evaluated. If necessary, more appropriate BMPs may be implemented to replace existing practices. Appropriate revisions should be made to the Plan to document BMP changes.

ROUTINE SITE OBSERVATIONS

A site reconnaissance must be performed at least once every two months with at least one performed after a significant storm event (generally any event that produces runoff, but at least as stated in the Minnesota general storm water permit regulations). See page 11 of Part II - Minnesota General Storm Water Industrial Permit.

EVALUATION AND UPDATE

The Plan is required to be updated when changes occur in physical site conditions, on-site operations, material-handling and -storage methods or other characteristics or activities. In addition to the changes, the observer must clearly document the results of the implemented BMPs and the condition of the structural BMPs.

Stormwater runoff observations made during a rainfall event and collection of stormwater samples for visual characterization is very useful in determining effectiveness of BMPs. One method for collecting stormwater samples for visual characterization is jar sampling. By dipping a clear glass jar into the stormwater outfall (*i.e.*, ditch, culvert, etc.), the observer can obtain samples of stormwater discharge. (**Safety note:** All jar sample collections should be performed from the ground surface. Do not enter manholes or catch basins to observe stormwater conditions or to collect samples. If necessary, the jar may be taped to a pole to obtain flows from storm sewer pipes). Stormwater observation results should be documented.

The first 10 to 20 minutes of an intense storm event are commonly known as “first flush” conditions. Sampling of this portion of the storm is critical. The first flush represents the high concentration of pollutants due to the buildup that has occurred on the surface areas since the last rainfall event. Additional jar samples should be taken at regular intervals (20 or 30 minutes) during the storm event. The jars should be allowed to sit a while to allow sediment to accumulate at the bottom of the jar. Some indicators of water quality are color, odor, oil sheen and sediment. The visual observation of storm water allows for qualitative description of storm water quality. For quantitative data, stormwater sampling and laboratory analysis are the only effective methods.

ANNUAL REPORTS

For permitted sites, the MPCA will send copies of a fill-in-the-blank annual report to the facility each year during the first week of January. Reports must be submitted to the MPCA no later than March 31 and may be sent as early as January 1 of each year. The facility's first annual report will cover the time period since the facility received coverage through December 31 of the reporting year. Subsequent annual reports will cover the calendar year January 1 through December 31. Information required in the annual report includes:

- a brief summary of the pollution prevention plan,
- list of any spills that occurred during the reporting period and corrective actions taken,
- description of inspections, and
- description of implemented structural and nonstructural BMPs.

If you are not required to submit a report, the process or a similar process may be helpful in evaluating the effectiveness of your Plan.

7.20 GENERAL PRACTICES

Pollution-prevention practices include good housekeeping/site maintenance BMPs, such as litter pick-up, lawn-management practices, sweeping, erosion control and maintenance of stormwater-conveyance systems. These practices usually take a minimal amount of effort compared to cleanup efforts, and should be part of the routines of businesses, personnel and users.

7.21 General Practices: WASTE-HANDLING AND WASTE-STORAGE AREAS

MANAGING SOLID WASTE

Litter not only ruins the beauty of Minnesota's waters and the environment, it can also injure and kill aquatic life. Encourage people to collect their trash and return it to proper disposal facilities by providing solid waste disposal service as part of normal practice. Post signs to encourage disposal of wastes in the proper waste containers. Separate waste streams, such as recycled water and solid waste.

HAZARDOUS WASTES

If storing hazardous wastes, mark each container with the words "Hazardous Waste" and the date you first placed waste in the container.

Examples:

- Hazardous Waste, Waste Paint Thinner 04-24-1999
- Hazardous Waste, Sanding/Blasting Waste 05-17-1999

Store the container on an impermeable surface. Coated concrete is a good choice. Coated asphalt is also acceptable. Uncoated asphalt is unacceptable for storing solvents, such as gasoline or paint thinners, because the solvents will dissolve the asphalt.

Seal any floor drains in the storage area to prevent spills from escaping. Provide storage devices to contain spills. Acceptable methods include curbs or cover, or covered spill pallets. Secure the area from access by unauthorized persons. If you are storing ignitable wastes, such as paint thinners or other solvents, outdoors, protect them from heat to prevent expansion and explosion; if water-based, such as latex, protect from freezing to prevent container expansion and possible leaks.

Metal or polyethylene drums should be used as appropriate for the type of wastes being stored. Keep the container closed unless adding or removing waste. Mark each container with a clear description of the contents.

Examples:

- Used Oil
- Waste Antifreeze
- Spent Absorbent Materials

Lead-Acid Batteries

Facilities that accept or store lead-acid batteries for recycling must store them on an impermeable surface, such as coated concrete or asphalt. If stored outdoors, the surface must also be curbed to contain leaks and covered to prevent snow and rain from entering. In many cases, covered pallets or secondary cases made of durable and chemical-resistant materials are a better option than curb and cover. Send spent batteries with a battery hauler for recycling. For more information on battery storage, request MPCA fact sheet #4.06, *Managing Spent Lead-Acid Batteries.*

MORE TIPS TO HELP YOU PREVENT POLLUTION

- Inspect parts, such as rubber fuel lines, regularly; replace before they break.
- Use cleaners only when absolutely necessary.
- When changing oil, wipe up spills immediately and catch all used oil in a container for recycling.
- Drain old antifreeze and other recyclable materials into a container for recycling.
- If using a boom or pillow to remove oil, replace it periodically and place it with other oil-soaked sorbents destined to be burned for energy recovery.

7.22 General Practices: SPILL PLANS

DESCRIPTION

Some facilities may already have a Spill Prevention Control and Countermeasures (SPCC) Plan which addresses the proper handling and storage of materials and the availability of equipment needed to prevent or respond to a spill. The Pollution Prevention Plan should incorporate parts of the SPCC and other management plans located at a site. If you witness a spill, call the Minnesota Duty Officer at (800) 422-0798 or (651) 649-5451.

PREVENTING SPILLS

- Do regular preventive maintenance on tanks and fuel lines.
- Train employees in proper management of hazardous materials, hazardous wastes and tanks.
- In facility leases, include a clause that allows employees to enter and conduct emergency measures.
- Keep hazardous product and waste containers closed when not in use.
- Do not fill gasoline tanks to the very top.
- Post signs or provide information on spill prevention and clean-up methods to patrons.

RESPONDING TO SPILLS

Even with the best care and training, accidental spills will happen. Be prepared to contain and clean them up as quickly as possible.

If a spill happens:

1. Contain the spill.
2. Call the Minnesota Duty Officer at (800) 422-0798 or (651) 649-5451.
3. Clean up the spill.

Stop the source of the spill immediately. Contain the liquid until cleanup is complete. Deploy oil-containment booms if the spill may reach waters of the state or drainageways to waters of the state. Cover the spill with absorbent material. Dispose of cleanup materials properly. Report the spill to the Minnesota Department of Public Safety Duty Officer (call 800/422-0798 or 651/649-5451) when there is a release of a reportable quantity (five gallons or more for petroleum spills). Spills of all other chemicals or materials of any quantity may be reportable. If in doubt, report, or contact the MPCA.

7.23 General Practices: LITTER CONTROL

DESCRIPTION AND PURPOSE

Litter can include scraps of paper, building materials, construction wastes, industrial scraps, leaves, grass clippings and other trash. Litter control involves the removal of litter from streets and other surfaces before runoff or wind moves these materials to surface waters.

PLANNING CONSIDERATIONS

A recycling program and/or proper disposal of waste will help reduce the volume of waste generated and assist in minimizing pollution.

Educational programs that explain the environmental benefits of litter control and leaf collection are helpful.

Ordinances, especially those that prevent debris and litter at construction and industrial sites, can be particularly useful and effective.

Maintaining a clean, litter-free facility includes street sweeping and picking up of debris and garbage on a regular basis or as necessary. Trash containers should be available and of adequate size. Containers should be covered to prevent wind from blowing their contents out and rain water from entering the container. It is best to locate trash containers a significant distance from the nearest storm sewer inlet.

Ultimate disposal of trash should be to an approved disposal or recycling facility.

7.24 General Practices: LAWN MANAGEMENT

DESCRIPTION

Improper lawn-management programs can result in release of pollutants, such as fertilizers, herbicides and eroded soil, into runoff waters. In addition, excessive use of fertilizers and pesticides is an expense that produces no benefit to the facility. On the other hand, inadequate fertilization can result in poor vegetative cover, which may result in soil erosion.

CONSIDERATIONS

Lawn-management BMPs involve proper fertilization, mowing, watering, and pesticide-application procedures. Applying fertilizers only at the rates necessary to maintain lawn areas will minimize potential pollution from lawns. Using the proper fertilizer composition, appropriate application rates, and avoiding spreading fertilizers on impervious surfaces will also minimize the potential runoff into the storm sewer system.

Significant nutrient loads can result from overapplication of lawn fertilizer in urban areas. Fertilizer management can be an effective practice. It involves controlling the type, rate, timing and method of fertilizer application in urban areas so that plant nutrient needs are met while the chance of polluting surface or ground water is minimized. Specifically, this practice is directed at control of phosphorus and nitrogen in runoff from landscaped areas. Nitrogen is of special concern because of potential ground water contamination from nitrates.

Phosphorus is a major water quality concern because it is a primary cause of lake enrichment leading to excessive growth of aquatic plants and algae. Although misuse or misapplication of phosphorus fertilizer can cause water-quality problems, it may be needed initially to establish a healthy stand of vegetative cover. Phosphorus is essential to seedling germination and growth. If a seeding fails or is sparse because of a phosphorus deficiency, the resulting erosion can cause sediment pollution, which carries a large nutrient load with it. In this case, the proper use of phosphorus fertilizer can actually reduce long-term nonpoint-source pollution. In new seedings, phosphorus fertilizer should be incorporated into the soil during seedbed preparation. The soil should then be protected with appropriate erosion-control practices.

Existing lawns should be aerated with a coring machine before the fertilizer is applied. Phosphorus fertilizer recommendations should be based upon a soil test. In some areas of Minnesota, soils are naturally high in phosphorus and other areas may have high levels because of a build-up from previous fertilizer applications. In these cases, fertilizers that do not contain phosphorus should be used.

Nitrogen is the fertilizer element that generally brings about the greatest response in plants. It is found in soils in the ammonium form, the nitrate form and as a component of soil organic matter. In all but very wet or dry soils, the ammonium form is readily converted to the nitrate form. This nitrate form is completely soluble and is not held tightly by soil particles. Therefore, nitrate can readily leach downward and contaminate ground water. Ground water contamination is most likely when excess nitrogen fertilizer is applied on highly permeable sandy soils. Because of the mobility of nitrate in most soils, nitrogen soil tests are not generally used for making nitrogen fertilizer recommendations in Minnesota. Nitrogen fertilizer guidelines for lawns and gardens follow:

- To avoid nitrogen loss on sandy soils, apply fertilizer at one-half the recommended rate but twice as often. Another option to avoid nitrogen loss on sandy soils is the use of slow-release nitrogen fertilizers or natural organic nitrogen sources. Applying no more than the recommended rate of nitrogen fertilizer will minimize the chance of ground-water-pollution problems.
- Leaving grass clippings on turf areas will provide nutrients to the soils and reduce the amount of fertilizer required to maintain the lawn. When mowing lawns or raking leaves, do not pile clippings or leaves in the street or on an impervious surface. Leaves should be composted.
- Overwatering lawns may result in soil, fertilizers pesticides or herbicides being washed off the lawn surface and discharged into the storm sewer conveyance system.

BMPs FOR FERTILIZER APPLICATION AND LANDSCAPE MAINTENANCE

- Have the soil tested and follow soil test recommendations. In some areas, city governments have passed ordinances regulating fertilizer use on lawns. Homeowners should be aware of any local regulations before applying fertilizer.
- For more information on calculating fertilizer rates and methods of fertilizer application, contact the University of Minnesota Extension Service.
- Water your lawn after fertilizing, but do not allow water to run off into streets or other direct conduits to water bodies.
- Promptly clean up any fertilizer spilled on roads or sidewalks.
- Never apply fertilizer to frozen ground.
- Do not deposit fertilizer in the water or onto street or sewer systems that discharge directly to water.

7.25 General Practices: DUST CONTROL

DESCRIPTION

Dust from smokestacks and vents as well as from stockpiles, cleared ground and open areas, often called "fugitive dust," is a form of air pollution. The surface and air movement of dust from disturbed surfaces may cause off-site damage, health hazards and traffic problems. Industries and local governments sometimes use various methods to control this dust. Filters and scrubbers are often used on regulated discharges, so this BMP is directed more toward fugitive dust, which may or may not be regulated by permit. Construction activities that disturb soil also can be a significant source of fugitive dust; large quantities of dust can be generated, especially in "heavy" construction activities, such as land grading for road construction and commercial, industrial or subdivision development.

This BMP also emphasizes some of the water-quality issues you should consider when using dust-control treatments on construction sites, roads, industrial sites and other disturbed areas, so that your air pollution solution doesn't turn into water pollution. For general guidance on road maintenance and water pollution control, consult the September 1992 EPA publication, *Rural Roads: Pollution Prevention and Control Measures (F15)*, available by calling the Terrene Institute at (800) 726-4853.

Industry-specific measures can vary widely, depending on the products and the physical properties of the materials used. Industrial associations are often a good source of information regarding pollution prevention. Flexibility is important because concerns regarding dust control need to address site-specific needs and changing circumstances.

PLANNING CONSIDERATIONS

- The greatest dust problems occur when the probability of rainfall erosion is lowest. Therefore, do not expose large areas of soil, especially during drought conditions. Maintain dust control measures through dry weather periods until all disturbed areas have been stabilized.
- Schedule construction operations so that the least area is disturbed at one time.
- Leave undisturbed buffer areas between graded areas wherever possible.
- Install temporary or permanent surface-stabilization measures immediately after completing land grading.
- For disturbed areas not subject to traffic, vegetation provides the most practical method of dust control (see: Surface Stabilization).
- When properly applied, mulch (including gravel mulch) offers a fast, effective means of controlling dust. Stone used to stabilize construction roads can also be effective for dust control.
- Use measures, such as roofs, tarps or other covers, and progressing to filters and scrubbers or surface treatments to minimize impacts.
- Deep plow large, open disturbed areas and bring clods to the surface. Tillage is a temporary emergency measure that can be used as soon as soil blowing starts. Begin plowing on the windward edge of the site.

- A board fence, wind fence, sediment fence or similar barrier can control air currents and blowing soil. Place barriers perpendicular to prevailing air currents at intervals about 15 times the barrier height. Where dust is a known problem, preserve windbreak vegetation.
- Reduce speed limits on roads that generate substantial dust.
- Pave roads that generate substantial dust.
- Use management practices which prevent problems first. Improved handling measures or reduced stockpiles are some of the measures that prevent dust creation.
- Know the exact chemical content, aquatic toxicity and human health effects of any dust-control material. Be sure to obtain this information from vendors before purchasing a chemical product.
- Be careful not to apply liquid materials so that they pond or run off the application area.
- Do not apply chemicals close to bridges, culvert crossings, ditches, streams, wetlands or other surface waters.
- Do not apply chemicals that may run off when it is raining, when it may rain soon, or if the surface is frozen.
- Do not apply chemicals near wells or where they can easily contaminate ground water.

PRODUCT-SPECIFIC ISSUES

Water should not be overapplied and any runoff should be controlled. The site may be sprinkled until the surface is wet. Sprinkling is especially effective for dust control on haul roads and other traffic routes. This method can be costly and must be performed during dry periods.

Used oil is prohibited by the MPCA for dust control in part due to the possible presence of contamination products in the oil and water pollution concerns from oil in the runoff.

Oil emulsions and resins (bitumens) contain hydrocarbons that can adversely impact aquatic life and drinking water.

Polyacrylamides pose some concerns for drinking and ground water.

Soybean soapstock contains vegetable oils, and is generally less likely to cause water-quality impacts than other dust-control products.

Lignosulfonates can harm vegetation and seedling growth. There are also potential water-pollution impacts due to oxygen depletion of water, acidity, corrosivity, ammonia, phenols, sulfate, zinc and other heavy metals, all of which can be potential water quality concerns. Therefore, lignosulfonates require more care in application than most other chemical stabilizers.

Salts can harm vegetation and may cause water-quality problems if used in high concentrations or in sensitive areas. Salt may be applied by mechanical spreader as loose, dry granules or flakes at a rate that keeps the surface moist but not so high as to cause water pollution or plant damage. Salts may contain high levels of lead, mercury or other metals, and anti-caking substances, such as cyanates. Oilfield brines also may contain petroleum hydrocarbon pollutants.

7.26 General Practices: EROSION AND SEDIMENT CONTROL

This management practice is covered in detail in chapter 6. Refer to that chapter for further details.

Most of the erosion- and sediment-control practices have been directed toward construction and agricultural practices. These same practices can be applied to existing erosion concerns at other sites. There is much documentation and information available on erosion and sediment control. BMPs for erosion/sediment control for construction activities are available from the USDA's Natural Resources Conservation Service (NRCS), MPCA, Minnesota Board of Water and Soil Resources, and county soil and water conservation districts. The Metropolitan Council and other local units of government may also be contacted for additional information.

Sediment has the ability to bind with other contaminants and transport them downstream. Controlling sedimentation is accomplished by minimizing clearing and grading, by establishing vegetative cover on soils and/or reducing stormwater runoff velocities by flattening slopes and/or installing flow-dispersion methods.

SEDIMENT- AND EROSION-PREVENTION PRACTICES

Any site where soils are exposed to water, wind or ice can have soil erosion and sedimentation problems. Erosion is a process in which soil and rock material is loosened and removed. Sedimentation occurs when soil particles suspended in surface runoff or wind are deposited in streams and other water bodies.

Human activities can accelerate erosion by removing vegetation, compacting or disturbing the soil, changing natural drainage patterns, and by covering the ground with impermeable surfaces (pavement, concrete, buildings). When the land surface is developed or "hardened" in this manner, storm water and snowmelt cannot seep into, or infiltrate the ground. This results in larger amounts of water moving more quickly across a site, which can carry more sediment and other pollutants to streams and rivers.

Plans must be developed for areas that may have a high potential for soil erosion. This includes areas with such heavy activity that plants cannot grow, such as soil stockpiles, stream banks, steep slopes, construction areas, demolition areas and any area where the soil is disturbed, denuded (stripped of plants) and subject to wind and water erosion. Steps to limit this erosion must be implemented as needed.

There are several ways to limit and control sediment and erosion on a site:

- Leave as much vegetation on the site as possible.
- Minimize the time that soil is exposed.
- Prevent runoff from flowing across disturbed areas (divert the flow to vegetated areas).

- Stabilize disturbed soils as soon as possible.
- Slow the runoff flowing across the site.
- Provide drainageways for the increased runoff (use grassy swales rather than concrete drains).
- Remove sediment from stormwater runoff before it leaves the site.

Using these measures to control erosion and sedimentation is an important part of stormwater management. Selecting the best set of sediment- and erosion-prevention measures for your industry depends upon the nature of the activities on your site (*i.e.*, how much construction or land disturbance there is) and other site-specific conditions (soil type, topography, climate and season). Section 4.51 discusses temporary and permanent ways to stabilize your site. Chapters 4 and 5 of this manual describe more structural ways to control sediment and erosion.

In arid regions, growing vegetation to prevent erosion may be difficult. The local NRCS office or county extension office can provide information on special measures necessary to promote the establishment of vegetation.

VEGETATIVE-PRESERVATION PRACTICES

Preserving existing vegetation or revegetating disturbed soil as soon as possible after construction is the most effective way to control erosion. A vegetative cover reduces erosion potential in four ways:

1. by shielding the soil surface from direct erosive impact of raindrops;
2. by improving the soil's water storage porosity and capacity so more water can infiltrate into the ground;
3. by slowing the runoff and allowing the sediment to drop out or deposit; and
4. by physically holding the soil in place with plant roots.

Vegetative cover can be grass, trees, shrubs, bark, mulch or straw. Grasses are the most common types of cover used for revegetation because they grow quickly, providing erosion protection within days. Other soil-stabilization materials, such as straw or mulch, may be used during nongrowing seasons to prevent erosion. Newly planted shrubs and trees establish root systems more slowly, so preserving existing vegetation is a more effective practice.

Vegetative preservation and other site-stabilization practices can be either temporary or permanent. Temporary controls provide a cover for exposed or disturbed areas for short periods or until permanent erosion controls are put in place. Permanent vegetative preservation practices are used when activities that disturb the soil are completed or when erosion is occurring on a site that has been otherwise stabilized. This manual describes other common vegetative preservation practices including:

- preservation of natural vegetation;
- buffer zones;
- stream bank stabilization;
- mulching, matting and netting;
- temporary seeding;

- permanent seeding and planting;
- sodding; and
- chemical stabilization.

7.27 General Practices: STREET SWEEPING

DESCRIPTION AND PURPOSE

Street sweepings are materials, such as sand, salt, leaves and debris that are swept from city streets, parking lots and sidewalks to prevent them from being washed into storm sewers and surface waters, and to improve the appearance of public roadways. If these materials are removed from the streets where they are deposited, they will not be in urban runoff. In most cases, the prime reason for street sweeping is for aesthetics and urban housekeeping rather than for water-quality benefits. Streets are normally swept with either a mechanical broom sweeper or a vacuum sweeper.

The timing of sweeping is important. For example, the most beneficial sweeping is accomplished early in the spring after snow melt; after activities that generate debris, such as construction entrances, the unloading and loading of salt, sand and gravel or other materials; and throughout the year as needed based on observation and traffic volumes.

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. Sweep in a pattern that keeps spilled material from being pushed towards the 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.

TARGET POLLUTANTS

Street sweeping is most effective for removing coarse particles, leaves, trash and other, similar materials. In some cases, there could be a relatively high delivery ratio for these materials to storm water if they are not removed from street surfaces. The pollutants generally reduced by street sweeping include sediment, nutrients and oxygen-demanding substances. Although streets may be swept at other times for aesthetic reasons, routine street sweeping is recommended as a BMP in Minnesota at only two times during the year—immediately following spring snowmelt to remove sand and other debris, and in the fall to remove accumulated debris, such as leaves that have fallen. Loading or unloading and tracking of mud onto paved surfaces from construction sites could require sweeping at any time of the year.

PLANNING CONSIDERATIONS

A semiannual street sweeping program is recommended to remove debris after spring snowmelt and after leaves fall in the autumn.

