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.

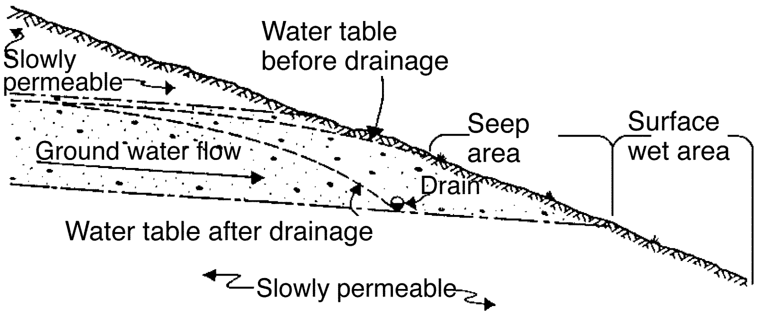


Figure 4.11-1 Interceptor drain for side hill seeps

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)	Poorly graded sands, gravelly sands.	Filter needed	Not needed where sand and gravel filter is used, but may be needed with flexible drain tubing and other filter types.	None
SM (fine)	Silty sands, poorly graded sand-silt mixture.			
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.			
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.			
GP	Poorly graded gravels, gravel-sand mixtures with little or no fines.	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).
SC	Clayey sands, poorly graded sand-clay mixtures.			
GM	Silty gravels, poorly graded gravel-sand silt mixtures.			
SM (coarse)	Silty sands, poorly graded sand-silt mixtures.			
GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.	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
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.			
SP,GP (coarse)	Same as SP & GP above.			
GW	Well-graded gravels, gravel-sand mixtures with little or no fines.			
SW	Well-graded sands, gravelly sands with little or no fines.			
CH	Inorganic, fat clays.			
OL	Organic silts and organic silt-clays of low plasticity.			
OH	Organic clays of medium to high plasticity.			
Pt	Peat			

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.