Two types of street sweepers are commonly used: vacuum sweepers and mechanical broom sweepers. 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.

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.

Street sweepings do not include potentially contaminated materials removed from spill sites, hazardous waste cleanup sites or other contaminated areas. Materials from these sources, whether or not they are removed by a sweeping process, must be tested to determine whether they are hazardous. If they are, they must be managed according to hazardous waste requirements. If you are working at a spill or cleanup site, contact the MPCA coordinator assigned to that site for more information.

Reuse of Sweepings

Before to reusing sweepings, trash, leaves and other debris should be removed from them. This is often accomplished by screening, but other methods may also be used. Dispose of trash and debris removed from the sweepings by recycling it (*e.g.,* aluminum cans), composting it (*e.g.,* leaves) or sending it to a sanitary landfill.

If you store sweepings prior to reusing them, cover the sweepings with a plastic tarp or other covering to prevent erosion.

Street sweepings can often be successfully reused in any of the following ways:

- Mix street 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.)
- Use street sweepings as daily cover material on landfills. When reusing sweepings as a cover material, the MPCA recommends using them only on sanitary or demolition landfills that have ground water monitoring systems.
- Removed sediments should be handled in accordance with part 7.28, Sediment Handling.

In most cases, these residuals are not “hazardous waste.” However, the material is contaminated well beyond levels associated with the raw storm water 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.

For More Information

A report titled *Best Practices: Street Sweepings,* which provides information on efficient and economical ways to conduct sweeping operations, is available from the Metropolitan Council. To request a copy, call (651) 291-6359.

7.28 General Practices: STORMWATER SEDIMENT HANDLING

DESCRIPTION

Controlling stormwater and snowmelt runoff is a pollution-control activity undertaken by cities, counties and private firms. Proper removal, transport and disposal of the sediments produced through this activity are important parts of the project. This part is intended to provide guidance on disposal practices for sediments from construction activities, publicly owned stormwater ponds and stormwater system grit chambers.

By following these guidelines carefully and completely, you can ensure that your project is protecting the environment.

GENERAL GUIDELINES FOR 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, disposal without proper precautions is not recommended.

Stormwater sediments should never be disposed in water or allowed to erode into waters, including wetlands. Rainwater and snowmelt should be diverted around and away from the removed sediments. This will prevent the liquid from carrying sediment back into a waterway.

SEDIMENTS NOT COVERED UNDER THESE GUIDELINES

The disposal guidelines in this manual do not apply to sediments specifically permitted under the National Pollutant Discharge Elimination System (NPDES), the State Disposal System (SDS) program, or other pollution control programs.

This means that sanitary sewer or combined sewer clean-outs or sludges should not be disposed under these guidelines, but may have specific requirements placed on them by those programs. Sediments from temporary ponds constructed under the stormwater general permit for construction activities can normally be disposed of in accordance with these guidelines.

Because some industrial sites may pose a greater environmental risk, sediments from industrial stormwater ponds located on private property and other the industrial stormwater treatment are ***not*** covered under these guidelines. To dispose of industrial pond sediments or sanitary sewer system wastes, you must assess the waste to determine appropriate disposal. Call the MPCA at (800) 657-3864 for more information.

Higher contaminant levels typically will occur when the area through which the storm water drains is the site of a major spill or an ongoing hazardous waste cleanup. When sediments are associated with such situations, these guidelines for disposal ***do not*** apply. In these cases, the sediments must be tested and handled appropriately, based on the testing. Contact the MPCA's cleanup coordinator for the specific spill or cleanup project (1-800-657-3864).

Municipal stormwater runoff is typically contaminated with heavy metals, petroleum hydrocarbons, pesticides and many types of organic chemicals. These guidelines ***do not*** apply to dredge spoil materials removed from permanent stormwater ponds, lakes, rivers and wetlands unless they have been determined to be exempt from MPCA State Disposal System Permit requirements. For these dredging projects, you may need to obtain a general or individual permit from the MPCA. Contact the MPCA at (800) 657-3864 for more information on dredging projects.

DISPOSAL IDEAS AND SUGGESTED LOCATIONS

In some areas of Minnesota, materials are needed for use as daily cover on landfills. Dewatered stormwater sediments may be used as daily cover material, although the MPCA prefers that they be used as cover on lined areas of permitted sanitary landfills or demolition landfills that have ground-water-monitoring systems. Individual counties may have additional restrictions. Contact the county's solid waste officer for more information.

When exempt from other permit requirements, upland areas can be used for sediment disposal, but precautions are necessary. Areas to be especially avoided for the storage or disposal of stormwater sediments include playgrounds, children's play areas and residential yards, or other areas where human contact with the sediments would occur. Also, because sediments usually have a fine texture, they should not be used in areas that may be used in the future for on-site sewage treatment systems.

In most cases, these residuals are not "hazardous waste." However, the material is contaminated well beyond levels associated with the raw storm water 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.

TIPS FOR REMOVAL AND TRANSPORTATION OF SEDIMENTS

Sediments from ponds, lakes, rivers, streams, harbors or other waters must be carefully removed to minimize turbidity, further sedimentation, or other adverse water-quality impacts. Careful transportation of sediments to the disposal site is essential to prevent spills:

1. Sediments should be transported by motor vehicle only after they are dewatered.
2. Hydraulically transported sediments should go only to a secure disposal facility designed to hold the entire volume of sediment and the transport water.
3. In general, supernatant, underdrains or wash waters are prohibited from being discharged to water bodies, except in unusual circumstances or after getting a permit. The MPCA recommends that these waters be evaporated, recycled or discharged to a sanitary sewer system, with the approval of the wastewater-treatment operator.
4. Should a spill occur during transportation, cleanup of the spilled material should be started as soon as possible. The spilled material should be cleaned up to the maximum extent practical.

MORE INFORMATION

For more information on disposal of sediments, contact the MPCA at (800) 657-3864 or (651) 296-6300.

7.30 SYSTEM STRUCTURE

This section covers practices that apply to the maintenance of the stormwater system.

7.31 System Structure: CATCH BASIN SUMPS

DESCRIPTION AND PURPOSE

Catch basins are chambers installed in a storm sewer, which allow surface runoff to enter the sewer. Many catch basins 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. However, these low areas must be cleaned out periodically to maintain their sediment-trapping ability.

TARGET POLLUTANTS

Catch basins with sumps are effective for trapping coarse sediment and large debris (Oberts and Osgood, 1988). In addition to reducing sediment loads, catch basin cleaning also reduces the load of oxygen-demanding substances that reaches surface water.

EFFECTIVENESS

Typical catch basins have been estimated to retain up to 57% of coarse solids and 17% of equivalent biological oxygen demand (BOD). Two large sumps installed in storm sewers as part of the Lake McCarron wetland-treatment system retained as much as 75% of solids in runoff although the typical efficiency was much less (Oberts and Osgood, 1988).

Most catch basins have a sediment capacity of 0.5 to 1.5 cubic yards. 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.

If they are not cleaned, catch basins may actually worsen water quality. It has been reported that once a sump is 40-60% full, any inflow could have a flushing effect and actually generate a sediment loading in water passing through the catch basin (Pitt, 1985). Also, the material that accumulates in catch basins undergoes decay, and the first flush of stagnant water and debris in the sewer system by the stormwater runoff may contain a high concentration of pollutants. The concentration of metals and hydrocarbon pollutants in catch basin sediments are higher than in street dust (Mineart, 1994).

Although it is not possible (based on the data currently available) to quantify the water-quality benefits of catch basin cleaning, such cleaning does provide benefits. Over a year's time, monthly cleaning removes about six times more sediment than cleaning annually. Other benefits include the removal of pollutant loads from the sewer system, the reduction of high pollutant concentrations during the first flush of a storm event, and prevention of clogging of the downstream stormwater-conveyance system (Mineart, 1994).

In most cases, these residuals are not "hazardous waste." However, the material is contaminated well beyond levels associated with the raw storm water 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.

Removed sediments should be handled in accordance with part 7.28, Sediment Handling.

7.32 System Structure: GRIT CHAMBERS

DESCRIPTION AND PURPOSE

A grit chamber is an enlarged chamber designed to settle out grit (sand, gravel and silt) in order to clean some of the storm water before it drains into lakes and streams. A grit chamber with an oil-removal mechanism, such as a skimmer, is often called an “oil grit separator.” Grit chambers are often made out of large box culverts but they can be any size. Some are from small tanks with innovative swirl, filter or plate removal mechanisms. Many are enlarged pipes the size of the construction trailers on construction projects. These devices are buried underground or otherwise located so that the storm water will drain through them on its way to lakes and streams. Because of the size of the chamber, the water slows as it passes through and the grit settles out. The grit collects in the bottom of the chamber and a maintenance crew periodically cleans it out. With oil separators, skimmers and other oil-removal devices may be used to remove the oil separately from the sediments.

EFFECTIVENESS

Grit chambers are effective, but they have to be cleaned regularly. Full grit chambers are ineffective. Grit chambers typically have to be cleaned every one to six months. Storm sewer maintenance crews should keep track of how much material they remove from each of the chambers so they know how often to clean them.

Every cubic yard of grit that is taken out of a chamber, is one that does not get into lakes and streams. If this sediment is not intercepted, deltas form at pipe outlets and dredging is required periodically. Sediment build-up and dredging destroy and disrupt to the natural habitat of the animal and plant species in the waterway. Removed grit should be handled in accordance with part 7.28, Sediment Handling.

In most cases, these residuals are not “hazardous waste.” However, the material is contaminated well beyond levels associated with the raw storm water 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.

Grit chambers are relatively expensive and are usually used where the cost of land would be prohibitive or where the resources are sensitive or valuable.

7.33 System Structure: ON-SITE TREATMENT SYSTEMS

DESCRIPTION

Sanitary sewers and storm sewers must be kept separate. One option for treating sanitary sewage in remote areas is an individual sewage-treatment system (ISTS), also known as a septic system. An ISTS generally consists of a septic tank and a soil adsorption system (also known as a drainfield or mound). An ISTS can provide a high degree of treatment of raw domestic sewage provided it is properly sited, designed, constructed and maintained. Industrial waste is regulated separately from raw domestic sewage and should not be discharged to the septic system, unless specifically authorized by the MPCA.

PURPOSE

The purpose of the ISTS is to treat raw domestic sewage to a level that will not pose a risk to human health and the environment. The treatment of the waste occurs in the septic tank and in the soil treatment system. Raw sewage flows into the septic tank, where the solids are separated from the liquids. The septic tank is sized to retain the sewage for 36 hours to provide the necessary separation of solids. The solids are trapped in the tank and undergo decomposition. The liquid effluent is further treated by the soil adsorption system. Its function is to provide treatment of septic tank effluent before it can enter surface or ground water.

SEPTIC SYSTEM PROBLEMS

Many small and some large communities rely on ground water for drinking water. With increasing residential and commercial development, the ground water may become contaminated. The improper use or design and construction of ISTSs can contribute to ground water pollution. Improperly constructed ISTSs can be a major contributor to the pollution of both surface and ground waters. Many products from industry or chemicals used around the house can be toxic to humans, pets and wildlife and may reach the ground or surface water.

Inadequate treatment can also allow excess nutrients to reach lakes or streams, promoting algal or weed growth. Algal blooms and abundant weeds not only make the lake unpleasant for swimming and boating but they also affect water quality for fish and wildlife habitat. As plants die, settle to the bottom and decompose, they use up oxygen that fish need to survive.

INSPECTIONS

Mandatory licensing of all ISTS professionals became effective March 31, 1996. The law (Minn. Stat. ch. 115) requires any business working on ISTSs to be licensed by the state. The licensee must meet the training, examination and experience requirements for the specific license sought and must follow the technical standards of Minn. R. ch. 7080.

A failing system is defined as any system that discharges sewage to a seepage pit, cesspool, drywell, or leaching pit, or to any system with less than 2 to 3 feet (ft) of soil or sand between the bottom of the distribution medium and the saturated soil level or bedrock, or any system posing an imminent threat to public health or safety. Systems that are not in compliance for any of the reasons listed above must be upgraded, replaced, repaired or discontinued within a time period established by the local unit of government or the MPCA.

Septic tank cleaning is required on a regular basis. Removed substances must be disposed of under contract to a local sewage treatment plant or land applied in accordance with federal, state and local requirements. Contact the MPCA regional office for further information.

7.34 System Structure: MANAGING FLOOR DRAINS AND FLAMMABLE TRAPS

This part is adapted from MPCA Fact Sheet #4.18, April 1998.

PROBLEM

Washing and maintenance of vehicles, machinery, trailers, other equipment and floors could allow vehicle fluids and other materials into a floor drain, resulting in a three-phase waste (floating oils, dirty water and sludge) collecting in traps. These traps must be evaluated and managed appropriately. Using good housekeeping methods and following the BMPs outlined in this part will help ensure that this waste is nonhazardous, making it easier and cheaper to manage.

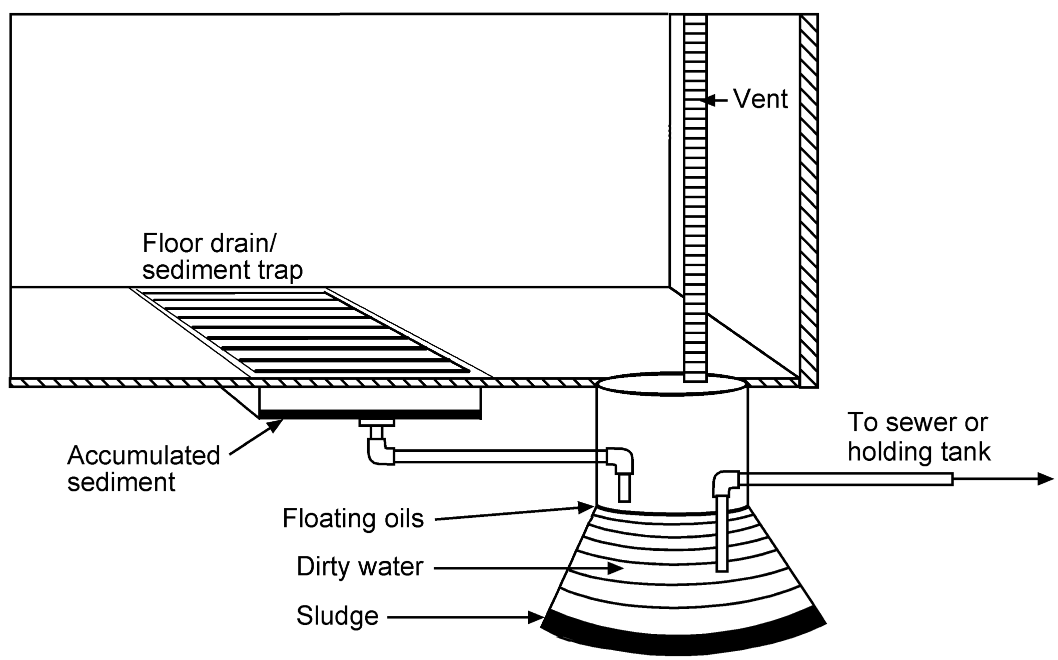

Figure 7.34-1 Phase trap waste

Businesses that discharge industrial wastes have additional concerns. If discharging to a holding tank, businesses must carefully monitor materials entering the tank to ensure they can be pumped and land applied later. Some waste can be approved by the system owner for discharge into a wastewater-treatment-plant (WWTP) system. Do not discharge industrial materials into septic systems as ground water contamination may occur and result in expensive environmental cleanups.

SOLUTION

Prevention is the best solution! Here are some preventive measures to consider:

1. Use good housekeeping techniques and follow the BMPs outlined in Table 7.34-1.

2. Follow good storage procedures: Use curbs or berms when possible; consider additional measures beyond those required for insurance purposes.

3. Cap drains in storage areas; eliminate them, if possible. For requirements and recommendations for capping drains, contact Gary Topp, Department of Health Plumbing Program, at (651) 215-0841.

4. Prohibit engine and transmission washing in vehicle wash and vehicle repair shops.

5. Sweep up nonhazardous solids on the floor and dispose of them in the solid waste. ***Hazardous materials should be collected separately and stored following hazardous waste requirements.*** For more information about hazardous waste storage requirements, request hazardous waste fact sheet #1.04/1.05, *Label and Store Hazardous Waste Correctly*, from the MPCA.

6. Use screens in the drain to prevent solids from reaching the trap.

   Use drip pans to collect fluids. First try to pick up liquids from the floor using a squeegee and dustpan. Combine recovered liquids with waste of the same type. For example, oil spills recovered with a squeegee and dustpan may be placed in the used oil container.

   If you cannot collect or recover liquid, use a sorbent material to soak it up. If using sorbent materials, they must be managed in the same way as the waste material they contain. (For example, if they contain used oil, they may be wrung and reused, burned for energy recovery or recycled.) Disposal of sorbent material in the solid waste is not allowed unless it has been shown to be nonhazardous.

7. Prepare and train for emergencies. Have a plan and the necessary equipment in place to quickly clean up a spill before it can escape.

8. Design and implement a plan to reduce the amount of slush and snow, sand and salt carried on tires before vehicles are parked indoors.

For more information or for help with prevention, contact the Minnesota Technical Assistance Program (MnTAP) at (612) 627-4646 or (800) 247-0015.

MAINTENANCE

Maintenance is second only to prevention in importance. Traps that are not cleaned regularly may allow oils and other chemicals into a septic system, holding tank or sanitary sewer, resulting in disposal problems and/or environmental damage. Be aware that maintenance of these systems may involve entry into a confined space and require additional employee training and precautions.

WASTE-MANAGEMENT OPTIONS

If you have not followed the BMPs in Table 7.34-1, you will need to test the liquid and solid portions to determine whether they are hazardous. Test results will determine how to manage each portion. Nonhazardous trap waste may be managed according to the guidance below. Hazardous waste must be managed according to the hazardous waste rules. For more information about hazardous waste management requirements, contact the MPCA.

If you carefully follow the BMPs, the MPCA allows you to assume that drain and trap wastes are nonhazardous. In most cases, these residuals are not hazardous waste. However, the material is contaminated well beyond levels associated with the raw storm water 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. Here are the options for managing them:

Floating Layer. If BMPs are carefully followed, little or no floating oily material should accumulate. (If there is a significant floating layer, the MPCA must assume that BMPs were not followed.) If a *thin* floating layer of oil is present:

1. Skim or vacuum the oil off and recycle it with other used oil.
2. Use an absorbent pad to remove the oil. Wring and reuse the pad or recycle it with other oil-contaminated sorbent materials by laundering, oil-extraction or burning for energy recovery. If these options for managing the absorbent material are not possible, test it for metal and volatile contaminants using the Toxicity Characteristic Leaching Procedure (TCLP). (For more information, see MPCA hazardous waste fact sheet #2.04, C*haracteristic Wastes*.) If the material is nonhazardous, it may be managed as an industrial solid waste and sent to a solid waste landfill or burner that can accept it. Check with the landfill operator before shipping!

Liquid Layer. Carefully following BMPs will keep levels of hazardous metals and organic compounds below maximum allowable concentrations. Your county solid waste officer or local WWTP operator can provide information to help you determine which of the following management options will work best for you:

1. If you are connected to a WWTP and discharge is approved, you may discharge the liquid layer to the sanitary sewer. The WWTP may require testing prior to discharge. Check with your local treatment plant operator first.
2. Nonhazardous liquid wastes discharged to a septic system or holding tank can often be managed like domestic septage. A certified septage hauler can pump out the waste and dispose of it at a WWTP or by land application in accordance with an MPCA-approved land application management plan. The WWTP should require testing. Check with your local treatment plant operator.
3. Send the liquid portion to a solid waste incinerator or power plant that is able to incinerate it. They may require testing. Check with your county solid waste officer to determine your local options.
4. Pretreat the liquid portion, using an appropriate pretreatment unit, such as an oil-water separator, reverse osmosis or activated carbon filter. Treated liquid may then be hauled or discharged to a WWTP (if approved by the plant operator), or land applied in an approved manner. Check with the MPCA to determine whether land application is appropriate. Contact MPCA's Underground

Injection Control Program for guidance. For help with pretreatment options, contact your local WWTP.

Sand/Sludge. Carefully following BMPs will keep levels of hazardous metals and organic compounds below maximum allowable concentrations. These are your management options:

- Dewater and send the sand/sludge to an approved mixed municipal or industrial landfill that is able to accept it. Contact the operator first; the landfill may require testing.
- Incinerate or thermally treat the sand/sludge (only if organic compounds in it are not halogenated) at an approved facility. For a listing of facilities, contact the MPCA.
- Some sand/sludge can be land treated in accordance with an MPCA-approved management plan. For more information, contact the MPCA.
- Send dewatered sludge to a mixed municipal compost facility if there is one in your area that will accept it. Contact the operator first.

Liquid and Sand/Sludge Together. If it will accept it, take or discharge to a WWTP. You must first get approval from your local WWTP operator to discharge.

Three Phases Together. If the waste is hazardous or you are not sure whether it is, vacuum it out. Then, ship it with a hazardous waste transporter who meets the U.S. Department of Transportation standards for transportation of hazardous wastes to a permitted hazardous-waste-disposal facility. (This may require testing; check with your transporter.) You may send this waste to a registered petroleum recycling-facility. A list of transporters, recycling facilities and treatment, storage and disposal facilities is available from the MPCA.

Table 7.34-1

Best Management Practices for Managing Floor Drains and Flammable Traps*

(Post in Shop)

Using these best management practices in your shop will enable you to manage flammable trap waste as an industrial solid waste rather than a hazardous waste.

If you:	You need to know that:	Best Management Practice
Use aerosol solvents or other degreasers	These chemicals can compound waste management problems by contaminating wash water and sludge with hazardous materials.	Clean parts over a drip pan — not on the floor; collect waste. Use a parts washer to clean engine parts and manage the solvent in the washer as a hazardous waste. To prevent contamination of the parts washer by listed** solvents, do not spray listed aerosols over the unit.
Change vehicle fluids (oil, brake fluid, antifreeze, etc.)	These chemicals can compound waste management problems by contaminating wash water and sludge with hazardous materials.	Use drip pans under vehicles to collect fluids. Recycle transmission and brake fluids with used oil. Drain radiators before flushing and recycle waste antifreeze.
Clean shop floors remove all screens	Hosing down the floors with water or solvent can flush contaminants into floor drains, contaminating liquids and sludges in the drain system.	Use drip pans to collect fluids. Use dry sweeping compounds. Reuse them as long as they remain absorbent. Combustible sweeping compounds may be burned to heat your shop if burned in an approved burning device.
Accidentally spill material	Many materials used in vehicle maintenance may be hazardous and can contaminate other wastes in the plumbing system.	Clean up spills immediately. Notify the Minnesota Duty Officer — (651) 649-5451 or (800) 422-0798 — if it is a petroleum spill of more than 5 gallons or if it is a spill of any material of any size that impacts soil or water. Have appropriate spill cleanup materials on hand and train employees how to properly use them.
Store solvents	Spilled or leaked solvents and their vapors are dangerous and can contaminate other wastes in the plumbing system	Keep containers sealed when not in use. Store solvents in a “flammables” cabinet. Do not use solvents near drains.
Store waste vehicle fluids in a room with a floor drain	Spilled or leaked solvents and their vapors are dangerous and can contaminate other wastes in the plumbing system	Keep containers sealed when not in use. Keep waste containers in a separate storage area with no floor drain. Install a curb or berm to contain any wastes that may leak from storage containers. Inspect containers for leaks on a weekly basis. See MPCA Hazardous Waste fact sheet # 2.41, *Documenting Container Inspections*.
Wash engines	The resulting wastewater is likely to be hazardous from greases, oils and solvents.	Only wash engines if absolutely necessary. If you do, separate the resulting wastewater and evaluate it.

* *From MPCA hazardous waste fact sheet #4.18 (April 1998).*

** *Listed solvents: Solvents on F-list like methylene chloride, methyl ethyl ketone, tetrachloroethylene, toluene and xylene.*

7.40 ACTIVITY-SPECIFIC PRACTICES

Activities applicable to an industry, a segment of an industry or an individual are addressed by the practices described for each activity. This is not a comprehensive list but is intended to address a variety of activities that help to illustrate how BMPs may be applied.

7.42 Activity-specific Practices: VEHICLE-WASHING SERVICES

DESCRIPTION

Vehicle washing involves the removal of dust and dirt from the exterior of trucks, boats and other vehicles, as well as the cleaning of cargo areas and engines and other mechanical parts. (Note: Discharge water from engine degreasing may be considered a hazardous waste and must be disposed of accordingly.)

TARGET POLLUTANTS

Washing of vehicles and equipment generates oil, grease, sediment and metals in the wash water as well as degreasing solvents, cleaning solutions and detergents used in the cleaning operations. The U.S. Environmental Protection Agency (EPA) considers wash water to be a non-stormwater discharge (*i.e.*, processed wastewater). Therefore, wash water from the facility must be directed to a sanitary sewer or treated on-site prior to discharge.

TREATMENT

Cleaning Chemicals

Cleaning chemicals can contain ingredients that pose threats to human health, if they enter ground water and drinking water supplies, and can be highly toxic to fish and other aquatic life. Here are some considerations in the use of cleaning chemicals:

- What are the goals in using chemical cleaners? Are these goals aesthetic only? Have you tried pressure cleaning with plain water, then steam cleaning without chemicals, to see whether these goals can still be achieved?
- Can you eliminate the use of some or all cleaning chemicals?
- Demand that vendors provide you with the <u>*complete*</u> ingredient list for each cleaner, so you can evaluate the potential risks of using the product. You will be introducing these cleaning chemicals into the environment, even indirectly through the sanitary sewer. You have the right to know 100% of the composition of a cleaner that may increase your environmental liabilities when you dispose of the washing wastewaters that contain the cleaning product.
- Dispersants and emulsifiers can limit the effectiveness and efficiencies of wastewater-treatment systems, especially in the removal of sediments, metals, oils and petroleum hydrocarbon pollutants. If immersion cleaning is used, emulsifiers may not be needed. Can you eliminate the use of chemical cleaners containing dispersants and emulsifiers?
- Alkylphenol ethoxylate (APE) non-ionic surfactant ingredients can biodegrade to compounds that are highly toxic, environmentally persistent, and may have adverse estrogenic or reproductive effects.

- Petroleum distillates (*e.g.,* kerosene, white spirits, mineral spirits, Stoddard solvent, petroleum naphtha) are sometimes unlabelled carrier solvents in some cleaners, and may be considered hazardous wastes after use. They can contain risky volatile organic compound (VOC) contaminants, such as hexane, methyl ethyl ketone (MEK), toluene, xylenes and naphthalene.
- Alkyl benzene sulfonates (ABS) and linear alkyl sulfonates (LAS) ingredients can be toxic to aquatic life, and may take a long time to biodegrade.
- Molybdates are sometimes corrosion-inhibitor ingredients in cleaners; molybdenum poses ground-water-contamination concerns.
- Caustic soda (sodium hydroxide) and potassium hydroxide are ingredients in many aqueous alkaline cleaners. If manufactured by the mercury cell process, these ingredients can contain significant levels of mercury. Be sure to request a low-level mercury analysis from the vendor of any product batch you purchase with these chloralkali ingredients.
- Acrylamide monomer, as well as acrylonitrile, are potential carcinogens. Both may be trace ingredients, or degradation products, of some acrylic polymers, particularly polyacrylamides. Acrylic polymers, which are often used as chelating agents in industrial cleaners, may be very persistent in the natural water environment.
- Phosphates are often used as chelating agents in industrial cleaners. Phosphorus poses water-pollution concerns, especially for lakes.
- Some cleaners, such as those with glycols, may deplete dissolved oxygen levels in surface waters when they biodegrade.
- Acids may also be used as cleaning agents, causing low pH and dissolving metals in the wash stream.

Sanitary Sewer Discharge

The preferred option is to discharge all wash water (except engine-degreasing water) to a wastewater-treatment plant with the approval of the plant owner, which is usually the city.

Holding Tanks

In areas not served by a sanitary sewer, a holding tank should be constructed to collect wash water from the wash station. The contents of the holding tank should then be hauled to a treatment plant or discharged to a sanitary sewer line.

On-site Treatment

Another suitable option is to contain and treat all wash water on the premises by using a detention pond or bermed area that will retain the wash water on site to evaporate and infiltrate. An individual NPDES/SDS permit is needed for such a treatment system, which cannot be covered under the general NPDES/SDS stormwater permits issued by the MPCA Separate containment is required for salt brine.

Vehicles should be washed in an area where the wash water can be treated and/or kept from infiltrating into the ground water. The primary BMP for washing operations is the identification of select areas where washing operations can be done. These areas should be located so the wash water can be directed to a place for treatment or collected for proper discharge. The following are BMPs for washing operations and/or handling of wash water:

- Use designated wash areas.
- Minimize rain water or snowmelt run-on conditions to wash area.
- Direct wash water to a sanitary sewer system or contain the wash water.
- Construct a concrete wash pad.
- Recycle/reuse wash water.

If you are currently washing on an outside lot, here are some suggestions:

- Initially clean vehicles without using water (*e.g.*, sweep loose material in cargo areas).
- Conserve water when rinsing and washing vehicles.
- Prevent seepage of salt brine into ground water.

An existing building could be used or a concrete or asphalt pad constructed that is large enough for at least one truck to be washed. The pad should have a collection sump and the wash water would flow by gravity or be pumped from the collection point to an existing sanitary sewer line. It is preferable to have a roof over the washing area to keep clean storm water out.

Collection of Wash Water with No Wash Station

In situations where a fleet of parked trucks is washed by a mobile washer, collecting the wastewater is more difficult. If the parking lot has a catch basin connected to a storm sewer, this can be used as a collection point. The storm sewer could be temporarily blocked or plugged so that a temporary pump or vacuum could collect the wash water and dispose of it in a sanitary sewer or holding tank.

Washing on Gravel or Dirt Lots

Washing on permeable soils will probably not create a surface water discharge, but there is still a concern about ground water impacts. Avoid washing trucks where there is no liner system to prevent wash water from infiltrating into the ground.

Recycling the Wash Water

Recycle units clean wash water only enough so that the water is suitable for washing but not rinsing. Therefore, rinsing will have to be done with fresh water. Normally, recycle units do not remove detergents, dissolved solids or heavy metals. This means your detergent usage will decrease, but it also means that if you recycle your wash water long enough, it will test hazardous and have to be disposed of at a hazardous-waste facility.

7.43 Activity-specific Practices: VEHICLE AND EQUIPMENT MAINTENANCE

DESCRIPTION

Fluids from vehicle-maintenance activities and breaking hoses also contribute to stormwater contamination on site or on a storage pile site. Any vehicle maintenance that has the potential to result in the loss of fluids or solvents should be done indoors on an impervious pad. Any spills should be cleaned up immediately. All fluids and solvents should be properly disposed.

The primary sources of stormwater contamination related to the maintenance of planes, vehicles or equipment are leaking fluids and the improper disposal of fluids removed during routine maintenance. A regular maintenance schedule for planes, vehicles or equipment provides periodic checking for leaks. Excess fluids in parking areas indicate the need for maintenance and/or checking for potential leaks. Parking vehicles in specified locations will identify slow, recurring leaks, and visual inspections of the pavement around specified parking areas will identify releases which may otherwise go unnoticed. Also, keeping vehicles washed and cleaned assists in identifying oil or other fluid releases from the vehicles. Once a leak is located, the following actions can be taken:

- Use an absorbent to clean up the spill and place a drip pan under the leak. If possible, move the vehicle or equipment inside. Schedule maintenance and identify the leak location. After maintenance complete, visually confirm that the problem has been corrected.
- When possible, all maintenance of vehicles and equipment should be performed inside. This greatly reduces the potential for spills to be exposed to storm water. If maintenance activities must be performed outside, provide drip pans and/or spill cloths for use under the area being worked on. Once maintenance has been completed, take the drip pan inside and place the fluids that accumulated in the pan in the designated container. Upon completion of the outside maintenance activity, inspect the maintenance area and clean it, if needed.
- Properly dispose of used oils and fluids. Keep documentation on file to prove that fluids were properly disposed. A regular schedule for proper off-site disposal of accumulated fluids should be established. Do not spread used oils or fluids outside to control dust or kill weeds. Clean drip pans when not in use and return them to their designated inside storage area.
- Traction sand, degreasing wastes, motor oil, motor oil filters, oil sorbent pads and booms, transmission fluid, power steering fluid, brake fluid, antifreeze, radiator-flush wastewater and spent solvents must be collected and disposed of in accordance with applicable solid- and hazardous-waste-management rules, including Minn. Stat. § 115A.916. These materials, which include the non-aqueous portion from flammable traps and oil/water separators, must not be released to surface or ground waters.
- As part of the regular maintenance schedule, check for releases from equipment and vehicles at least twice a year. The identification of releases and spills and the maintenance operations to repair or clean up these incidents are BMPs that will help decrease the amount of oil and grease exposed to storm water.

The following suggestions will help prevent pollution from vehicle and equipment repair operations.

Keeping the Workplace Clean

- Clean shop floors by sweeping, spot cleaning or other methods to prevent runoff into storm drains.
- Sweep clean surfaces that drain to the storm drainage system and properly dispose of the sweepings.
- Use drip pans in shops to hold fluids while doing repair work.
- Conduct repair work indoors.
- Clean up shavings, paint chips, dust and sandings and properly dispose of them.
- Drain cars, engines, transmissions, differentials, and equipment of all fluids when dismantling them for parts, and properly dispose or recycle the fluids.

Maintaining Drainage Systems

- Routinely inspect catch basins and clean when needed.
- Inspect the oil/water separator (inside or outside) and maintain appropriately.
- Handle removed wastes in accordance with part 7.34, Managing Floor Drains and Flammable Traps.

Washing Vehicles and Equipment

- Wash vehicles only with water if parking areas do not drain to a storm drain.
- If vehicles and equipment are washed with soaps, washed them only in a designated area that is covered and leads to a properly approved sanitary sewer system connection, recirculating system or sump.

Handling and Storing Materials

- Recycle or reuse hazardous materials whenever possible.
- Keep hazardous waste containers and dumpsters covered to prevent the contents from leaking out.
- Dispose of hazardous materials that are not recycled or reused through a treatment, storage and disposal facility.
- Properly label containers awaiting recycling or disposal as to their contents.
- Provide secondary containment for all hazardous materials.
- Handle materials carefully and keep the workplace orderly to prevent spills.
- Develop and maintain a spill-prevention-and-cleanup plan for each potentially harmful liquid, such as gasoline or oil.
- Post the spill-prevention-and-cleanup plan where it can be easily accessed.
- Dispose of used tires in an approved manner.

7.44 Activity-specific Practices: FUELING FACILITIES

DESCRIPTION

Fueling systems usually consist of two major components, the fuel-storage tank and the fuel-dispensing system. Other related fueling activities include mobile fueling and checking airplane fuel with a fuel sampler during the pre-flight check.

Fueling-related releases are a major source for contamination of surface waters and aquifers. Proper design and operation of fueling facilities and systems are high environmental priorities.

Fueling Areas

Minimize run-on of storm water into the fueling area by use of a canopy over the fueling area, berms or other diversionary measures.

Use dry cleanup methods for the fuel area rather then hosing it down. Use dry sweeping compounds, which can be reused as long as they remain absorbent.

Install treatment devices, such as filter strips, sediment traps or sedimentation ponds, to remove pollutants from runoff before it discharges from the site.

Developing an underground storage tank (UST) inventory control management plan can aid in detecting releases from UST systems and in minimizing the impacts associated with a UST release.

Above-ground storage tanks (ASTs) are being used more frequently for fuel as regulations and problems with USTs increase. For AST installations, provide for containment of a spill or a leak through use of a dike, berm or double-walled tank. Information on specific design requirements for above-ground fuel-storage tanks can be obtained by contacting the MPCA AST program.

When filling above-ground or underground fuel-storage tanks, follow standard procedures and the guidelines given in the UST inventory control plan.

Clean up minor spills with absorbent materials and dispose of these materials properly.

Clean up spills and releases in accordance with an established spill/release response plan.

Report all reportable spills and releases (five gallons or more) to the MPCA (State Duty Officer) spill hotline by calling (800) 422-0798 or (651) 649-5451.

All spills and releases reported to the MPCA must get a letter from the MPCA approving of cleanup procedures and a post-cleanup letter indicating satisfactory cleanup.

Fuel Dispensing

Spills often occur when fuel is dispensed into airplanes, vehicles and equipment. These spills tend to be small volumes, which may accumulate on the ground over time and/or get washed off by each rainfall. Visually, these small spills may not appear to merit concern, but they can result in a substantial quantity of pollutants being discharged from the site over time. Simple activities that help minimize the potential for spilled fuel to be discharged into storm water from the fuel-dispensing area are:

- Avoid topping off fuel tanks, which may cause spills by overfilling.
- Remove locking devices on fuel dispensing handles so that operators must hold the handle open and cannot walk away while filling tanks.
- Have absorbent materials available at the fueling area for use in cleaning up small spills.
- Instruct the operators on how to use absorbent materials and where to properly dispose of them.
- Do not wash or rinse fueling areas with water, which could cause fuel spills to be discharged into stormwater systems. Use absorbent materials to soak up spills.
- Provide a spill-containment system and education on spill-response procedures.

Topping off fuel tanks is probably the largest source of small spills. Simply educating operators and breaking old fueling habits will go a long way in minimizing potential pollution of storm water by fueling operations. More extensive dispensing area BMPs that could be implemented to minimize storm water contact with fuel spills include:

- Install a canopy over the fueling island to keep precipitation from falling directly upon the fueling pad.
- Provide impervious pavements at all fueling locations. This allows for spill cleanup using dry absorbent materials before precipitation can wash these spills away.
- Install a diversion berm and/or trench around the fuel-dispensing pad to minimize the quantity of run-on from outside areas. This, in turn, will keep fuel from small spills from being washed off the pad.

Mobile Fueling

Mobile fueling is more difficult to manage than fixed fueling facilities. The disadvantage of mobile fueling is the difficulty in controlling the following items for each of the many potential fueling sites:

- providing proper surface drainage conditions and discharge outlets,
- providing an impervious ground surface at the fueling locations, and
- providing containment/absorbent materials by each fueling location.

A major advantage of having mobile fueling is that it is more likely that fully trained, experienced individuals will dispense that fuel rather than less trained general users at stationary fueling stations.

The most effective BMP for mobile fueling is the identification of specified locations where this activity can be performed. Cleanup of spills in these areas can then be facilitated by having the appropriate cleanup equipment and materials adjacent to the fueling activity.

7.45 Activity-specific Practices: SURFACE-PREPARATION ACTIVITIES

SANDING, STRIPPING AND SPRAY PAINTING

Sanding, sandblasting, scraping and stripping boats, barges and bridges produces wastes that are toxic to fish, animals and humans. If possible, work indoors and collect the resulting waste. If you cannot work indoors, choose a day that is calm and use tarps and drop cloths to contain and collect the waste. When stripping paint, minimize the amount of waste generated by using only as much stripping chemical as is necessary.

Waste from sanding and stripping operations is often hazardous and must be collected for disposal. Place it in a closed container marked with the date, the words “Hazardous Waste” and a clear description of the waste (*e.g.,* Waste Paint Scrapings). Contact a hazardous waste hauler for disposal.

AIR-QUALITY ISSUES

Operators should track use of volatile organic compounds (VOCs). VOCs are found in solvents, petroleum distillates, antifreeze, paints, varnishes and thinners. If you use less than 200 gallons of VOCs in a 12-month period, an air quality permit is not required. If you perform spray-painting operations, you may need to do further calculations to determine whether a permit is needed. For more information, call the MPCA.

Steam or Pressure Cleaning

Do not perform pressure washing over the water. Use just enough pressure and cleaning agent to clean but not remove the paint. Again, choose water-based biodegradable cleaners. Do not allow harmful cleaners or solvents to escape into a lake or river. If possible, collect runoff from pressure washing, filter it, and reuse the water.

Use of Antifouling Agents

Antifouling paints work by releasing toxic chemicals from the paint, often into the surrounding air and water. In general, the more effective the paint, the more toxic its ingredients. When using or removing antifouling agents, remember they are regulated as pesticides and must be registered by the EPA and the Minnesota Department of Agriculture for use in Minnesota.

7.50 Material Storage: GENERAL REQUIREMENT

DESCRIPTION

Stockpiles are stores of material for subsequent uses, not for further disposal. They may be raw materials, containerized storage, or recycling and parts stockpiles. These materials often generate wastes through contact with storm water, wind erosion or releases, such as leaks and spills.

SITE MANAGEMENT

Cover

Inventories of materials should be managed so that needed materials can be stored in covered buildings. Tarps or other covers may be appropriate for large stockpiles and temporary storage areas.

Pads

Pads placed under material piles should be impervious. They prevent infiltration to the ground water and allow the storm water to run off the material pile and be collected for treatment.

Since material-pile runoff can be very acidic or corrosive, a material must be chosen that is impervious to the discharge.

Concrete can crack, resulting in infiltration. Also, concrete will not hold up under exposure to acidic runoff.

Asphalt can also crack, resulting in infiltration to the ground water. There may also be some contaminants associated with stormwater runoff from asphalt that are of a water-quality concern.

Compacted clay pads are recommended, but are expensive. The clay should be 3 ft thick.

A pervious base, such as gravel, will allow the water to infiltrate to some extent and will help control sediment loss. Runoff and leachate from storage yards should be sampled to determine whether they should be allowed to infiltrate the gravel (*i.e.*, that they will not pollute ground water).

The pad should be sloped to facilitate runoff to the proper areas, such as detention basins, when such treatment is required.

Berms

Berming is a practice that can prevent uncontaminated storm water from washing across the exposed stockpile and becoming contaminated. It also can keep storm water from carrying particulates off the site. The topography of each site should be evaluated for direction of surface flow. Impermeable berms can be used to route surface flows away from stockpiles, which should be on high ground so that surface water flows away from them.

A berm around the yard or storage area can keep off-site flows from the storage site and also help to slow down and capture yard runoff. Storage areas can be bermed on all sides with a ramp for truck and equipment access. If soil is used for the berm, it should be covered in vegetation to keep it intact and prevent erosion from the berm itself.

Vegetative Buffer Strips

Strips or areas of vegetation around the storage yards can also be used to control water entering or leaving the site. A vegetative strip will slow down water flowing from the site and can capture some of the sediment. Sediment controls in the yard, such as gravel, should also be used, as most vegetative strips will not be able to handle large sediment loads. Do not allow material storage or traffic through the buffer strips; the soil compaction may be detrimental to the health of the vegetation in the strip.

Source Area Controls

Many of the pollutants associated with storage facilities can be controlled with source area controls. Sediment and debris control can reduce total suspended solids, biological oxygen demand, chemical oxygen demand, floatables and the pollutants associated with wood chips, bark, sawdust and other natural materials.

Control of processing material can eliminate most of the stormwater pollutants associated with these materials. Many processing facilities retain all products and collected waste inside a building. The products and waste can then be loaded directly onto a truck for sale or use at the plant for fuel or other purposes.

If other chemicals, such as petroleum products or insecticides, are used at the site, special treatment may be required. Infiltration of storage area leachate should not be allowed until it has been determined that a discharge of this leachate to the ground water will not violate ground water standards.

Reduce Amount of Material Stored at the Site.

Source-reduction options include reducing the amount of material used and stored at the site. This should be given consideration in the facility pollution-prevention plan.

When adding to a pile, compact it and keep it as confined as possible. This will reduce the amount of material that comes in contact with storm water and reduce the potential for contaminants to be dissolved or dislodged and washed into a nearby water body. The following actions will help keep the pile intact:

- Keep only one pile on site if possible.
- Sites may be combined or moved to a more suitable location to reduce management needs.
- Each site where materials are stored should be evaluated for need.

HOUSEKEEPING

Sediment Control in the Yard

Regularly sweep the area back onto the pile to pick up any spillage and dust generated during loading and unloading.

Spray piles and roads as needed to suppress dust; however, do not spray to the extent that runoff from the site is created. The addition of 0.01 inch of water, either as rain or spray, will usually produce a dust-free condition.

The storage area should be paved to prevent sediment from being discharged and tracked off the storage yard.

Collection of Debris and Yard Material

As materials are removed from the storage area for processing, the areas on which they were stored should be cleaned. Loose material should be picked up. If there is a significant amount of soil mixed with debris, the material may be composted. A state permit may be required for the compost pile. The compost pile should be constructed and operated to avoid ground water and surface water contamination. It can be placed on a pad, with runoff collected and sprayed back onto it. The compost can be used for landscaping operations.