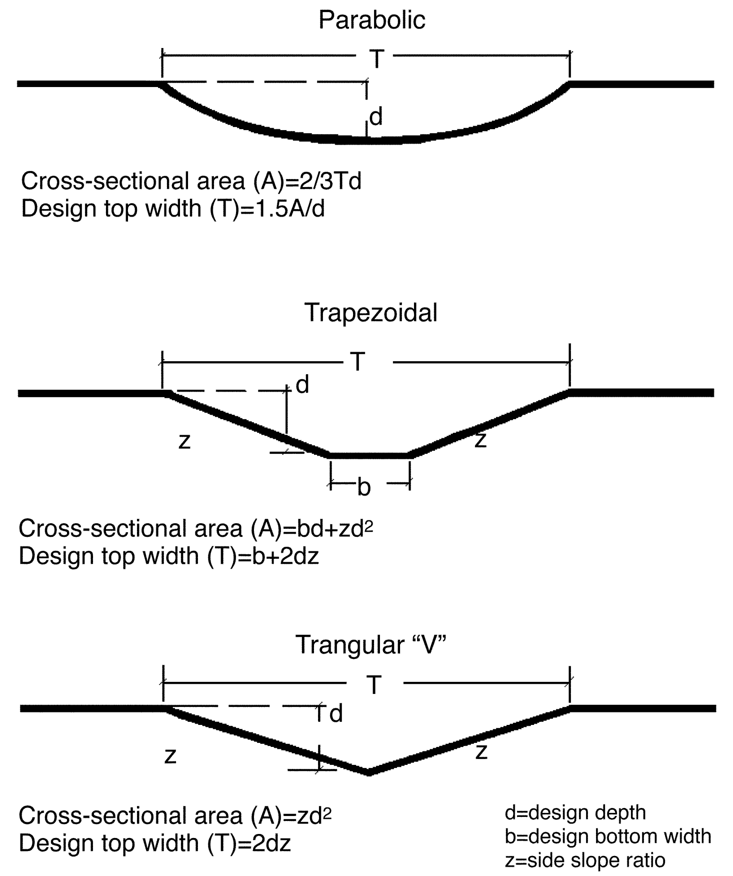


Figure 4.12-1 Storm water conveyance channel cross sections

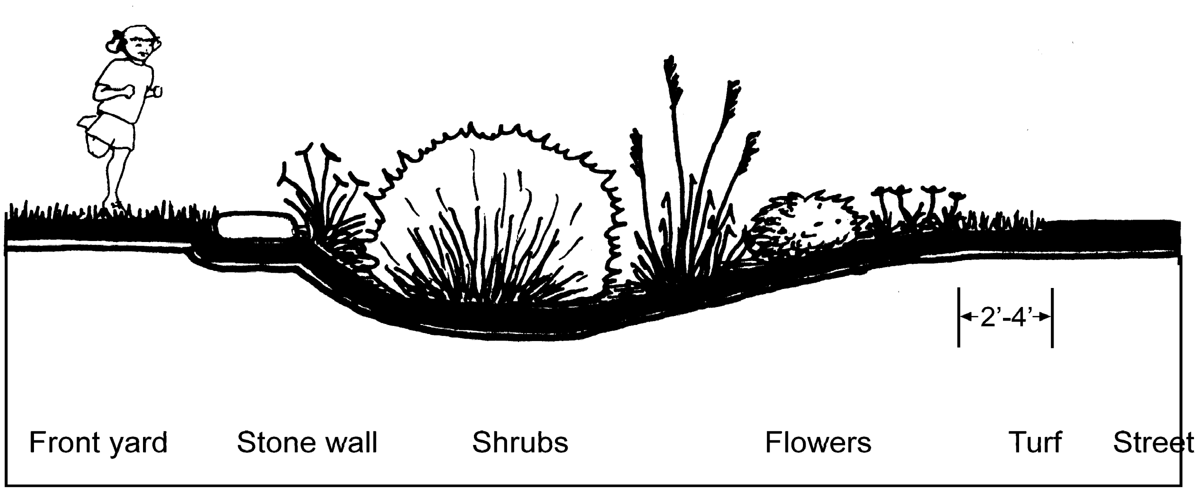
EFFECTIVENESS

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.

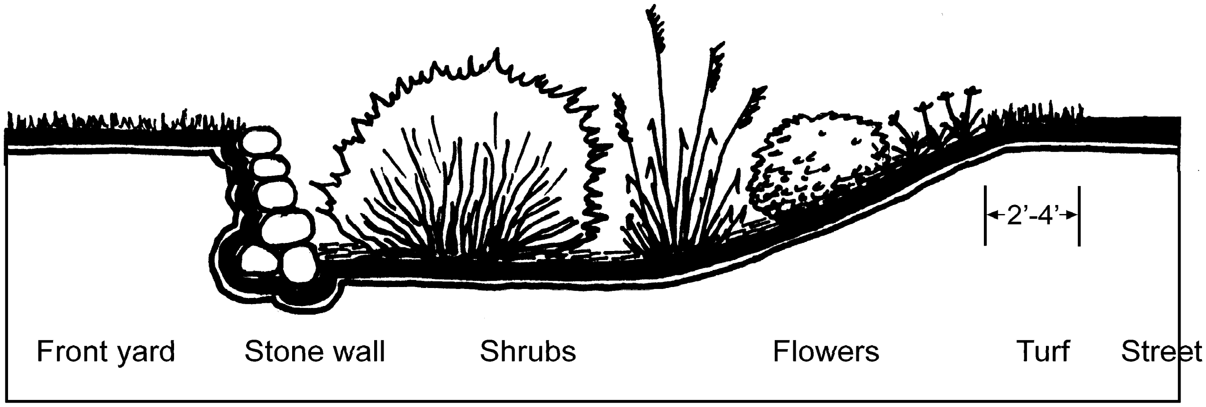
PLANNING CONSIDERATIONS

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.