LOADING AND UNLOADING CONCERNS

A great deal of dust and spillage can take place when materials are bagged, conveyed or loaded. The following practices should be considered when materials are processed or loaded:

- Many materials should be handled indoors so dust may be contained. After handling operations, the dust should be swept up and disposed.
- If dust is generated when a truck is loaded a chute or boom should be used to place the materials in the truck and the truck should then be tarped. The area should be swept after the truck is loaded.

Much dust and spillage can occur as material is unloaded onto a pile and subsequently loaded onto vehicles for shipment off site. The following practices should be followed when material is being moved:

- If dust is being generated during loading, unloading or transfer, the material should be sprayed to control the dust. Many facilities must do this as a requirement of their air permit. Spray should be controlled to avoid creating runoff from the site.
- Spillage into a water body during loading and unloading must be prevented. The use of covered chutes or booms should be considered to prevent spillage.
- Uncovered storage piles should be evaluated for dust-control needs. Blowing material can be an irritant to neighbors and may damage vegetation near the site.

TREATMENT PRACTICES

Capture and Recycling of Yard Runoff

If there is more storm water and process water generated from the yard operations than can be safely infiltrated in the yard, it should be directed toward a ponding area. Sediment can then be allowed to settle out. The water can then be recycled and reused. Once the water is removed or recycled from the low-lying area, the debris should be collected. This debris can then be treated, disposed or reused. It is important to design the low-lying area so that it can be frequently drained and cleaned to avoid a buildup of waste.

Filtration and Vegetative Strips

Both filtration and vegetative areas can be used to keep storm water from washing across the material storage area and picking up contaminants.

Vegetative filtration areas can be used to allow infiltration of uncontaminated storm water into the ground before the storm water reaches the material pile. The amount of storm water moving towards the pile should be calculated. A filtration area can then be designed to allow all of this water to infiltrate before it reaches the material-storage area.

Both filtration and vegetative areas can be designed as shallow depressions to capture storm water and allow it to infiltrate over time. These practices should not be used with contaminated storm water unless approval has been obtained from the proper regulatory agency.

When source area controls do not keep pollutant levels low enough to avoid violating a water-quality standard or effluent limit, treatment of the material-pile runoff must be considered. When considering the following treatment options, the owner or operator may want to consider primary treatment of the initial runoff.

Recycling of Runoff Back onto the Pile

When infiltration of contaminated storm water is not a concern, the best treatment practice may be to spray the water back onto the material pile. If the pile is not on an impervious pad, extensive monitoring of the leachate should be done before the runoff is sprayed back onto the pile. The owner or operator must avoid allowing infiltration of leachate that will violate ground-water standards.

The runoff from the material pile can be collected in a detention ditch or basin. To avoid clogging the spray equipment, the runoff may need to be filtered before it can be recycled back onto the pile. Evaporation from the detention area may also reduce the amount of water to be recycled. Recycling back onto the material pile can be especially advantageous for piles that need dust control.

Detention and Settling

In some instances, settling of the material pile runoff may be enough to reduce pollutants to acceptable levels. The detention basin should be designed to remove 90% of the suspended solids from the runoff from a 1.25-inch or 0.3-year return frequency 24-hour storm event. See chapter 5 for a description of these definitions and methods of designing these facilities. The settling times needed will vary with the contaminant levels in the runoff and type of solids that were washed from the material pile during the rain event. The treatment outflow rate will not necessarily be the same as the rate defined for ordinary storm water. The treatment discharge rate depends on the particle size distribution and needs to be adjusted to reflect the stockpile particle distribution size. Also note that settling alone may not bring the runoff to acceptable levels unless suspended solids are the only pollutant of concern.

Adjustment of pH

The runoff and leachate from some stockpiles, such as coal piles, can be very acidic. pH values of stormwater discharges from material-pile runoff must be between 6.0 and 9.0 to meet federal water quality effluent limits. Sampling results have shown that many times pH values of runoff from material piles, are below pH 6. If there is a direct discharge to surface water, the pH may need to be adjusted.

One method of pH adjustment is the addition of lime to the runoff, which requires an equalization basin for homogenous mixing of the runoff, a storage facility for the lime, a feed system, instrumentation, electrical connections and piping.

Removal of Metals

A number of metals, including chromium, copper, lead, nickel, antimony, mercury, selenium, zinc, beryllium, arsenic, aluminum and cadmium, have been shown to be of concern in material pile runoff. A long settling time may be enough to remove metals so the discharge meets water quality limits. If not, the metals must be removed to prevent the material-pile discharge from causing a violation of a water-quality standard.

Chemical precipitation or flocculation is one method to remove metals. A polymer can be added to the discharge to allow the metals to settle out.

Using a lime-feed systemto elevate pH can also be used to settle out metals which are less water soluble at higher pH levels. The sediment will need proper disposal.

A polymer-feed system can include storage hoppers, chemical feeders, solution tanks, solution pumps, interconnecting piping, electrical connections, and instrumentation.

Subgrade Cutoff Walls to Prevent Ground Water Contamination.

In instances where material pile infiltration or runoff is violating ground-water standards and an impervious pad is not an option, a subgrade cutoff wall may be an option. The cutoff wall can be a slurry or grout curtain. This wall is built around the material pile. It should extend to relatively impermeable subsoil to prevent movement of ground water under the slurry wall. The wall should have a permeability of less than 1×10^{-7} cm/sec.

A drainpipe system is placed inside the slurry trench below the ground water table. Collection pumps located at various points around the slurry wall keep the ground water level inside it slightly lower than outside it to prevent migration of material pile leachate into the surrounding ground water. This system also prevents excessive migration of uncontaminated ground water into the material pile area. The sumps empty into an impervious basin. This water is then treated as necessary to remove any pollutants that could cause a violation of a water-quality standard.

7.51 Material Storage: SNOW PILES

DESCRIPTION AND PURPOSE

Winter maintenance operations involve snow plowing, sanding, and salting of roadways, parking lots, sidewalks and other impervious areas. 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.

DISCUSSION

Plowed snow cannot be directly discharged to lakes, streams or wetlands. Storage locations should be chosen to avoid direct drainage into surface waters. Ice, snow, salt, sand, sediment and debris are all components of plowed snow. Snow piles require some monitoring for blowing debris. Also, plan to contain sediment and sand after the snow melts in the spring and give consideration to aesthetic issues. As snow piles melt, sediment will accumulate on the surface of the melting ice and the piles will appear black. This is visually unappealing and may be a source of complaints.

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.

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.

7.52 Material Storage: SALT PILES

DESCRIPTION AND PURPOSE

De-icing chemicals are used each winter on roads, parking lots and sidewalks in Minnesota. Sodium chloride (salt) is the main chemical used. Proper use and storage of salt will reduce the chance of high chloride concentrations in runoff that may damage the environment.

TARGET POLLUTANTS

Sodium chloride is the main pollutant addressed by this practice; however, trace metals in runoff have also been found to be associated with the use of salt for de-icing (Oberts, 1986).

A complex iron cyanide (sodium hexacyanoferrate II) is added to road salt to keep salt piles from caking. Research has demonstrated that sodium hexacyanoferrate II will dissociate under varying environmental conditions (*i.e.*, ultraviolet rays, pH and specific bacterial populations) to release hydrocyanic acid, more commonly referred to as free cyanide (Cherryholmes, 1981; Cherryholmes *et al.*, 1983). Typically, 0.25-0.50 lb of sodium hexacyanoferrate II is blended with each ton of road salt. Recent (1999) monitoring of runoff from salt piles by the MPCA has shown free cyanide concentrations that range 130-890 micrograms/L. These concentrations exceed acute toxicity levels.

EFFECTIVENESS

It has been estimated that most of the environmental damage from de-icing chemicals is caused by the concentrated runoff that can be created by inadequate storage facilities. Proper storage practices can control sodium chloride pollution in runoff from stockpiles. Virtually all salt applied for de-icing eventually enters surface or ground water (Pitt, 1985). Therefore, any reduction that can be achieved by preventing overapplication of salt would reduce chloride loading by an equivalent amount.

PLANNING CONSIDERATIONS

To prevent salt brine chloride from entering surface or ground water, the following practices should be used at stockpile locations to minimize the opportunity for the chemicals and water to come in contact with each other:

- Salt piles should be on impervious surfaces.
- All salt piles should be covered with polyethylene if they are not in a shed. Cover outside sand/salt piles with tarps and use diversion berms to minimize run-on.
- All sand/salt piles should be moved to areas not subject to flooding and placed in salt sheds or covered during the nonfreezing spring and summer months.
- Any runoff from stockpiles should be contained for disposal or added back to a winter sand pile.
- Wash water from trucks used for salting and sanding is very high in chlorides. To avoid ground-water contamination, this water should not be discharged to septic system drainfields. Wash water should be contained for disposal, or discharged into sanitary sewers. Earthen basins are

generally ineffective in storing salt brine runoff unless they are sealed and do not have a discharge.

OTHER CONSIDERATIONS

The quantities of salt applied can be reduced in several ways. The first is to prevent over-application. A second way is to watch the weather; anticipation of storms, including their duration, temperatures, and conditions allows for planning that reduces the need for deicing materials. A third way is to properly calibrate equipment and closely monitor the need for de-icing material. A fourth method is to 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.

7.53 Material Storage: COAL PILES

DESCRIPTION AND PURPOSE

Coal is used by power companies and industries for fuel. It is stored at various locations in route from the mine and at the point of use. The size of these storage piles can range from several to hundreds of thousands of tons. Coal is often stored on harbor docks and near bays as it is transferred from one type of transportation to another. It is usually stored outside as it is easier to load and unload in large areas and there is less danger of spontaneous combustion (Schueler, 1992).

POLLUTANTS

Contaminants from coal piles exit the pile either through runoff (storm water running off the pile during a rainstorm), leachate (water trapped in the pile infiltrates into the ground water or is flushed out during rain storms) and airborne emissions. Runoff from the pile can also occur when the pile is sprayed to control dust emissions. Water pollution can also occur during loading and unloading of coal. Coal can be spilled directly into the water, or dust can be generated during the transfer of coal between the rail car, storage pile or ship.

The vast majority of the monitoring results either meet or exceed these limits for metals (including chromium, copper, lead, nickel, antimony, mercury, selenium, zinc, beryllium, arsenic, aluminum and cadmium), suspended solids, pH and polyaromatic hydrocarbons (PAHs), including phenanthrene, pyrene, benzidine, benzo (ghi) perylene, flouranthene and acenapthene. A literature review done for the Pennsylvania Power and Light Company concluded that "many if not all constituents of coal pile seepage are far in exceedance of the water quality criteria" (Ripp, 1988).

Several studies have also concluded that coal pile leachate may be a source of ground water contamination (Mann, 1981).

Coal piles located next to surface waters may contribute pollutants to the surface water via runoff and ground water infiltration. If depth to ground water is shallow and ground water is discharging into the surface water, there may be little or no attenuation of pollutants from the time water infiltrates beneath the pile until it discharges into the surface water.

Use of Low-sulfur Coal

High-sulfur coals tend to produce runoff and leachate, which have lower pHs and higher concentrations of metals and organic compounds. There are, however, some problems associated with the use of low-sulfur coal. It has a lower BTU value per pound, thereby requiring more coal to achieve the same energy output. Low-sulfur coal is also more spontaneously combustible, increasing the likelihood of fires in the pile. Also, electrostatic precipitators, used for reducing air emissions, do not function as well with low-sulfur coal.

7.54 Material Storage: WOOD-PROCESSING PILES

DESCRIPTION

As logs are harvested from a forest, they are stored in piles in the forest or placed in intermediate storage locations. The logs are eventually transported to wood-processing facilities.

Once on site at the wood-processing facility, the logs are eventually debarked and then cut or chipped, depending upon the eventual use of the wood. The debarking process results in large amounts of bark debris. The cutting and chipping processes leave behind piles of sawdust. The bark and sawdust is either stored on the sawmill site, burned for fuel at the sawmill or placed in trucks and sold for fuel or to mills to use in paper-making operations. Bark chips and sawdust are also occasionally sold or given away for landscaping purposes.

POLLUTANTS

Logs, bark and sawdust stored outside have been shown to contribute a number of pollutants to surface waters and ground water. These pollutants include biochemical oxygen demand (BOD), chemical oxygen demand (COD), fecal coliform bacteria, phenols, tannic acid, sediment and hydrogen sulfide. Aesthetics are also a concern with log leachate and storage pile runoff. Runoff from log-storage facilities, which is noticeably darker than surface water, is not aesthetically pleasing. There may also be floatables associated with discharge from some log- and wood-storage facilities.

Federal effluent limitations from mechanical-barking and log-washing operations are applicable.

Collection of Bark

Each wood-processing operation must have a plan to properly dispose of bark. Debarking should take place indoors or under cover. Bark will then either be chipped or left in strips to be used for fuel or by other wood-processing facilities. In either case, the bark should be placed directly in trucks for transportation to the facility that is buying the bark or utilized on site without being exposed to rainfall or storm water.

If used on site, the bark can be moved by covered conveyors to the appropriate point on site or placed in trucks and transported to an indoor or covered facility on site. If it is necessary to store bark or bark chips uncovered outside, the storage site should be appropriately bermed and the runoff treated. Berms should be placed to keep uncontaminated storm water from flowing across the bark-storage area. Storm water that comes in contact with the bark should be collected and the debris and sediment removed before it is allowed to discharge off the site. This can be done by using a settling pond. Or, the runoff can be recycled and used for site-spraying operations.

Collection of Sawdust

As sawdust is generated, it should be contained indoors or under cover. There is a potential for spontaneous combustion in sawdust piles. Sawdust can be used as a fuel on site. It can also be sold for fuel or used in other wood-processing operations. If used on site, it should be transported under cover to the appropriate location. This can be done using covered conveyors or trucks. If sold to another facility, sawdust should be bagged indoors or placed in a covered truck for transport.

Sawdust should never be exposed to rain or storm water. Stormwater discharge permit requirements do not allow a discharge of floatables from the site. It is difficult and expensive to remove sawdust from runoff and it is difficult to clean it from yards.

Proper Storage of Wood Chips

At some facilities, wood chips are brought on site and used as the main material in the facility's operation. At other sites, wood chips are generated in the facility's operation and subsequently sold. At either type of facility, wood chips must be properly handled to avoid contamination of storm water. It is strongly recommended that wood chips be kept under cover or indoors. Stormwater-discharge permits do not allow any discharge of floatables. If wood chips get into the storm water, they must be removed before the contaminated storm water can be discharged from site. If storm water that becomes contaminated with wood chips should be routed through a detention basin and screened before it is allowed to discharge.

7.55 Material Storage: USE AND DISPOSAL OF TREATED WOOD

DESCRIPTION

Wood is often with chemical preservatives to make the wood last longer. While wood treatment lengthens the useful life of the wood, thus conserving timber, the chemicals used in treating wood are toxic and can create a need for special use and disposal practices. Wood treated with the following chemicals is addressed in this section: pentachlorophenol, (or "penta," used typically for telephone poles, declining in use); creosote (typically used for railroad ties), and arsenic preservatives (chromate copper arsenate, or CCA, or other preservatives containing arsenic and/or other heavy metals typically used for structural wood). Constituents of concern in these chemicals are dioxins and furans in penta, creosols in creosote, and arsenic and chromium in arsenicals.

POLLUTANTS

While these preservatives are toxic, the wood they are contained in may not necessarily display the toxicity characteristic of hazardous waste. In fact, industry testing has shown that creosote- and penta-treated wood does not display the toxicity characteristic. However, arsenically treated wood has been shown to be toxic. Because of the toxic constituents contained in treated wood, there are special precautions for its use and disposal.

Use of Treated Wood

There are some restrictions on the use of treated wood for structural purposes. The use of treated wood is prohibited in situations where the wood would come in contact with human or animal food or drinking water and in beehives. However, use of treated wood is allowed where it would come into contact with surface water, such as for docks or supports for bridges. Use of treated wood is also allowed where it comes into contact with ground water, as in building foundations. For more information on the use of treated wood as it applies to ground water, contact the MPCA. For more information on the use of treated wood, contact the Minnesota Department of Agriculture.

Reuse of Treated Wood Waste

Treated wood that is to be reused is not considered a waste, so it is not subject to disposal requirements. For example, old railroad ties may be used for landscaping. Caution should be used to ensure that people or animals will not be exposed to chemicals from the reuse of the treated wood.

Operations storing treated wood waste that is to be recycled or reused may be subject to solid waste permitting if more than 10 cubic yards of treated wood waste is stored for more than 48 hours.

For more information on the requirements for treated wood waste that is to be reused or recycled, contact the MPCA.

Use of Treated Wood as Fuel

Treated wood may be burned at industrial or commercial sites as long as the wood is not found to be hazardous waste and as long as the burner has addressed treated wood as a fuel source in their air emissions permit. Municipal-solid-waste combustors may also burn treated wood under these conditions, and must also address treated wood in their industrial waste-management plans. Ash from the burning of treated wood is subject to evaluation to determine whether it is hazardous waste.

The burning of treated wood for heat in wood stoves, fireplaces, or campfires is illegal since the burning of the wood releases toxins into the air, from which they may be inhaled. ***Do not open burn treated wood!***

For more information on the burning of treated wood waste, contact the MPCA.

DISPOSAL OF TREATED WOOD

Hazardous Waste Regulation

The hazardous waste rules allow households to manage treated wood waste they generate as solid waste. However, the hazardous waste rules do require businesses to evaluate waste they generate to determine whether it is hazardous. Treated wood waste that is considered to be demolition debris (wood from demolished structures) is exempt from hazardous waste regulation.

Though all treated wood has the potential to display the toxicity characteristic of hazardous waste, only arsenicallytreated wood has been shown to be toxic hazardous waste. Although federal regulations exempt arsenicallytreated wood from hazardous-waste-management requirements, the Minnesota hazardous waste rules do not. Therefore, businesses generating arsenically treated wood waste that is not demolition debris must determine whether the treated wood waste is toxic. If it is found to be a toxic waste, it must be managed as a hazardous waste.

Penta- and creosote-treated wood waste has been shown to only contain low levels of toxic constituents. Based on industry data, generators of creosote- and penta-treated wood waste may assume that it does not exhibit the toxicity characteristic and manage it as industrial solid waste.

For more information on the hazardous waste requirements for treated wood waste, contact the MPCA.

Solid Waste Regulation

Although demolition debris containing treated wood is exempt from hazardous waste regulation, demolition landfills are prohibited from accepting treated wood waste unless the demolition landfill is lined. Treated wood waste not regulated as hazardous waste may be disposed in municipal solid waste landfills. Construction debris is accepted by landfills, but many landfills will not accept some types of treated wood. Check with the Industrial Waste Management Plans at the landfills. Because of the restrictions on land disposal of treated wood waste, disposal by regulated burning processes may be more appropriate or feasible in some situations. For more information on solid waste requirements for treated wood waste, contact the MPCA.

Requirements for Wood-treating Activities

Operations that commercially treat wood are subject to specific site and waste-management requirements, including using drip pads and disposing of spent preservative formulations as hazardous waste. For more information on the requirements for wood-treating operations, see the MPCA fact sheet, *Hazardous Waste from Wood-Treating Operations*.

Treating wood after it is already in place or in use should be done with great caution to prevent the toxic preservatives from contaminating the environment. For example, surface water has been contaminated in the past from the application of wood preservatives to bridge supports standing in water. Reapplication of preservative should either be avoided, or done with precautions for preventing environmental contamination.

7.60 Containerized Storage: GENERAL

DESCRIPTION

Compounds, such as fuels, lubricants and solvents, are kept in some type of storage containers. For the purpose of this manual, containerized storage is defined as storage in above-ground or underground storage tanks or in drums.

Containerized storage management involves compliance with the requirements of local, state and federal regulations, as well as sound management practices to prevent and/or minimize the possibility of a leak or spill. Regulations for containerized storage vary and are dependent on volume, type of product stored, use of product, and proximity to surface water.

Best management practices are to safeguard ground water resources, protect the water from future degradation and to correct existing water-quality problems.

POLLUTANTS

Many storage containers have released or will release chemicals into the environment through spills, overfills or leaks. The greatest potential hazard from a leak or spill is that the substance can seep into the soil and contaminate ground water or surface waters.

Spills and overfills often result from bad filling practices. Human error causes most spills; many result from spills made during delivery. Spills and overfills can be avoided by following good filling practices and installing overfill-protection devices. Faulty installation or inadequate operating and maintenance procedures also can cause storage tanks to release their contents to the environment.

SOURCE AREA CONTROLS

Storage

- Store drums inside if doing so is permitted by the fire marshal. If drums are to be stored outside, create some type of shelter so that the drums are not directly exposed to the elements.
- Prepare and train appropriate employees in properly dealing with spills and leaks. Properly trained employees will be equipped to avert or at least minimize a leak or a spill.
- Install some type of impervious surface under drums. Store drums on this impervious surface to minimize the potential of leaks or spills.
- Prevent run-on to, and runoff from, the tank/drum storage area and provide adequate containment to hold spills and leaks. This can be accomplished by use of overhead canopies as well as berms or other measures to prevent the run-on and runoff of storm water. Covered spill pallets or secondary storage containers made of appropriate materials can be used for secondary containment.

7.61 Containerized Storage: UNDERGROUND STORAGE TANKS

DESCRIPTION

(Minn. R. ch. 7150)

Regulated tanks:

Includes:	**Exempt:**
	All tanks of less than 110 gallons capacity
Petroleum tanks over 110 gallons Farm and residential motor fuel tanks over 1,100 gallons	Farm and residential motor fuel tanks that hold 1,100 gallons less containing a product not for resale
Heating oil tanks over 1,100 gallons Used oil tanks over 110 gallons	Heating oil tanks that hold 1,100 gallons and less containing product used consumptively on the premises where stored
Hazardous substance tanks over 110 gallons	

General requirements for regulated tanks:

Registration with the MPCA Corrosion protection for tank and piping	Use of certified contractors for installation, repair and removal
Approved method of leak detection, spill containment and overfill prevention	Ten-day notice to MPCA prior to tank installation or removal

Notes:

1. Regulated bare steel/asphalt-coated steel tank systems installed before December 22, 1988, are required to be upgraded with corrosion protection (tank and piping), spill prevention and overfill prevention by December 22, 1998.
2. Used oil tanks do not require spill containment and overfill prevention unless a quantity greater than 25 gallons is placed in the tank at one time.
3. Tanks used to store hazardous substances must comply with the above requirements and also must have secondary containment and interstitial monitoring (CERCLA Sec. 101 (14)).
4. Spill containment provided by a catchment basin. Overfill prevention provided by an automatic shut-off device, overfill alarm, or ball float valve.

5. Corrosion protection of the tank is provided by one of the following:

- Steel tank has corrosion-resistant coating ***AND*** cathodic protection.
- Tank is made of noncorrodible material (such as fiberglass).
- Steel tank is clad with (or enclosed in) noncorrodible material.
- Uncoated steel tank has a cathodic protection system.
- Uncoated steel tank is interior lined with noncorrodible material.
- Uncoated steel tank has cathodic protection ***AND*** is lined with noncorrodible material.

6. Corrosion protection for piping provided by ***one*** of the following:

- Uncoated steel piping has corrosion protection.
- Steel piping has a corrosion-resistant coating ***AND*** cathodic protection.
- Piping is made of (or enclosed in) noncorrodible material.

A method of leak detection should be installed on the tank and piping since the deadline for leak detection has passed already.

7.62 Containerized Storage: ABOVE-GROUND STORAGE TANKS

GENERAL REQUIREMENTS FOR REGULATED TANKS

(Minn. Rules ch. 7100)

Facilities that have less than 1 million gallons in tank capacity are covered under a general permit issued on November 1, 1995. These requirements pertain to above-ground storage tanks storing liquids, such as petroleum products, used oil, chemicals, food products and pulp. A site is considered to have a liquid storage permit for its above-ground storage tanks if the following requirements are met.

Tanks over 110 gallons capacity must be registered

Includes:	**Exempt:**
Petroleum tanks Chemical tanks	Farm, residential, and heating oil tanks 1,100 gallons and less
Farm, residential and heating oil tanks over 1,100 gallons	Flow-through process tanks Compressed gas tanks
	Agricultural chemical tanks

Tanks over 1,100 gallons capacity must have secondary containment

Includes:	**Exempt:**
Petroleum tanks Chemical tanks	Farm, residential and heating oil tanks 1,100 gallons and less.
Tanks which store a liquid which *could* pollute the waters of the state	Flow-through process tanks. Compressed gas tanks.
Food tanks (*e.g.*, molasses, vegetable oil)	Agricultural chemical tanks.

Notes:

1. Tanks of 1,100 gallons and less capacity that are located within 500 ft of surface water must have full secondary containment:
    - 110% capacity of the largest tank in the area
    - Materials reasonably impervious to, and compatible with, product stored
    - Secondary containment for regulated tanks must comply with Minn. R. 7100.0030
2. Tanks of 1,100 gallons and less capacity that are located beyond 500 ft of surface water must have reasonable safeguards to prevent a release into the environment, such as:
    - Concrete pad or floor
    - Location away from drains
    - Sorbent material on site
    - Good spill plan on site
    - Other methods which achieve the result of pollution prevention
3. Tanks of 1,100 gallons and less capacity that are used for storage of nonhazardous materials are not required to be registered under Minn. Stat. § 116.48.

It is a special condition of the general permit that tanks be monitored at least once a month for leaks or other problems. Results of the monitoring must be documented.

Larger facilities may need to obtain additional permits from the MPCA. Sites that store flammable liquids need approval from the State Fire Marshal's office. Local jurisdictions may have permit requirements.

FOR FURTHER INFORMATION

The information provided has outlined the general requirements for most types of storage containers. Please refer to the following list of regulations to ensure compliance with the appropriate regulations:

- UST - Minn. R. ch. 7150, Technical Standards for Underground Storage Tanks
- AST - Minn. R. ch. 7100, Storage or Keeping of Oil and Other Liquid Substances
- Drum Storage - OSHA Regulated - 29 CFR 1915
- Minn. Stat. chs. 115 and 116

7.70 FACILITY-SPECIFIC ACTIVITIES

7.71 Facility-specific Activities: MARINAS, BOATING AND FISHING

Many recreational activities involve the use of motorized watercraft, including jet skis, inboard and outboard motor boats for fishing or water-skiing, and houseboats, or even snowmobiles on lakes and rivers. The following BMPs will help minimize potential damage to lakes and rivers:

- Avoid spilling gas, oil, paint, varnish or stripper, and never pour liquids over the water during fueling or boat maintenance.
- Do not “top off” fuel tanks.
- Install fuel-storage tanks away from the waterfront.
- Properly store and dispose of all wastewater, both graywater (from sinks) and human waste, while boating or fishing, especially on houseboats.
- Adjust your speed to reduce the wake and consequent wave action that can damage the shoreline.
- Observe surface water use guidelines, including no-wake and low-speed zones.
- It is illegal to deposit fish entrails or parts into public waters or onto lake or stream shores. Fish responsibly.
- Inspect boats and trailers to avoid moving non-native plants or animals from one water body to another. In Minnesota, it is illegal to transport exotic species.
- Store and properly dispose of wastewater when ice fishing. Human waste from several ice houses can have a significant impact on the water quality of a lake or river.
- Prevent contamination of bilge water by oils and gasoline.
- Do regular maintenance to prevent oil leaks and fix leaks promptly.
- Place an absorbent pillow in the bilge that is designed to pull oil and other petroleum products out of the water. These pillows can hold over a gallon of petroleum product and can be wrung out and reused/recycled.

MANAGING WASTE

Discharging sewage to waterways is illegal. To encourage proper disposal of sewage, marinas should provide pumpout facilities or dump stations and public restrooms. To encourage proper disposal of sewage, post numerous signs explaining:

- that discharging sewage into the water is prohibited and
- where pumpout services and public restrooms are located and how to use the pumpout facilities.

Three types of pumpout systems often used by marinas include:

1. Fixed point: Often used by marinas servicing larger boats, these collection systems include one or more centrally located sewage pumpout stations.
2. Portable or mobile: Considered by many smaller marinas to be the most convenient, accessible and affordable, portable units consist of a pump and a small storage tank. They may also have a discharge hose. Note: Even though they are portable, moving these systems can be difficult.
3. Dedicated: Usually used by larger marinas servicing live-aboard vessels, dedicated “slipside” systems provide continuous waste-water collection at a slip through a “hydrant” located on the

dock by each slip. Other areas of the marina may be serviced by a fixed-point or portable system.

Dealing with Wastes from Boat Maintenance

When washing boats above the water line, always choose water-based, biodegradable cleaners rather than detergents containing ammonia or sodium hypochlorite, chlorinated solvents, petroleum distillates or lye. Read labels carefully and handle products according to instructions. Collect spills and residues and dispose of them appropriately; use of chemical cleaners will often result in a hazardous waste.

Wash the hull above the water line by hand. Removing the boat from the water will make it easier to capture the debris for proper disposal. Do not scrape the hull while the boat is in the water.

7.72 Facility-specific Activities: AIRPORTS

Airports include a wide range of activities that are covered under many of the previously discussed BMPs. In addition to those previously discussed activities, the following BMPs may be applicable.

These facilities are required to get an Industrial Storm Water General Permit or Individual Storm Water Permit from the MPCA. The permit requires a management plan (the Plan) for stormwater runoff. The MnDOT has developed general guidance on how to develop a stormwater plan, listing the various problem areas and suggesting potential solutions. The plan needs to specifically address the various potential problems at the site.

Preflight Fuel Samples

During preflight checklist procedures and after fueling smaller airplanes, three fuel samples are commonly obtained to check for the presence of water, grit and proper fuel. If the fuel is contaminated, additional samples may be taken. It is common practice to throw contaminated samples, and even clean samples, into the air or onto the ground, contributing to air pollution (when the fuel vaporizes) and stormwater pollution (when fuel residues are washed away with storm water).

The simplest BMP for fuel-sampling operations is to recycle samples. Provide barrels or other containers at each fueling location for disposal of samples. Use fuel testers which separate out all non-fuel contaminants; this can allow the fuel samples to be put back into the airplane. As with any pollution-control effort, considerations of convenience and location of the disposal systems are critical to assuring they will be used. With proper education of airport users, fuel sample disposal can become a routine activity, like walking to a garbage can to dispose of garbage. The education program developed for a particular airport facility can identify the best way to educate airport users on this issue.

The key to controlling fuel spills and implementing cleanup procedures when spills occur is getting employees interested and providing adequate and easily assessable materials for them to use as part of their routine activities.

Airport Deicing (Runways, Taxiways)

Winter maintenance operation should address sand, salt and snow plowing BMPs and/or runoff from parking lots, roadways. Airport deicing on the runway and taxiways should address the fate of the materials used for deicing. Urea and sand are the materials typically used for deicing.

Reviewing the chemical decomposition of urea is helpful in understanding why this chemical is considered an environmental pollutant. Urea, when chemically reacted with ice or water, breaks down into ammonia. Under proper conditions, the ammonia will result in a nitrate composition. Urea, as with glycol (described later), has a high biological oxygen demand (BOD) in water. Sand contributes to sediment loading when it is carried off-site by storm water.

There are minimal options to attempt to reduce the uses of these materials. The BMP for these materials is to use them wisely under the appropriate conditions. As always, safety should be the first concern in considering application rates. Proper application techniques should be used to minimize wasteful application. Monitoring the spray (cast) of applicators can reduce overspray and waste, directing the material where it is needed.

Constructing a detention pond and/or constructed wetland-treatment system may assist in removing some of the solids and/or organics in the deicing materials.

Snow plowing operations should be monitored and directed so that snow is accumulated in areas where it is least likely to run off when it melts, carrying contaminants with the runoff water. If possible, snow piles should be placed in areas where treatment systems are available to treat runoff and where the runoff drains directly to the treatment system.

Airplane Deicing

Airplane deicing operations typically involve the use of the chemicals ethylene and propylene glycol. When released into water, these chemicals have a BOD. It is estimated that each gallon of glycol has an oxygen demand equal to raw sewage generated from 25 people per day. Airports' usage of glycols varies, depending on weather conditions, type of planes and number of flights per day. Using 20 gallons per day results in a significant environmental impact. Large airports can use up to 400 gallons per plane and up to 20,000 gallons per day. According to an EPA notice published in the Federal Register, "Deicing fluids have been implicated in several fish kills across the nation." Therefore, deicing operations and the use of glycol need special attention.

Typically, deicing occurs at loading/unloading areas, terminal gates or on taxiways. The excess glycol from overspray or drips from the plane lands on the ground and is washed away with the storm water. The glycol is usually diluted glycol and it is typically stored in a 55-gallon drum. The application to the plane is performed by a spray applicator and is pumped from the drum. The diluted glycol drum may be on its own mobile platform, a fixed barrel and/or on a vehicle. The location where the mixing occurs and the handling of full-strength glycol and diluted glycol must be addressed in the Plan. The following are BMPs that should be considered for implementation in handling bulk glycol and the diluted mixture:

- Obtain Materials Safety Data Sheets (MSDS) on the glycol.
- Read and understand MSDSs before handling glycol.
- Store drums containing glycol and diluted glycol inside buildings.
- Load and unload glycol barrels inside buildings if possible.
- It is not possible to load and unload glycol barrels inside, load/unload glycol barrels as close to an inside storage area as possible.
- Mix glycol and water inside buildings or on a deicing pad.
- Identify where unloading/loading spills enter the storm sewer system.
- Prepare spill/release response plans for glycol.
- Conduct training sessions on spill/release response plans for glycol.

Aircraft safety concerns limit the available BMPs for deicing operations. Because the glycol has good deicing properties, dilution usually will not lower the BOD to an acceptable discharge level. Aircraft safety is the primary concern in glycol application rates; however, overapplication could be avoided by reviewing actual application rates required under specific weather conditions. Review and training in applications required for safe aircraft operation would be considered a BMP related to deicing operations. Because of the high BOD of glycol and limitations on reduction of application rates due to safety concerns, capturing and/or treating the runoff from the deicing operations will most likely be the BMP that provides the most beneficial environmental result.

The structural BMPs considered for implementation in application of glycol to airplanes should consist of constructing one or more deicing pads which will capture and contain most of the glycol. The deicing pad should consist of a raised concrete area large enough to hold the airplane and the deicing vehicle/equipment. The deicing pad would be connected to an underground tank which would store the runoff from the deicing pad, consisting of glycol and precipitation.

To minimize the dilution of the glycols with precipitation, the pad should have snow removed prior to performing deicing operations. In addition, there should be a valve or diversion pipe to divert precipitation that occurs on the pad during non-deicing events. The discharge in the diversion pipe should contain essentially clean storm water. Because of the possibility that the diversion pipe could occasionally have some deicing materials in the flow, it should discharge into a constructed wetland which has the potential to reduce residue BOD.

Once the glycol is contained, there are a few ways to dispose of the material:

- recycle;
- discharge it into a sanitary sewer system; or
- provide treatment.

If glycol can be maintained at a concentration of approximately 15% or greater, it has the potential to be recycled. Minimizing the dilution of glycol with precipitation is the key to being able to recycle it. Cleaning snow/ice from the deicing pad prior to use and diverting clean storm water from the tank as soon as practical will minimize dilution of the glycol. If concentrations higher than 15% can be achieved, the glycol may have some value to recycling companies.

The glycol can generally be discharged into a public sanitary sewer system, but the area treatment plant should be contacted to evaluate volumes, concentrations and costs. On-site septic systems will not provide adequate treatment for glycol.

Treatment systems can be designed to chemically reduce the BOD of glycol. Another option for treatment would be constructing wetlands using peat and vegetation for BOD reduction.

"Treating" glycol accumulation by allowing it to evaporate is not considered a BMP, since:

- evaporated glycol is an air pollutant;
- some residue from the glycol solution can still remain on the ground, contributing to stormwater pollution; and
- glycol is commonly applied during periods of precipitation, so it does not get a chance to evaporate.

For all the above reasons, provisions for collecting and treating glycol should be considered for inclusion in BMPs for airport facilities.

CHAPTER 8

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8.00 MODELS AND MODELING

This chapter will provide the user with a basic understanding of runoff characteristics and flow-routing procedures. These concepts provide the mathematical basis for many of the computer models discussed at the end of this chapter. It is important to have a good understanding of hydrological principles before attempting to use any computer models to design stormwater systems and structures. All models have limitations and are designed for relatively specific application.

The guidance introduces the concepts of computer models and the types of models available. It also describes criteria that can be used to select models that address a project's particular needs, as well as to consider in model-use-and-results analysis. Some models available for water quantity and quality modeling are also discussed.

Computer modeling can be one of the more effective and efficient methods for predicting the quantity and nature of runoff, and the effectiveness of best management practices (BMPs). However, computer simulations and models have inherent limitations that users should be aware of and should factor into their decision-making processes. Usually, the best source for finding model limitations is the user manual, but sometimes this is not the case.

8.10 MODELING CONCEPTS

What Is a Model?

The word "model" has many meanings. This is how Snyder and Stall (1965) defined "model": "A model is simply the symbolic form in which a physical principle is expressed. It is an equation or formula, but with the extremely important distinction that it was built by consideration of the pertinent physical principles, operated on by logic, and modified by experimental judgment and plain intuition."

A hydrologic model can be defined as a mathematical model representing one or more of the hydrologic processes resulting from precipitation and culminating in watershed runoff. Hydrologic models aid in answering questions about the effect of land-management practices on quantity and quality of runoff, infiltration, lateral flow, both saturated and unsaturated subsurface flow, and deep percolation.

Hydrologic models are planning tools that ask "what if" questions (*e.g.,* What would happen to the water quality of a lake if the surrounding forest were partially cleared for an apartment building and a golf course?). Traditional water-resource analyses of historic records are clearly inappropriate planning tools in that kind of changing environment. Understanding the ways in which historic patterns and trends should be interpreted, not as predictors of the future, but rather as baselines against which the effects of changes can be compared, is essential for effective planning and resource management.

Hydrologic models should be used with caution as stated by Artemus Ward (quoted by Burges, 1986), "It ain't so much the things we don't know that gets us in trouble, but it's the thing we know that ain't so." While models can be extremely useful in determining the effects of projects on water quality and quantity, a model is most accurate when it is used with actual data and measurements. Also, the more actual measurements properly applied to calibrate a model, the more accurate the model will be.

Advantages of Models

Bross (1953) identified the following advantages of models:

- A model provides a frame of reference for considering a problem.
- Developing a model points out information gaps, and thus suggests needed research.
- A model brings out the problem of abstraction in complex systems, and uncovers questions that might not otherwise be raised. It develops understanding.
- A model, once expressed, provides relatively easy manipulation of components and a basis for comparison.
- A model offers a relatively inexpensive way to make predictions.

Disadvantages of Models

- Most models are only effective under certain specified conditions (Chapman and Dunin, 1975).
- Models involve gross simplifications of the true physical system that they represent.
- Time scales are significantly compressed. Observations made over many years in the physical system are reproduced in a much shorter period of time.
- Models use a number of mathematical or graphical representations to describe various hydrologic and hydraulic concepts, each of which is considered to be relevant to the overall hydrologic response of the catchment.
- Data inputs to the model usually apply to discrete time intervals and are not continuous. Consequently, the model output is affected by the size of the time interval used for the input data.

Selecting Models and Modeling Protocols

Hydrologic models can be used in two ways:

1. to assess the existing hydrology and water-quality conditions of a water resource, and
2. to predict future hydrology, which may develop as a result of changes in land use, climate or any other physical alteration to the environment.

Models should be used with caution and within their span of applicability. Each model is developed for a specific purpose with certain underlying assumptions. Precautions should be taken that these assumptions are not violated. The end goal of a model is the successful prediction for the situation in which it is to be used. The final test is a comparison of the model results with independent data.

Monitoring is always essential. Modeling can never replace monitoring. However, modeling is usually an effective way to evaluate the nature of a problem. The data collected in monitoring can help improve modeling predictions and development. Modeling is feasible only for evaluating problems that are understood well enough to be expressed in concise, quantitative terms. As models are developed to represent complex hydrologic systems, assumptions are incorporated in each model. The equations and formulas used to represent a complex system are never complete, due to the complexity of the system. In some situations, modeling may not be feasible or necessary. Modeling a situation may help determine whether monitoring would be beneficial. Models are used for analytical convenience. As tools for addressing hydrological questions, models do have limitations.

The Process

The steps in developing a monitoring and modeling protocol are:

1. Determine the issues of concern (what you want to find out).
2. Determine the available data.
3. Determine the available analytical tools and methods.
4. Determine the project constraints.
5. Determine the additional data needs.
6. Determine the acceptable levels of assurance within project constraints. If assurance levels are acceptable, proceed; if not, return to step 1.

Model Selection

The following points should be considered when choosing a model:

- What model is best for solving a particular problem in a particular location?
- What are the data requirements for both model and problem?
- What computer hardware and staff are required?
- What documentation is available?
- How much will it cost to apply the model?
- How accurate will the model be in representing the real world?

Basic Criteria for Evaluating Models (from Baker and Carder, 1976)

In selecting a model, one must consider (1) the ease of running the model and interpreting the results, (2) availability of data, (3) availability of models, (4) applicability to land-use activities, (5) applicability to broad geographic areas and (6) accuracy of prediction.

1. Ease of running the model and interpreting the results

- user friendliness by field-level user
- skills required
- ease of interpreting results
- type of results displayed
- assumptions required by the model

2. Availability of data

- ability to use readily available or estimated data rather than exotic parameters
- ability to handle small and variable time increments
- ability to substitute data parameters
- kinds of input data needed
- data accuracy
- data resolution

3. Availability of models

- accessibility of system and support to train users
- cost to operate and number of runs needed to provide data necessary to make management decisions

4. Applicability to land-use activities
- ability of model to represent common alternative management activities
- sensitivity to change in management activities
- number of parameters predicted

5. Broad geographical areas
- ability of the model to operate in diverse hydrologic areas
- extrapolation of the model

6. Accuracy of prediction
- ability to predict relative change and absolute effects
- need to calibrate model
- ability to estimate recovery rates of various types of disturbances
- accuracy in predicting range of events (*i.e.,* high and low)
- precision of the model's predictions
- percent error between actual and predicted values for volumes, peak discharge and time to peak for both water and sediment

Model Verification

A model should generally be verified by running the model against known conditions to compare modeled versus monitored results. This type of analysis is much more difficult to do accurately than it would first appear. Many modelers warn against this type of verification, stating that certain models are better used for comparison projections than for finding exact values.

Monitoring error or interpretation of monitored data can be one of the main sources of error in model verification. Rainfall can vary significantly within short distances, even fractions of a mile. If monitoring stations do not cover the entire basin, assumptions must be made about the distribution of rainfall in the basin. Grab samples do not show variability of concentration with flow unless flow data are correlated with concentration and a significant number of samples are taken. Any averaged or composited sample methods tend to miss the extreme events. Flow-weighted mean samples depend on good sample values for each representative unit of flow. Small flow-measurement errors or unrepresentative sample values can significantly affect any loading estimate.

The variation can be random or correlated with other factors. Flow almost always correlates with loading. But concentration of a parameter may vary directly or inversely with flow. The assumptions made about variability such as this can affect the model output considerably.

Random judgment errors or estimation errors can accumulate or cancel each other out with a sufficient number of trials. Systematic errors, such as using the highest possible values, may be desirable for "worst-case scenarios" but they also tend to multiply in an unrealistic manner if not properly utilized.

Sensitivity Analysis

Sensitivity analysis tells us how much the model changes the results when specific assumptions are changed. Most models rely on hydrologic components, such as rainfall and runoff predictions. These factors can be correlated to pollutant concentration, loading and expected treatment in stormwater-treatment facilities. Even if the model is appropriate for the application, there may be variables that must be estimated. For example, one of the primary variables, with regard to hydrologic analysis, is the runoff coefficient utilized by the various models. The effect of changing these variables can be significant especially when there may be a variety of possible future conditions.

Analysis/Interpretation of Results

Clearly, the key task in any modeling study is the analysis and interpretation of the model outputs.

Since models are simply tools for a quantitative, systematic analysis of specific environmental problems or issues, they do not provide simple “yes” or “no” answers to managers, regulators or decision-makers. Rather, they usually provide detailed information about the expected response of the system to a given perturbation in order that a more informed, objective decision can be made. The computer output generated by a model must be analyzed and interpreted in a logical and consistent fashion to answer the decision-maker’s questions, “What do the results mean?” and “How accurate and reliable are they?”