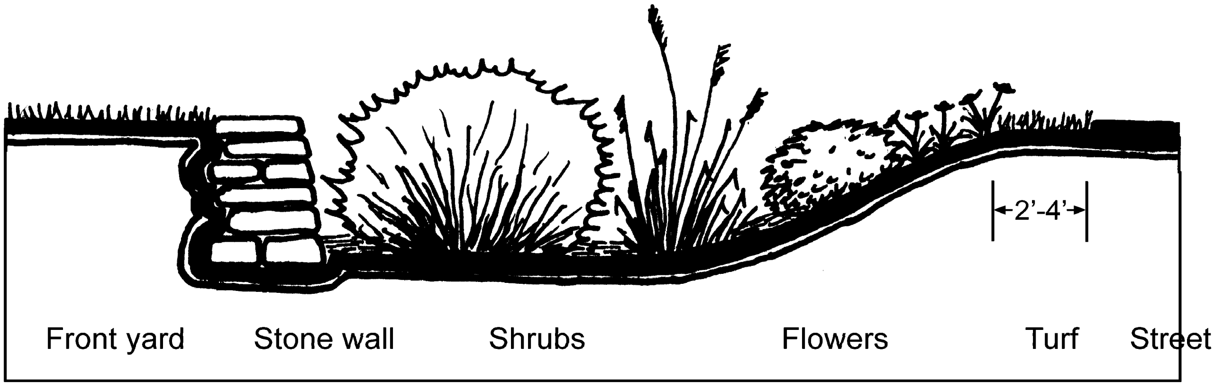
The two main considerations when designing a stormwater-conveyance channel are adequate capacity and sufficient erosion resistance. Also, if vegetation is used for a lining, storm water conveyance channels can help to reproduce predevelopment hydrologic conditions by promoting infiltration and slowing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

γ = *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.