To understand the true meaning of modeling results within a decision-making framework, both the assumptions of the analysis and accuracy of expectations (*i.e.,* reliability) must be clearly defined. Both of these considerations are difficult, if not impossible, to discuss in general terms without discussing the specific characteristics of the particular model. However, assumptions usually are included, and required, both in how the model is configured or designed and how it is applied. Thus, a model may be used in many applications, with the same set of model assumptions common to all applications, while the application assumptions may differ from one case to another. The decision-maker or analyst must be aware of both kinds of assumptions and their associated limitations to appreciate the validity of the modeling results.

The accuracy associated with the results of modeling studies depends on the model used, the accuracy of the input data, the characterization of the environmental system being simulated, and the expertise/experience and resources available to the model user. Decision-makers must understand that all these factors determine the ultimate accuracy and reliability of the model results. Even under the best circumstances, the model results should be considered estimates or approximations, since the model itself is an approximation of a real environmental system.

This does not detract from the utility of models; it simply emphasizes the use of models as tools. It is also a very valuable learning tool for understanding the critical factors that determine the behavior of the simulated system. With this knowledge, the system can be better managed.

Most models are often more accurate in a relative sense, than in an absolute sense. That is, when models are used to compare alternatives (such as management or control options), the relative differences predicted between alternatives are sometimes more reliable than an absolute value predicted for any one alternative. Models are often used to evaluate these relative differences. When absolute values are needed, such as when estimating the probable exposure concentrations of a chemical needed for comparison with drinking water or health-effects levels, model results should be supplemented with sensitivity and/or uncertainty analysis in order to analyze the potential "real-world" variability about the model-predicted values. In other words, consideration of the uncertainty of the simulated results is at least as important as are the results themselves in any decision-making process.

8.20 STORMWATER RUNOFF AND PEAK DISCHARGE

A wide variety of stormwater-runoff models exist. Quantity models vary from those that estimate peak discharges for a single summer storm to those that provide continuous streamflow simulation for months and years, summer and winter. This chapter outlines the basic components or processes included in stormwater-watershed modeling and attempts to address assumptions associated with the various processes. While stormwater models can be very useful in many situations, other methods, such as gage data statistical analyses or peak discharge regression equations, should also be considered.

Watershed or catchment runoff models combine various mathematical relationships representing processes or components of the hydrologic cycle to simulate peak flows or flow hydrographs. Measured data to varying degrees are used as part of individual components. Assumptions are made by the model and modeler that dictate how well the simulated processes simulate the result to be achieved. Errors associated with measured data will also impact the ability of the model to reliably produce the desired simulation.

Federal agencies, such as the U.S. Army Corps of Engineers (COE), U.S. Department of Agriculture Natural Resources Conservation Service (NRCS, formerly the SCS, or Soil Conservation Service), the U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Service (USGS) have developed much documentation related to models, methods used and assumptions involved. Documentation, technical publications and models are electronically available from agency Internet sites: http://www.wrc-hec.usace.army.mil/ for the COE Hydrologic Engineering Center (HEC) and http://www.wcc.nrcs.usda.gov/ for the NRCS National Water and Climate Center (WCC). Web search engines can also lead the user to extensive documentation on models and their use.

General

Single-event rainfall-runoff models, such as TR-20 and HEC-1, simulate streamflow hydrographs at locations throughout a watershed. These models are generally used to simulate the watershed-runoff characteristics of a single-precipitation event of a specific frequency and duration.

Single-event rainfall-runoff models generally operate in the following manner: The precipitation event is first described in terms of total volume, time and area of distribution. Losses, consisting of interception and infiltration, are simulated and subtracted from the precipitation, resulting in direct runoff or rainfall excess. Direct runoff is transformed into a direct runoff hydrograph usually by unit hydrograph methods. Base flow is simulated and added to the direct runoff hydrograph, resulting in the total runoff hydrograph. The total hydrograph is routed downstream through a reservoir or channel reach, as needed to produce the downstream hydrograph. Hydrographs from smaller watersheds are combined as needed to simulate the flow hydrograph at locations throughout the watershed or basin.

Continuous models, such as SWMM or HSPF, continuously account in time for climate and watershed processes, usually in a more comprehensive manner than single-event models.

Precipitation

Whether it occurs as rain or snow, precipitation is the principal source of surface runoff in small watersheds and is variable over time and area. The areal of distribution of the storm and the time distribution of rainfall throughout the duration of the storm are two major factors, in addition to the total amount, or depth, that affect the peak rate of runoff.

In calibration and especially in verification, assumptions made to distribute the measured rainfall over the watershed and throughout the time distribution of the precipitation event may greatly impact the simulation results. The farther the precipitation-monitoring station is from portions of the watershed, the less likely the data from the station will adequately represent the depth or time distribution that actually occurred in that portion of the watershed.

The storm line distribution can be thought of as a measure of how the rate of rainfall (intensity) varies within a given time interval. For example, in a given duration of rainfall, a certain depth of precipitation will have been measured or obtained from records. However, the intensity throughout the entire period varies considerably and is not constant. When the intensity has not been measured or is not available from records for the precipitation period, or duration, assumptions will have to be made as to the variation in intensity. Generally, the greatest intensity is placed from early in the storm to near the center of the storm period.

The size of the storm is often described by the length of time over which precipitation occurs (the duration), the total amount of precipitation occurring (the depth) and how often this same storm might be expected to occur (the frequency or return period). Thus, a 100-year, 24-hour storm can be thought of as a storm producing the amount of rain in 24 hours with a 1% chance of occurrence in any given year.

For design and analysis purposes, a design rainfall depth, duration and frequency are selected and used in the model. The simulated hydrographs and the runoff results are generally assumed to have the same frequency and duration of the design rainfall. Different duration events will generally produce different runoff results and the modeler must assume which duration is appropriate for design or analysis. Assumptions about the time distribution of these statistical events must also be made. The COE and the NRCS have published procedures for developing synthetic time distributions and incorporating them into analyses.

Losses

Losses are that portion of the total precipitation that does not contribute to runoff. Initial losses and infiltration are principal losses subtracted from the total precipitation by typical single-event models. Initial losses include water held in the vegetation canopy, water stored in surface depressions and water lost to evapotranspiration. Infiltration includes gravity processes and capillary (suction) due to soil characteristics. Land use, soil type and the hydrologic condition of the watershed at the start of the storm are factors that impact the amount of losses. Continuous-event models tend to simulate and account for infiltration and its impact on soil moisture and groundwater as opposed to considering it a loss.

1. Soil Type

Different soil types have different infiltration characteristics. Fine-textured soils, such as clay, generally produce a higher rate of runoff than do coarse-textured soils, such as sand. In general, the higher the rate of infiltration, the lower the quantity of stormwater runoff.

Soils have been divided into groups called “hydrologic soil groups” (HSGs) to describe their potential to produce runoff. HSGs for various soils are identified in soil surveys published by the NRCS. These groups are based on infiltration and transmission rates. Soils are classified into HSGs to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The infiltration rate is the rate at which water enters the soil at the soil surface. It is controlled by surface conditions. The HSG also indicates the transmission rate — the rate at which the water moves within the soil. This rate is controlled by the soil profile. Musgrave (USDA, 1955) first published approximate numerical ranges for transmission rates shown in the HSG definitions.

The four hydrologic soil groups used in measuring runoff potential are:

Group A: Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well- to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 inch per hour).

Group B: Group B soils have moderate infiltration rates when thoroughly wetted. They consist chiefly of moderately deep to deep, moderately well- to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 inch per hour).

Group C: Group C soils have low infiltration rates when thoroughly wetted. They consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 inch per hour).

Group D: Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 inch per hour).

Disturbed soil profiles

As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the following table to determine HSG according to the texture of the new surface soil, provided that significant compaction has not occurred (Brakensiek and Rawls, 1983):

Table 8.20-1

Hydrologic Soil Group	Soil textures
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay

Drainage and Group D Soils

Some soils in the list are in group D because of a high water table that creates a drainage problem. Once these soils are effectively drained, they are placed in a different group. For example, Ackerman soil is classified as A/D. This indicates that the drained Ackerman soil is in group A and the undrained soil is in group D.

Consideration should be given to whether heavy equipment has or will compact the soil significantly more than natural conditions; whether much of the pervious area is barren with little sod established; and whether grading has mixed the surface and subsurface soils, causing a completely different hydrologic condition. Any one of the above can cause a soil normally in hydrologic group B or C to be classified in group C or D.

Partsch *et al.* (November-December 1993) found that the compaction of the soil significantly affected infiltration amounts and patterns, sometimes more than 20 years after compaction had occurred. Pitt (1994) observed significantly higher rates of runoff (sometimes as high as impervious surfaces) from lawns, playfields and other areas with compacted soil. Site-specific infiltration data or conservative estimates of infiltration rates should be used in urban areas.

Soil maps are extremely useful. However, soil types can be highly variable, especially in rapidly developing urban areas where soils may be removed or otherwise disturbed by human activity. Inspection by professionals and infiltration studies may be useful to verify the soil types related to a specific watershed. Disturbed urban areas can have highly variably runoff rates in most soil types, even after vegetation has been re-established.

2. Land Use (surface cover)

The type of cover and its condition affects runoff volume through its influence on the infiltration rate of soil. For a given soil type, disturbed land yields more runoff than forests or grassland. This is because the foliage and its litter maintain the soil's infiltration potential by preventing the sealing of the soil surface by the impact of the raindrops. Also, some of the raindrops are retained on the surface of the foliage, increasing their chance of being evaporated back to the atmosphere. Some of the intercepted moisture takes so long to drain from the plant down to the soil that it is withheld from the initial period of runoff. Foliage also transpires moisture into the atmosphere, thereby creating a moisture deficiency in the soil that must be replaced by rainfall before runoff occurs.

Vegetation, including its ground litter, forms many barriers along the path of the land, which slows the water down and reduces its peak rate of runoff. Covering areas with impervious material reduces storage and infiltration and thus increases the amount of runoff.

3. Antecedent Moisture Content

The soil moisture content also affects the runoff from a storm. Soil moisture may come from precipitation, ground water movement, or previous runoff and infiltration. The infiltration rates and runoff rates of all soils are affected by climatic conditions, such as freezing. Regardless of this hydrologic soil group, frozen soils can exhibit rapid runoff rates. Low soil temperatures typical of the colder seasons decrease rates of infiltration and thereby increase the volume of runoff. Rains on frozen ground may cause the largest runoff of the year.

4. Temporary and Depressional Storage

A considerable amount of surface runoff may be retained in temporary or depresssional storage in wetlands or on very flat areas where ponding occurs, thus reducing the rate at which runoff will occur.

Hydrograph Development

Unit hydrograph methods are generally used to transform the direct runoff volume into the direct runoff hydrograph. Unit hydrographs reflect the time-distribution characteristics of flow movement through the watershed or subwatershed. Unit hydrographs can be developed from stream gage data if these data are available for the watershed. Watershed size and shape and land and channel slope and length are characteristics that influence the size and shape of the unit hydrograph.

Time of concentration, lag time or travel time are key parameters used by these methods to shape the runoff volume into a unit hydrograph characteristic of the watershed. Synthetic unit hydrograph methods are available in most models and are commonly used in rainfall runoff modeling. SCS, Snyder and Clark are typical methods in common use.

Time of concentration is the time that it takes water to travel from the most distant part of the watershed to the point of interest. The time of concentration affects the peak rate of runoff and the shape of the hydrograph. Hydrology textbooks describe several methods to calculate time of concentration.

Base Flow

The streamflow hydrograph is usually comprised of both overland flow, represented by the direct runoff hydrograph, and subsurface flow, commonly called “base flow.” It is dependent on the hydrogeology in the vicinity of the stream and ground water levels at the time of the precipitation event. While methods exist to estimate base flow from analysis of stream gage flow records, runoff models use only very approximate methods to account for this portion of the total hydrograph. The importance of this parameter is generally less when simulating large-storm events; however, it becomes increasingly important as smaller-storm events are considered. It also can be a significant consideration when calibrating and verifying with actual streamflow events.

8.30 FLOW ROUTING

Flow routing is the technique used to simulate the changes that occur to a streamflow hydrograph as it moves through a river reach or reservoir. The effects of storage and flow resistance of the reach are reflected by changes in the shape and timing of the hydrograph as it moves from upstream to downstream. As movement proceeds downstream, the peak is attenuated and the hydrograph shape broadens. The basic premise used in any flow-routing procedure is that the total inflow is equal to the total outflow plus the change in storage.

Flow routing can be grouped into two different types: lumped flow routing and distributed flow routing. Lumped, or hydraulic routing, discretizes the system in the time domain (flow is calculated as a function of time at one location), while distributed, or hydraulic routing, discretizes the system in both the time and space domains (flow is calculated as a function of space and time throughout the system).

Chow *et al.* (1988) presents a detailed discussion on the assumptions and methodology of reservoir flow routing, which is summarized below.

For a hydrologic system, inflow, outflow, and storage are related by the continuity equation:

$$\frac{dS}{dt} = I(t) - Q(t) \qquad \textbf{(Equation 8.30–1)}$$

where: I = Inflow, [L^3/T],
Q = Outflow, [L^3/T],
S = Storage, [L^3/T]
t = Time

For a pond, the inflow hydrograph (*I(t)*) is known, leaving two unknowns in Equation 8.30–1: outflow (*Q(t)*) and storage (*S*). Since it is not possible to solve this equation for outflow directly, a function must be developed to relate inflow, outflow, and storage.

One of the more widely used methods for routing flow through detention or sediment basins is the Level Pool Routing (also known as Modified Puls or Storage Indication Method). This flow-routing procedure is based upon solving the continuity equation for small time steps. This method is most commonly used for routing through a reservoir, lake, pond or wetland. It is less frequently used for channel routing by assuming a series of small reservoirs that comprise the river reach.

In general, storage is a function of inflow, outflow, and the time derivatives of inflow and outflow. The level pool routing method assumes that storage is a nonlinear function of outflow

(Q) only, and can be applied to basins with an invariable relationship between outflow and storage. Such basins have:

- a horizontal water surface,
- a pool that is wide and deep compared to the length of the pool in the direction of flow,
- a low flow velocity,
- an outlet with a fixed discharge for a given pool elevation, and
- an uncontrolled outlet or an outlet that is unmoveable (a weir) or held at a fixed position (dam gates).

For a pond with a horizontal water surface, the outflow is a function of the hydraulic head above the outlet, or the water elevation in the pond. Storage for such a pond is also a function of water surface elevation, or depth of water in the pond. Combining these two relationships results in an invariable function where storage is solely a nonlinear function of pond outflow, which is illustrated graphically in Figure 8.30–1 and mathematically as:

$S = f(Q)$ **(Equation 8.30–2)**

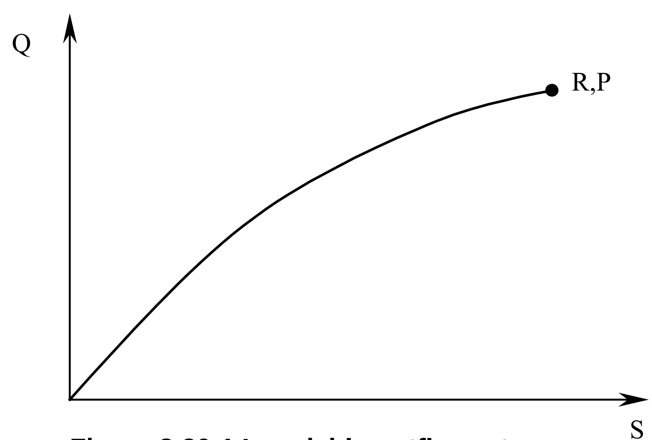

Figure 8.30-1 Invariable outflow–storage relationship (adapted from Chow *et al.,* 1988)

It follows that the peak outflow (P in Figure 8.30-2) from such a pond occurs when the inflow hydrograph intersects the outflow hydrograph, as the maximum storage occurs when the change in storage with respect to time, or the first derivative of the storage function, is zero.

$dS / dt = I(t) - Q(t) = 0$ **(Equation 8.30–2)**

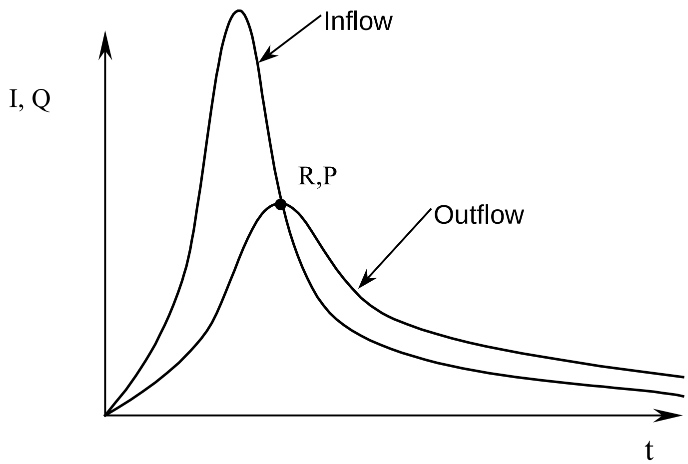

Figure 8.30-2 Hydrographs for an Invariable Storage Pond (adapted from Chow et al., 1988)

Ponds with a variable relationship between outflow and storage tend to be long and narrow — approaching the shape of a river or stream. The water surface profile of such a pond may be significantly curved due to backwater effects. The retarding of wave propagation in the reservoir from backwater causes the peak outflow of the reservoir to occur after the inflow and outflow hydrographs intersect, as shown in Figure 8.30–3. Figure 8.30–4 illustrates that the backwater effect results in a relationship between storage and outflow that is not single–valued, but exhibits a curve in the form of a single or twisted loop, depending on the storage characteristics of the system. If the backwater effect is not significant, and the graph of storage versus outflow results in a loop which is fairly narrow in width, the loop relationship may be replaced with an average curve, which is represented by the dashed line in Figure 8.30–4. This approximation will allow the use of the level pool method of flow routing through the pond.

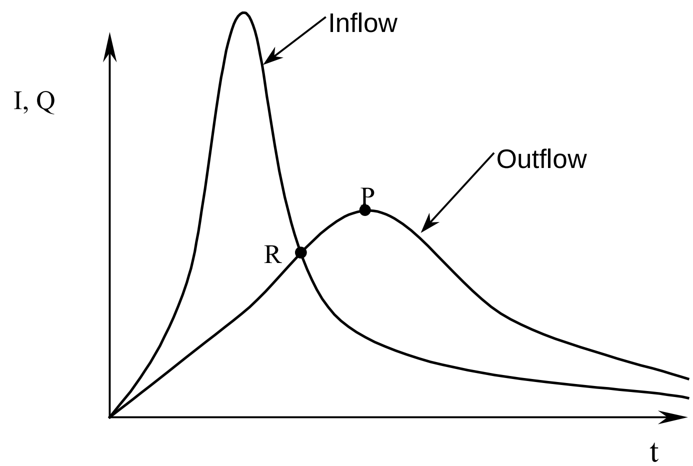

Figure 8.30-3 Hydrographs for a Variable Storage Pond (adapted from Chow et al., 1988)

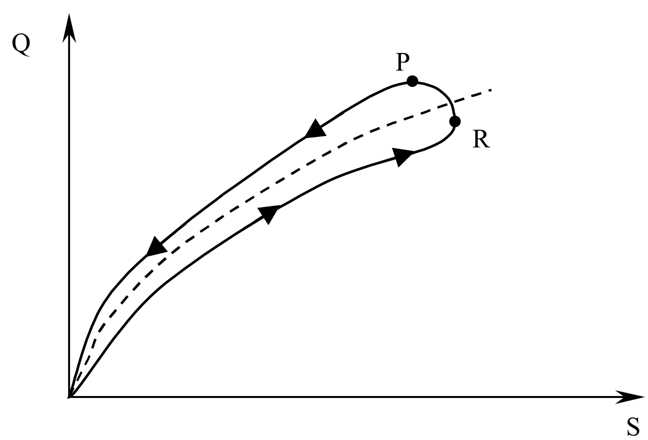

Figure 8.30-4 Variable Outflow–Storage Relationship (adapted from Chow et al., 1988)

The difference in shape of the inflow and outflow hydrographs shown in figures 8.30–2 and 8.30–3 is due to the effect of storage in the pond shifting the position of the centroid of the hydrograph. Figure 8.30–5 illustrates the time of redistribution of the hydrograph, which is the shifting in time of the centroid of the inflow hydrograph to the centroid of the outflow hydrograph from the effect of pond storage.

In a pond with a long axis in the direction of flow, the time for the flood wave to travel through the pond may be of such duration that the centroid of the hydrograph may be shifted by a time period longer than the time of redistribution. This additional time is illustrated in Figure 8.30–6 as the time of translation, which does not change the shape of the hydrograph, but does change the position. The total time of flood wave movement illustrated in Figure 8.30–7 is the sum of the time of redistribution and the time of translation.

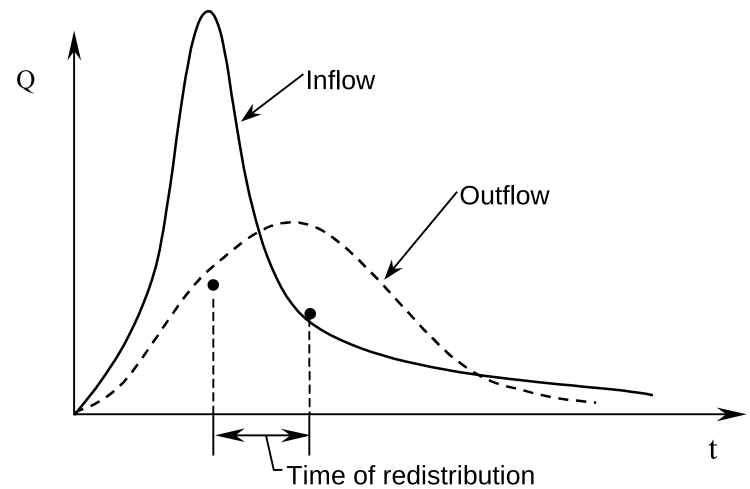

Figure 8.30-5 (adapted from Chow et al., 1988)

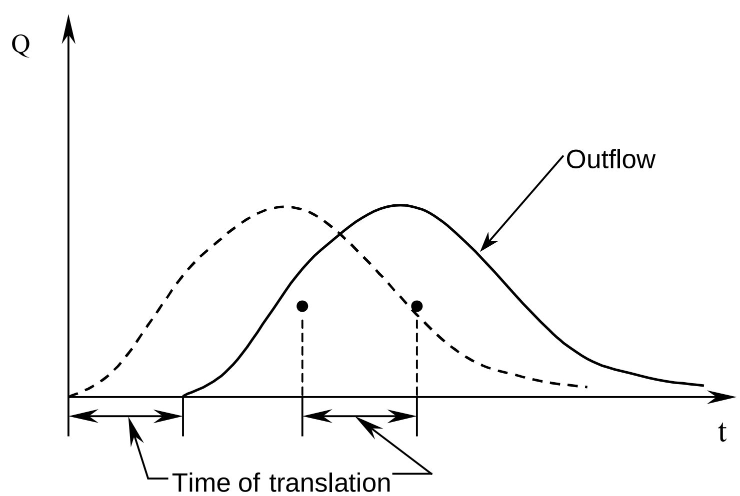

Figure 8.30-6 (adapted from Chow et al., 1988)

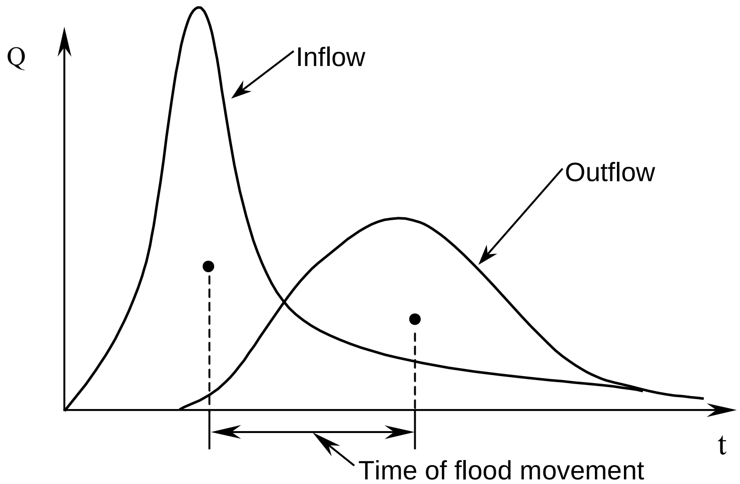

Figure 8.30-7 (adapted from Chow et al., 1988)

Level Pool Routing Methodology

The level pool routing procedures used to route an inflow hydrograph through a pond with a horizontal water surface can be divided into two categories: graphical methods and tabular methods. Graphical procedures are quicker and easier to execute by hand, while tabular methods are more complex but are conducive to computerization. With the increase in power and availability of personal computers, the tabular methods are replacing graphical methods as the commonly used method of flow routing.

The graphical level pool routing method involves breaking the time horizon of the inflow and outflow hydrographs into equal intervals of duration Δt (*i.e.,* Δt, $2\Delta t$, $3\Delta t$, …, $j\Delta t$, $(j+1)\,\Delta t$, as shown in Figure 8.30–8.

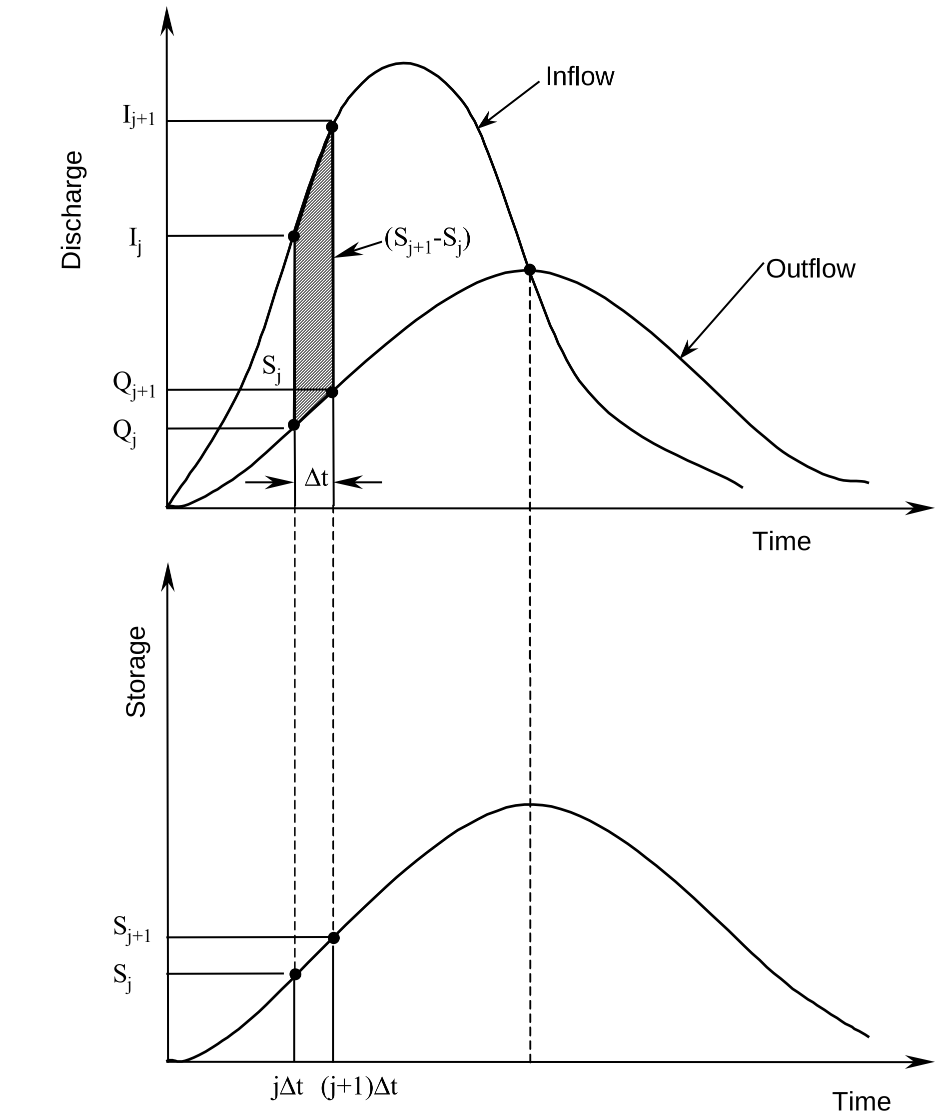

Figure 8.30-8 Change in storage during level pool routing.

The continuity equation (Equation 8.30–1) is integrated over each time interval, which for time interval j is:

$$\int_{S_j}^{S_{j+1}} dS = \int_{j\Delta t}^{(j+1)\Delta t} I(t)dt - \int_{j\Delta t}^{(j+1)\Delta t} Q(t)dt \qquad \textbf{(Equation 8.30–3)}$$

The inflow and outflow rates at the beginning of time interval j are I_j and Q_j, while the inflow and outflow rates at the end of time interval j are I_{j+1} and Q_{j+1}. By definition, the integral of a function is the area under the curve of the function. Therefore, the area under the inflow hydrograph of the slice in time from j to $j+1$ is the volume of inflow to the pond during timestep j. Likewise, the area under the outflow hydrograph of the slice in time from j to $j+1$ is the volume of outflow from the pond during the timestep j. From Equation 8.30–3, it follows that the storage in the pond during timestep j is the difference in volume of the inflow and outflow hydrographs shown as the cross–hatched area in figure 8.30–8.

Assuming that the change in inflow and outflow over the timestep is linear (the cross–hatched area in Figure 8.30–8 is a trapezoid), Equation 8.30–3 can be solved for the change in storage over the time interval j by subtracting the area under the outflow curve from the area under the inflow curve:

$$S_{j+1} - S_j = \frac{I_j + I_{j+1}}{2}\Delta t - \frac{Q_j + Q_{j+1}}{2}\Delta t \qquad \textbf{(Equation 8.30–4)}$$

Appreciable deviations from the linearity assumption require a shorter timestep.

In Equation 8.30–4, I_j and I_{j+1} are determined from the inflow hydrograph, Q_j and S_j are determined in the previous timestep, and Δt is fixed. The variables remaining as unknowns are S_{j+1} and Q_{j+1}. With one equation and two unknowns, another function must be developed to relate outflow (Q) to storage (S). By introducing a third variable — water surface elevation (H) — a graphical relationship between outflow and storage can be developed.

Solving 8.30–4 for storage and outflow at the j+1 time interval gives:

$$\left(\frac{2S_{j+1}}{\Delta t} + Q_{j+1}\right) = \left(I_j + I_{j+1}\right) + \left(\frac{2S_j}{\Delta t} - Q_j\right) \qquad \textbf{(Equation 8.30–5)}$$

By developing curves or tables which relate water surface elevation to storage and to outflow rate, a subsequent curve or table can be constructed which relates outflow rate to the unknown term $2S/\Delta t + Q$. This process is illustrated graphically in Figure 8.30–9. The relationship between pond water surface elevation and pond storage can be developed by digitizing curves of constant elevation of the pond bottom from the topographic design plan for the pond. The rating curve for the pond outlet can be determined from equations for standard outlets, such as culverts and weirs, or by direct measurement. Direct measurement involves measuring the cross-sectional area of water flow and flow velocity at the outlet utilizing a current meter for incremental water elevations.

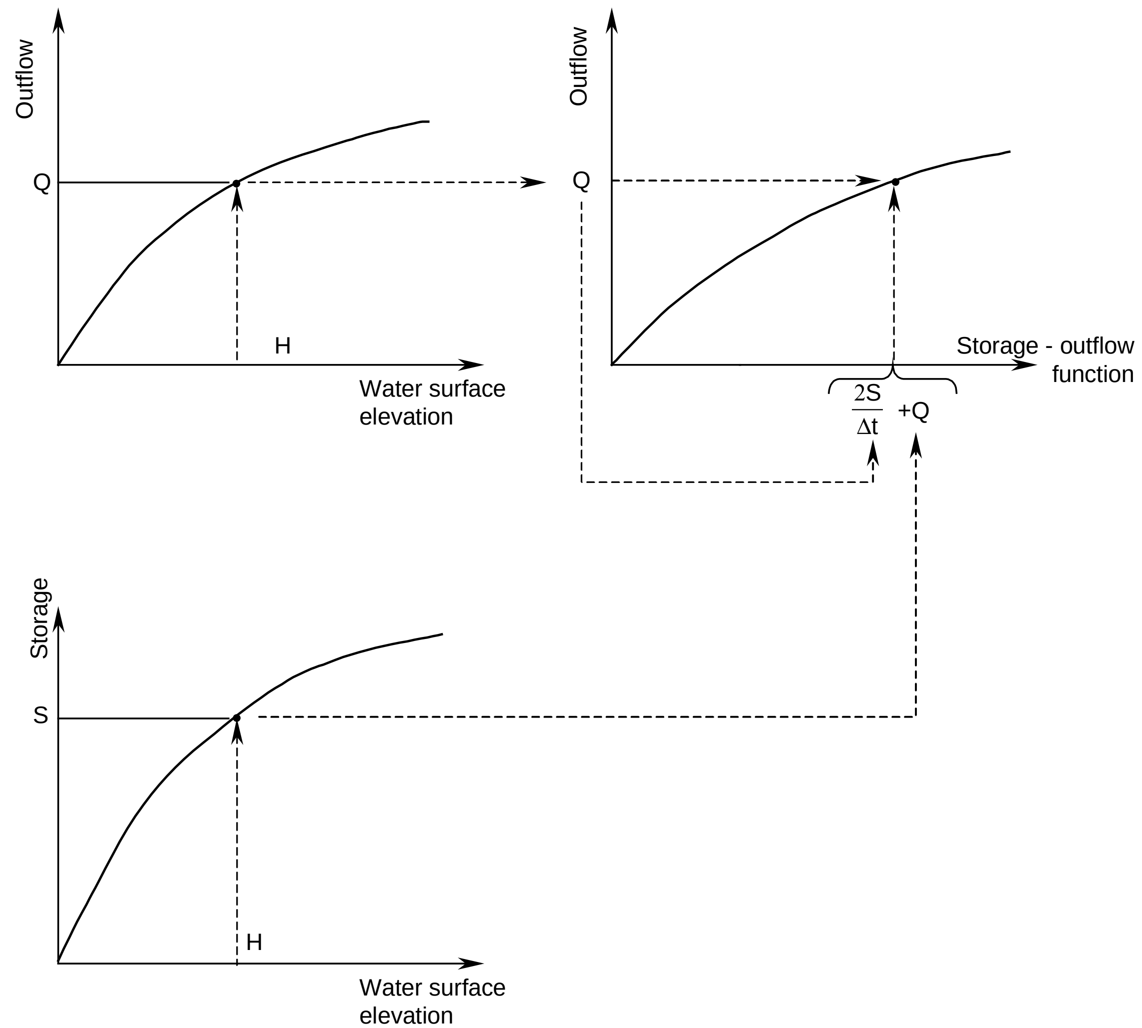

Figure 8.30-9 Development of a storage-discharge function

At time interval j, all the terms in the right–hand side of Equation 8.30–5 are known, so the value of $2S_{j+1}/\Delta t + Q_{j+1}$ can be calculated. Utilizing the preconstructed table or curve (Figure 8.30–9) of outflow (Q) versus the storage–outflow function ($2S/\Delta t + Q$), the outflow rate at timestep $j+1$ (Q_{j+1}) is determined by either reading the value directly off of the curve, or in the case of tabular values, linear interpolation. For the next time step, the unknown value $2S_{j+1}/\Delta t - Q_{j+1}$ in the right-hand side of Equation 8.30–5 is calculated by using the following equation:

$$\left(\frac{2S_{j+1}}{\Delta t} - Q_{j+1}\right) = \left(\frac{2S_{j+1}}{\Delta t} + Q_{j+1}\right) - 2Q_{j+1} \qquad \textbf{(Equation 8.30–6)}$$

This procedure is repeated for the duration of the routing period.

Models generally offer one or more channel-routing procedures. They range in complexity from the complete solution of the Saint Venant equations of motion to solutions solving only the portion(s) of the equations deemed most important and to those employing approximate methods. The TR-55 graphical method is a short-cut Storage-Indication Method of reservoir routing that is based on investigation of average storage and routing effects from many structures. Muskingum, Muskingum-Cunge and Modified ATT-KIN are some methods based on portions of the equations of motion. As computer capabilities increase, more models, such as SWMM, are including complete solution methods as data needs are often not substantially increased over some of the more rigorous partial solutions. Hydraulic routing models, such as UNET or FLOODWAV, focus only on routing, and hydrographs from recording gages or other models are a necessary input.

In routing, the shape and volume of the inflow hydrograph are as important as the peak discharge. For this reason, peak discharges derived from runoff methods intended only to predict peak discharge should be used with caution.

8.40 MODEL DESCRIPTIONS

Many methods for computing runoff, peak discharge and other information useful in designing stormwater-management systems have been developed. Table 8.40-1 shows the relative suitability of some models for various types of analysis and gives short descriptions of the major nonproprietary computer models that are available. A description of some of the more specialized water-quality-analysis models is also included later in this section.

Table 8.40-1 Relative suitability of some stormwater models

Model	Water Quality Analysis		Simulation Type[a]	Drainage Area up to 20 Acres	Drainage Area 20 to 2,000 Acres	Drainage Area 3 to 20 Square Miles	Peak Discharge and Runoff Volume	Hydrograph Produced?
	Pollutograph	Average Annual Loading						
AnnAGNPS	No	Yes	C	Yes	Yes	Yes	Yes	No
CREAMS/ GLEAMS	Yes	Yes	C	Yes	Yes	No	Yes	Yes
DETPOND	No	Yes	ME	Yes	Yes	Yes	Yes	Yes
HEC1	No	No	ME	No	Yes	Yes	Yes	Yes
HSPF[b]	Yes	Yes	C	Yes	Yes	Yes	Yes	Yes
P8[b]	Yes	Yes	ME	Yes	Yes	Yes	Yes	Yes
Rational Method	No	No	SE	Yes	No	No	No	No
SLAMM	No	No	ME	Yes	Yes	No	Yes	Yes
SWMM[b,c]	Yes	Yes	C, ME	Yes	Yes	Yes	Yes	Yes
TR20	No	No	ME	Yes	Yes	Yes	Yes	Yes
TR55-Graphical	No	No	SE	Yes	Yes	No	No	No
TR55-Tab. Method	No	No	SE	Yes	Yes	No	Yes	Yes

a SE = single event, C = continuous, ME = multievent

b It is recommended that these models be used in conjunction with a water quantity model for large-storm peak discharge designs.

c Also allows analysis of reverse flow, which can be important in two-cell stormwater-treatment systems.

AnnAGNPS (Annualized Agricultural Nonpoint Source Pollution Model)

Description

AnnAGNPS is a continuous simulation surface water pollutant transport model that estimates the amount of sediment, nutrients, and pesticides in runoff from land areas and in streams. This model was developed for agricultural watersheds in Minnesota, and has also been tested in Nebraska and Iowa. It supersedes the predecessor to AnnAGNPS – AGNPS 5.0 – a storm event version of the model that is no longer distributed or supported. AnnAGNPS is a distributed simulation model and is implemented by dividing a watershed into irregularly shaped cells. The cells can be up to 10,000 acres in area, and the watershed can be of any size. Land use, topography, and soil type are assumed to be homogeneous within each cell. AnnAGNPS gives estimates of bed–and–bank, gully, and sheet–and–rill erosion in each of the particle sizes of sand, silt, clay, small aggregates and large aggregates. AnnAGNPS is also capable of handling point-source input from feedlots, waste-water-plant discharges, and streambank and gully erosion. It also represents the effects of impoundments on water quality at the watershed outlet. Output can be obtained by storm event, monthly, or on an annual basis. The model also has a source accounting capability that quantifies the amount of pollutants contained in runoff at any point of interest in the watershed, such as the watershed outlet, from individual cells upgradient in the watershed.

Uses and Applications

- Evaluates the effect of various BMPs on the downstream sediment, nutrient, and pesticide load.
- Simulates the amount of soluble nutrients and chemical oxygen demand present in feedlot runoff.
- Predicts erosion for five particle sizes (sand, silt, clay, small aggregates and large aggregates).
- Predicts water quality and erosion on a cell, reach, and watershed basis.
- Incorporates the spatial variation of hydrologic, nutrient, and sediment processes when the watershed is divided into cells.
- Divides pollutant transport into soluble pollutants and sediment-attached pollutants.
- Source accounting feature creates the ability to rank individual cells based on impact to receiving water at watershed outlet.
- Soil erosion is determined using the Revised Universal Soil Loss Equation.
- Simulates snowmelt.
- Simulates changes in runoff pollutant concentrations due to conservation tillage, nutrient management, contour farming, and stripcropping on agricultural fields.

Input Data

Input data requirements are quite extensive for a continuous simulation. AnnAGNPS input consists of 34 categories of data for job control, landuse, topography, hydrology, soils and climate. The model can be run for a single-storm event, which reduces the required amount of input data significantly (to 24 sections). The development of topographic input data can be assisted by the use of a flownet generator which automates the task of developing stream reach and cell physical characteristics. The flownet generator, TopAGNPS, is based on the USDA–Agricultural Research Service Topographic ParameteriZation (TOPAZ) model, and allows the user to utilize existing

Digital Elevation Models (DEMs) for the development of topographic parameters. The program can also utilize a synthetic weather generator, Generation of weather Elements for Multiple applications (GEM), to develop a portion of the climatological input. Required input data can be obtained from the Minnesota Land Management Information Service (LL45 Metro Square, 7th and Robert, Saint Paul, MN 55101), Soil Survey Geographic (SSURGO) data base, USDA–NRCS soil surveys, field analysis, and United States Geographical Survey topographic maps and DEMs.

Output Available

- Runoff hydrology, sediment, nutrient, pesticide and chemical oxygen demand.
- Output available at the outlet of any cell or for any reach in the watershed.
- Daily, monthly, or yearly values are available.

Limitations

- AnnAGNPS is a comprehensive watershed model and as such the amount of input data required can become quite demanding with increasing watershed size and/or resolution.
- The development of topographic input data utilizing the flownet generator with DEMs is cumbersome.
- Wetland and lake nutrient processes are not simulated.
- Agricultural field tile drainage is not simulated.
- Documentation is not completed.

Future Modifications

- The interface of AnnAGNPS with Geographical Information Systems is being enhanced.
- Incorporation of a lake and a wetland model is under development.
- Completion of a one-dimensional, unsteady, advanced channel dynamics component that simulates streambank stability, bank erosion and channel evolution.
- Integration of Next Generation Weather Radar (NEXRAD) technology.

CREAMS (Chemicals, Runoff and Erosions from Agricultural Systems) GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)

Description

Chemicals, Runoff and Erosions from Agricultural Systems (CREAMS) is a continuous field-scale model developed by the U.S. Department of Agriculture – Agricultural Research Service (USDA–ARS) that simulates surface runoff, infiltration, evapotranspiration, erosion, sediment yield, and plant nutrient and pesticide delivery (Knisel, 1980). CREAMS can simulate aerial spraying or soil incorporation of pesticides, animal waste management, and alternative agricultural practices such as minimum tillage and terracing. The parameters needed for the model are physically measurable and *there is no calibration required for individual watersheds*.

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) was developed by the USDA–ARS to analyze the effects of pesticide and nutrient infiltration into the root zone of the soil profile (Knisel, 1993; Leonard, 1987; Leonard *et al.,* 1990). GLEAMS is an extension of CREAMS in that the hydrology, plant nutrient, and pesticide components of CREAMS were modified to simulate the movement of water, nutrients and chemicals through the root zone. The representation of the various management practices presented in CREAMS were also improved.

Uses and Applications

- CREAMS and GLEAMS represent soil processes with reasonable accuracy.
- CREAMS and GLEAMS simulate on a continuous basis, and also considers event loads.
- CREAMS and GLEAMS can simulate up to 20 pesticides at one time.
- CREAMS and GLEAMS can represent various agricultural BMPs.
- CREAMS and GLEAMS are not intended for use as an absolute pollutant prediction tool — they are most effective in comparative analysis, such as comparing pollutant loads under existing conditions to pollutant loads with BMPs implemented.

Input Data

Extensive data on meteorology, hydrology, soil properties, and chemistry of pollutants are required.

Output Available

An extensive output listing for hydrology, nutrient, and pesticide simulation results is available on a storm, monthly or annual basis.

Limitations

- CREAMS and GLEAMS require extensive data inputs.
- CREAMS and GLEAMS do not simulate pollutant movement in the saturated zone.
- CREAMS and GLEAMS can only be used on field-scale plots.
- CREAMS and GLEAMS do not simulate receiving waters.
- CREAMS and GLEAMS do not simulate in-stream process.
- CREAMS and GLEAMS data-management and -handling capacity is limited.

DETPOND

Description

DETPOND is a stormwater quality model developed by Robert Pitt and John Voorhees that is used for designing of detention ponds. Its purpose is to predict how much particulate solids a wet detention pond will remove from urban runoff. It allows the user to design a detention pond as both a water-quality-control device and a water-quantity-control device. It is both user friendly and flexible, allowing either user-defined or default parameters for many input variables.

DETPOND, Version 4, routes urban runoff to a detention pond. The rain events that generate runoff are entered either individually as single events or as an inflow hydrograph, or in a series. Runoff is generated from rain events using either the SCS Curve Number method, the combined runoff method, or from runoff volumes calculated using SLAMM. The detention pond routing algorithm is based on the storage-indication reservoir routing subroutine in HEC-1 and in TR-20. Pond particulate removal is based on the particle size distribution entering the pond and the theoretical upflow velocity of the water through the pond.

Uses and Applications

DETPOND is used for stormwater and detention pond design.

Input Data and/or Model Components

- State and area information
- Rainfall
- Runoff coefficients
- Particle size distribution
- Outlet size and type

Outputs Available

Outputs available from DETPOND include outflow and inflow, evaporation, storage and stage, and particle sizes removed.

HEC-1

Description

All ordinary hydrograph computations associated with a single recorded or hypothetical storm can be accomplished with the U.S. Army Corps of Engineers' HEC-1, Flood Hydrograph Package.

Uses and Applications

Capabilities of HEC-1 include rainfall, snowfall and snowmelt determinations; computations of basin-average precipitation from gages or hypothetical storms; unit hydrographs via direct ordinates or Clark, Snyder or SCS methods, or by kinematic wave transforms; hydrograph routing by level-pool reservoir, average lag, modified Puls, Muskingum, Muskingum-Cunge, and kinematic wave methods; and complete stream system hydrograph combining and routing. Best-fit unit hydrograph, loss rate, snowmelt, base freezing temperatures and routing coefficients can be derived automatically. HEC-1 may also be used to simulate flow over and through breached dams. Expected annual flood damage can also be computed for any location in a river basin.

Input Data and/or Model Components

Batch processing is employed and the sequence of input data records prescribes how the river basin is simulated. Basin simulation data records are structured by the user to reflect the topography of the basin.

Outputs Available

Text output includes immediate simulation results, summary results and error messages. Printer plot routines are provided. HEC-1 interfaces with HEC-DSS routines for storing, retrieving, graphing and tabulating data.

Limitations

Simulations provided by HEC-1 are limited to single-storm events because no provision is made for soil moisture recovery between storms. HEC-1 does not account for backwater effects from downstream reaches or reservoirs.

HSPF (Hydrological Simulation Program – Fortran)

Description

HSPF is a comprehensive package for simulation of watershed hydrology and water quality. It is an integrated program that simulates the hydrology and the behavior of conventional and organic pollutants in surface runoff and receiving waters. The Agricultural Runoff Management (ARM) model is used to describe the processes that affect the fate and transport of pesticides and nutrients from agricultural lands. Several main application modules are contained in HSPF: The PERLLND (pervious land) and IMPLND (impervious land) modules perform soil simulation for land surfaces and the RCHRES (reach/reservoir) model simulates the processes that occur in a single reach and at the bed sediments of a receiving water body (a stream or well-mixed reservoir). Extensive and flexible data management and statistical routines are available for analyzing simulated or observed time series data. The modules are arranged in a hierarchical structure that permits the continuous simulation of a comprehensive range of hydrologic and water-quality processes.

Use and Application

- Continuous hydrologic simulation can be done with HSPF.
- HSPF integrates the loading from nonpoint sources (including alternative control practices) and receiving water quality simulation into a single package.
- HSPF analyzes both point- and nonpoint-source loading.
- HSPF provides the option of using simplified or detailed representation of nonpoint-source runoff.
- HSPF performs risk analysis due to the exposure of aquatic organisms to the toxic chemicals present in receiving waters.
- HSPF incorporates agricultural management practices by changing parameter values.

Input Data and/or Model Components

HSPF requires extensive data along with meteorological and hydrologic data.

Outputs Available

The output of HSPF includes system variables, temporal variation of pollutant concentrations at a given spatial distribution, and annual summaries describing pollutant duration and flux. A summary of time-varying contaminant concentration is provided along with the link between simulated receiving water pollutant concentration and risk assessment.

Limitations

- HSPF needs calibration before it can be applied to a particular site.
- HSPF requires extensive data along with meteorological and hydrologic data.
- Two to three months are required to learn HSPF’s operational details.
- Cost associated with different BMPs is not linked to pollutant delivery.
- Computer costs for model operation and data storage can be a significant fraction (10-15%) of total application costs, depending on the extent to which the model will be used.

MFES (Minnesota Feedlot Evaluation System)

Description

MFES is the model developed to evaluate and rate the pollution potential of feedlot operations. It consists of two parts: (1) a simple screening procedure that evaluates the potential pollution hazard associated with the feedlot and (2) a more detailed analysis that is better able to identify feedlots that are not potential pollution hazards. Runoff is estimated using the SCS Curve number approach. The pollutant indicators are phosphorus and chemical oxygen demand. Currently, the MPCA uses this model in its feedlot permit program.

Uses and Applications

- MFES is an excellent screening tool.
- MFES evaluates different land-management practices.
- MFES considers both surface and ground-water pollution.
- MFES is a fast and effective tool.

Input Data

The input data, except the physical dimensions of the feedlot, are presented in the manual for the model.

Output Available

The pollutant delivery is present at the discharge point.

Limitations

- Runoff calculations are not valid for large areas (more than 100 acres).
- MFES does not deal with receiving waters.
- MFES handles potential pollution threats to ground water loosely.

NTRM (A Soil-Crop Simulation Model for Nitrogen, Tillage, and Crop Residue Management)

Description

Nitrogen, Tillage, and Crop Residue Management (NTRM) is a large, broad-based computer-simulation model for tillage, crop residue and nitrogen fertilizer management. The NTRM model is designed mainly to provide management assistance at the farm management and engineering levels. This model simulates physical, chemical and biological processes in the soil-water-crop continuum using integrated submodels for soil temperature, soil carbon and nitrogen transformations, unsaturated flow of water, crop and root growth, evaporation and transpiration, tillage, interception and infiltration, chemical equilibrium processes, solute transport and crop residues. The NTRM model is capable of seasonal and longer-term estimates of soil fertility and its effects on crop yield. Model validation and verification have been obtained for each submodel and for the overall model package. The NTRM model has been made user-friendly, and also has computer graphics capability.

Uses and Applications

- NTRM simulates physical, chemical, and biological processes in the soil-water-crop continuum.
- NTRM predicts the effect of soil environment on crop growth.
- NTRM serves as a tool for nitrogen-fertilizer management.
- NTRM can be used for long-term agricultural planning.

Input Data

With the NTRM model, extensive data are needed for individual submodels. Submodels that need input are the soil temperature model; carbon and nitrogen transformations in soil, unsaturated flow model; crop growth model; root growth model; till and surface residue and sensitive potential evaporation submodel; transpiration model; tillage model; model for simulating interception, surface roughness, depression storage and soil settling; chemical equilibrium model; solute transport model and the crop residue model.

Output Available

The outputs available from NTRM are related to crop yield and nitrogen availability in soil; for example, effect of tillage practices on crop yield, or initial soil nitrogen and fertilizer nitrogen. Outputs can be in the form of graphics, tables and homographs.

Limitations

- NTRM currently can only simulate corn growth.
- NTRM requires large data input.
- NTRM requires additional testing for many components of the model.

Pondsize

Description

Pondsize is a spreadsheet program that can be used to determine the volume and dimensions of a sedimentation basin to retain the runoff generated from a given precipitation event for a given land use. The program was written for the Lotus 1-2-3 spreadsheet program, but it can readily be imported into other spreadsheet packages. The equations presented in the report upon which the spreadsheet is based (Walker, 1987b) can also be solved manually.

Uses and Applications

The Pondsize program is used to determine the size and shape of a sedimentation basin to detain the runoff from a given precipitation event for a given land use.

Input Data and Model Components

- Twelve user inputs are required: watershed area, runoff curve number, connected impervious fraction of watershed, precipitation volume (2.5 inch recommended), antecedent moisture condition, pond maximum depth, aquatic bench width and slope, permanent pool sideslope, pond shape, length-width ratio, and pond top length.
- Pondsize uses the NRCS runoff curve number method to determine runoff from pervious areas and unconnected impervious areas (such as rooftops) for a single-precipitation event.
- The entire volume of runoff from connected impervious areas is routed directly to the pond without watershed retention.
- Pond shape can be either triangular (preferred), rectangular or elliptical.
- By varying the length-width ratio and the top length, the spreadsheet can be used iteratively to determine a pond volume that is greater than or equal to the watershed runoff volume. Alternatively, an “autofit” macro can be used which will determine a top length for the user for a given length-width ratio.

Outputs

- Pondsize calculates pond surface area, mean depth and volume.
- Pondsize determines dimensions of pond bottom, aquatic bench and pond surface.
- Pondsize produces plots of the pond in plan view and in cross section.

Limitations

- Runoff volume is determined for one homogeneous watershed. Variations in pervious landuse are lumped into one runoff curve number.
- Pondsize does not design the principal or emergency spillway.
- Pondsize does not provide for temporary flood prevention storage.

PRZM (Pesticide Root Zone Model)

Description

The PRZM model simulates the vertical movement of pesticides in the unsaturated soil, within and below the plant root zone, and extending to the water table. It uses generally available input data that are reasonable in spatial and temporal requirements. The model consists of hydrology and chemical transport components that simulate runoff, erosion, plant uptake, leaching, decay, foliar washoff and volatilization of a pesticide.

Uses and Applications

- Relates pesticide leaching to temporal variations of hydrology, agronomy and pesticide chemistry.
- Simulates snow hydrology.
- Performs simulation for pesticides applied to the soil surface or to plant foliage.

Input Data

Input data required include soil characteristics, meteorological data and pesticide information.

Output Available

Various output options regarding the fate of pesticide in the root zone are available.

Limitations

- Some parameters are difficult to estimate.
- Model calibration is limited.

P8 Urban Catchment Model (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds)

Description

The P8 Urban Catchment Model was developed by the Narragansett Bay Project (Providence, Rhode Island). It is used to predict the generation and transport of stormwater-runoff pollutants in small urban watersheds (Walker, 1990). It incorporates the algorithms of existing stormwater-runoff models, such as HSPF, SWMM, DR3M, STORM and TR20. Runoff from impervious areas is calculated directly from rainfall once depression storage is exceeded. Particle build-up and wash-off processes are obtained using equations derived primarily from the SWMM program. The SCS curve number equation is used to predict runoff from pervious areas. Water balance calculates percolation from the pervious areas. Baseflow is simulated by a linear reservoir. Without calibration, use of model results should be limited to relative comparisons. This menu-driven computer program runs on IBM-compatible personal computers, and includes extensive user interfaces, such as on-line help and look-up tables for input parameters.

Uses and Applications

The P8 Urban Catchment Model can be used for:

- selecting and sizing BMPs.
- surface water quantity routing.
- small urban area assessments.
- watershed-scale land-use planning.
- site planning and evaluation for compliance.
- simplified watershed-scale pollutant generation and transport simulations.
- routing through control structures.

Input Data and/or Model Components

The following are input data and/or components needed to run the P8 Urban Catchment Model:

- time series meteorological data
- land area
- impervious fraction
- SCS curve number
- BMP characteristics
- device (hydraulic) parameters for pond, basin, buffer, pipe, splitter and aquifer
- depressional storage

Outputs Available

Outputs available from the P8 Urban Catchment Model include:

- water and mass balances, removal efficiencies, mean inflow/outflow concentrations and statistical summaries by device and component;

- comparison of flow, loads and concentration across devices;
- peak elevation and outflow ranges for each device;
- sediment accumulation rates by device; and
- violation frequencies for event mean concentrations.

Limitations

The P8 Urban Catchment Model has some limitations:

- No snowfall, snowmelt, or erosion is calculated.
- Effects of variations in vegetation type/cover on evapotranspiration are not considered.
- Watershed lag is not simulated.
- Quantitative analysis should be checked using another method.

Rational Method

Description

Approximates the peak flow that results from a given rainfall intensity and duration. Used widely around the world on small rural and urban drainage basins.

Use and Applications

The Rational Method should generally be used for watersheds that are smaller than 200 acres.

Input data and/or model components

Input data and/or model components for the Rational Method include:

- Q_P = CiA
- Q_P = peak flow rate (cfs)
- C = runoff coefficient for drainage area
- I = rainfall intensity (inches/hour)
- A = drainage area (acres).

Outputs Available

Specific results of the Rational Method are peak flow from solving the equation, although software exists that incorporates this method with routines providing more output options.

Limitations

- In practice, runoff coefficient is only related to type of terrain; however, in reality, it is also related to storm event frequency (intensity/duration).
- Assumes no temporary storage (basin or stream) within watershed.
- Published coefficients are valid only for two- to 10-year storm events.

SLAMM (Source Loading and Management Model)

Description

The Source Loading and Management Model (SLAMM) was originally developed to better understand the relationships between sources of urban runoff pollutants and runoff quality. It has been continually expanded since the late 1970s and now includes a wide variety of source area and outfall control practices (infiltration practices, wet detention ponds, porous pavement, street cleaning, catch basin cleaning and grass swales). SLAMM is strongly based on actual field observations, with minimal reliance on theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool to better understand sources of urban-runoff pollutants and their control.

SLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rains, development characteristics and control practices. As with all stormwater models, SLAMM needs to be accurately calibrated and then tested as part of any stormwater-management effort.

SLAMM incorporates unique process descriptions to more accurately predict the sources of runoff pollutants and flows for the storms of most interest in stormwater-quality analyses. However, SLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water-quality controls on drainage design.

Uses and Applications

SLAMM can be used for:

- water-quality planning,
- site design,
- water-loss determinations,
- predicting runoff yields, and
- checking structure effectiveness.

Input Data and/or Model Components

Input data and model components for SLAMM include:

- rainfall characteristics,
- runoff characteristics,
- land use types by percentage, and
- stormwater-control practices.

Outputs Available

The outputs available from SLAMM include:

- particulate analysis,
- runoff yields,

- percentage of contribution by land use type,
- curve number calculation, and
- comparative structure effectiveness.

SWMM (Storm Water Management Model)

Description

The USEPA's Storm Water Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Extran Block solves complete dynamic flow routing equations (St. Venant equations) for accurate simulation of backwater, looped connections, surcharging and pressure flow.

Uses and Applications

SWMM can be used for both planning and design. The modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through drainage network, storage and treatment.

Input Data and/or Model Components

The SWMM-Windows interface was developed to assist the user in data input and model execution to make a complex model user friendly.

Outputs Available

Basic SWMM output consists of hydrographs and pollutographs (concentration vs. time) at any desired location in the drainage system. Depths and velocities are also available, as are summary statistics on surcharging, volumes, continuity and other quantity parameters. Additional quality output includes loads, source identification, continuity, residuals (*e.g.,* sludge) and other parameters.

Limitations

Technical limitations include lack of subsurface quality routing (a constant concentration is used), no interaction of quality processes (apart from adsorption), difficulty in simulation of wetlands quality processes (except as can be represented as storage processes), and a weak scour-deposition routine in the Transport Block. The biggest impediment to model usage is the user interface, with its lack of menus and graphical output. The model is still run in a batch mode (the user constructs an input file with an editor). Third-party software that can greatly facilitate pre- and post-processing is available.

Technical Release 20 (Computer Program for Project Formulation Hydrology)

Description

This model was developed by the USDA NRCS, formerly the SCS. The Technical Release 20 (TR20) model is used to simulate the runoff process from a watershed through the generation and routing of hydrographs through stream reaches and structures. The SCS hydrology methods described in *National Engineering Handbook* section 4 (NEH-4) are used. Without calibration, use of the model results should be limited to relative comparisons. The recent addition of an input program makes the model easier to use. TR20 can be used in conjunction with a water surface profile model, for determining the flood profile of a stream.

Uses and Applications

Uses and applications for the TR20 model include:

- watershed-scale planning,
- design of water-management structures,
- surface water quantity routing,
- hydrograph development, and
- structure routing and approximate sizing.

Input Data and/or Model Components

The input data and components of the TR20 model include:

- rainfall amount and time distribution,
- land use data and soils for developing a runoff curve number (RCN) for each subarea,
- time of concentration (Tc) for each subarea,
- stream reach length and typical cross section for reach-routing applications,
- structure stage/discharge/storage tables and
- antecedent moisture condition.

Outputs Available

Outputs available from the TR20 model include:

- peak discharge,
- runoff volume,
- hydrographs,
- estimated elevations and
- results of structure and stream-reach routings.

Limitations

- The TR20 model is a single-event model.
- Snowmelt inputs cannot be entered directly.
- Using the TR20 model requires an understanding of hydrologic processes.

- Three hundred time increments for hydrographs in the 1983 version (400 points in the newer version that is being developed).
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

Technical Release 55 (Urban Hydrology for Small Watersheds - Graphical Method)

Description

The graphical method in Technical Release 55 (TR55) is used to determine the peak discharge for a single storm event on a watershed. The method applies to an urban or a rural watershed or one in transition. The method uses NRCS hydrology as described in *National Engineering Handbook* section 4, “Hydrology” (NEH-4), and was developed from hydrograph analysis using Technical Release 20: Computer Program for Project Formulation–Hydrology. The procedure calculates the runoff curve number (RCN) and time of concentration (Tc) based on measured watershed parameters.

Uses and Applications

Uses and applications for the TR55 Graphical Method model are:

- small-scale watershed planning and
- comparison of “before” and “after” conditions for installation of structures or watershed-development actions.

Input Data and/or Model Components

Data to be input into the TR55 Graphical Method include:

- rainfall amount and choice of synthetic time distribution,
- land-use data and soils for developing a runoff curve number (RCN) for the watershed, and
- time of concentration using measured parameters or the lag equation.

Outputs Available

Outputs available from the TR55 Graphical Method model include:

- peak discharge and
- runoff volume in watershed inches.

Limitations

- TR55 Graphical Method is a single-event model.
- Use of TR55 is limited to watersheds of less than 2,000 acres.
- Only a single homogeneous watershed may be simulated.
- Time of concentration must be less than 10 hours.
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

Technical Release 55 (Urban Hydrology for Small Watersheds - Tabular Method)

Description

This method was also developed by the USDA NRCS (formerly the SCS). The tabular method in Technical Release 55 (TR55) is used to determine the peak discharge and an approximate hydrograph for a single-event storm on a single watershed. The method applies to an urban or a rural watershed or one in transition. The model uses SCS hydrology as described in National Engineering Handbook section 4, "Hydrology" (NEH-4). The program will calculate the runoff curve number (RCN) and time of concentration (Tc) based on watershed parameters that are measured and entered into the program.

Uses and Applications

Uses and applications for the TR55 Tabular Method include:

- small-scale watershed planning,
- comparison of "before" and "after" conditions for installation of structures or watershed-development actions, and
- simple hydrograph development (limited detail).

Input Data and/or Model Components

Input data for the TR55 Tabular Method include:

- rainfall amount and choice of synthetic time distribution,
- land use data and soils for developing a RCN for each subarea,
- time of concentration using measured parameters or the lag equation for each subarea, and
- travel times through subareas.

Outputs Available

Outputs available from the TR55 Tabular Method include:

- peak discharge for each subarea,
- runoff volume in watershed inches, and
- simple hydrograph.

Limitations

The TR55 Tabular Method has the following limitations:

- TR55 Tabular Method is a single-event model.
- Watersheds must be less than 2,000 acres in size.
- Watershed subareas must be hydrologically homogeneous.
- Ten subacres or less
- Time of concentration less than two hours in each subarea
- Travel time of three hours or less in each subarea
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

APPENDICES

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Appendix III: Important Contacts and Telephone Numbers

Minnesota Pollution Control Agency (MPCA)
520 Lafayette Rd. N.
St. Paul, MN 55155-4194
www.pca.state.mn.us

- **MPCA Information Line**
  (651) 296-6300 or (800) 657-3864, TTY: (651) 282-5332
- **Customer Assistance Center**
  (651) 297-2274 or (800) 646-6247
- **24-hour Emergency Number (Spills)**
  Duty Officer, Minnesota Department of Public Safety
  (651) 649-5451 or (800) 422-0798,
  TTY: (651) 297-5353 or (800) 627-3529

Abandoned Wells
(651) 201-4600

Above-Ground Storage Tanks
(651) 297-2274 or (800) 646-6247

Agricultural Runoff
James Klang
(651) 296-8402

Best Management Practices
See *Minnesota Stormwater Manual* listing

Board of Water and Soil Resources (BWSR)
(651) 296-3767

Citizen Lake Monitoring Program
Jennifer Klang
(651) 282-2618
Pamela Anderson
(651) 296-8544

Citizen Stream Monitoring Program
Laurie Sovell
(651) 296-7187
Pamela Anderson
(651) 296-8544

Clearinghouse, MPCA (Environmental education materials)
Jeanne Giernet
(651) 215-0232

Construction Stormwater Permit

Shanna Denis (Construction stormwater permit forms, applications and permit status)
(651) 297-1457 or (800) 657-3864

Construction Stormwater Permit Enforcement

See *MPCA Regional Offices* listing or go to http://www.pca.state.mn.us/complaints.html to report an observed pollution problem

Feedlots

See *MPCA Regional Offices* listing

Hazardous Waste

Business assistance
(651) 297-2274 or (800) 646-6247

Landfills

Jim Chiles
(651) 296-7223

Don Kyser
(651) 215-0191

Richard Andre
(651) 215-0195

Minnesota Stormwater Manual

http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

MPCA Regional Offices:

Brainerd	(218) 828-2492
Detroit Lakes	(218) 847-1519
Duluth	(218) 723-4660
Mankato	(507) 389-5977
Marshall	(507) 537-7146
Rochester	(507) 285-7343
St. Paul	(651) 296-6300
Willmar	(320) 214-3786

Plants for Stormwater Design

Ruth Monzel (to order a copy)
(651) 297-8509

Protecting Water Quality in Urban Areas

Kelly Turner (to order a copy)
(651) 297-5754

Public Information Office

Dan McLean (MPCA Stormwater Program)
(651) 297-1607