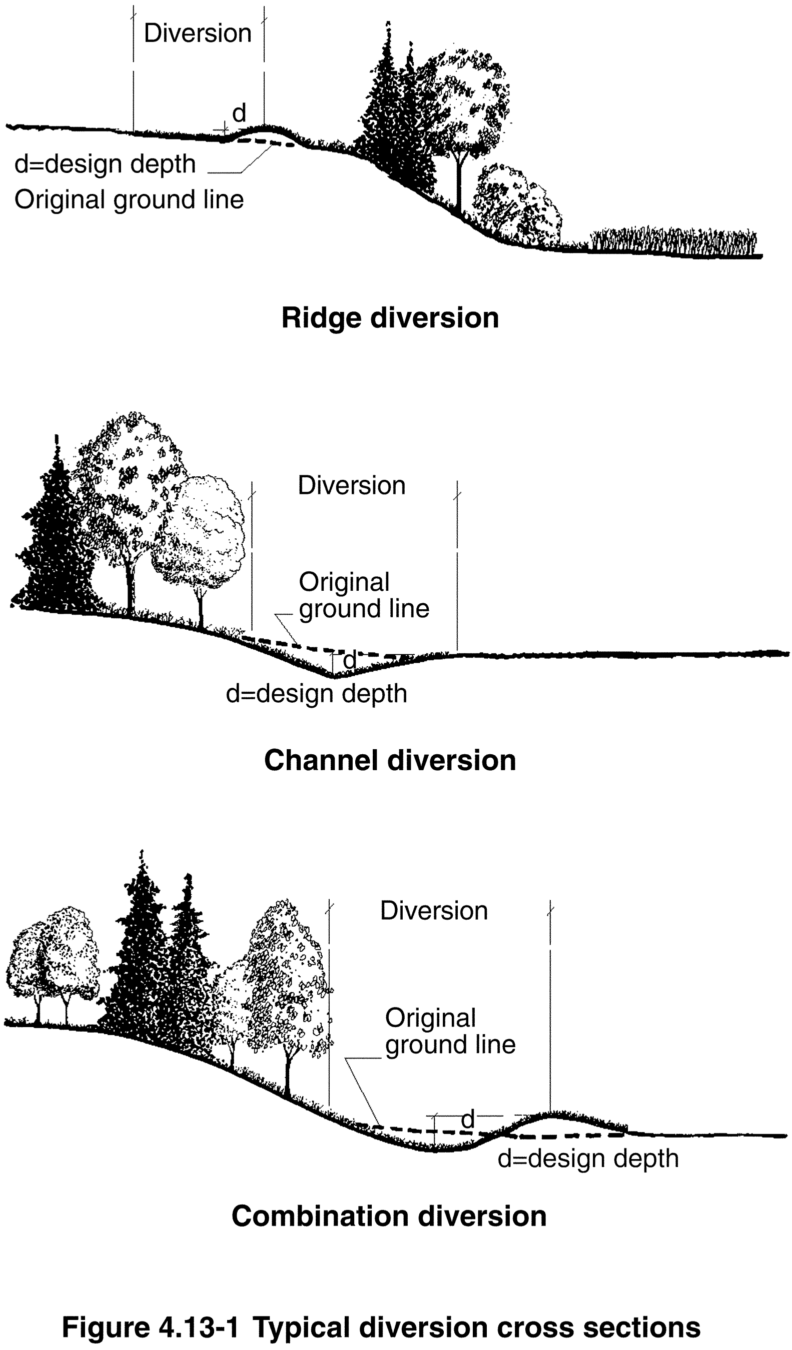


Figure 4.13-1 Typical diversion cross sections

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 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.

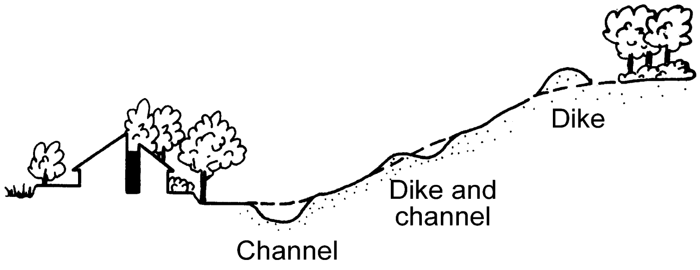


Figure 4.13-2 **Use of diversions to protect cut or fill slopes, protect structures or off-site property, or break long slopes**

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.

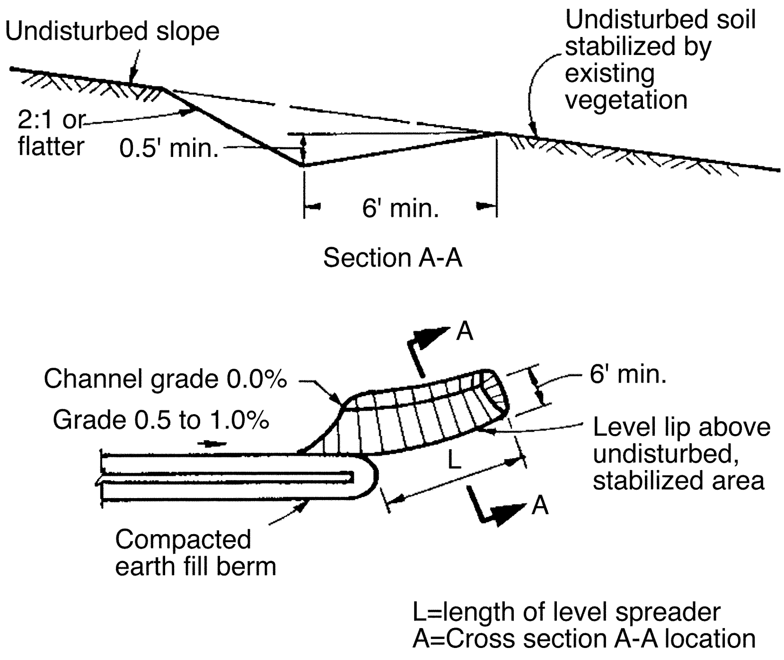


Figure 4.14-1 Level spreader layout and plan view

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.

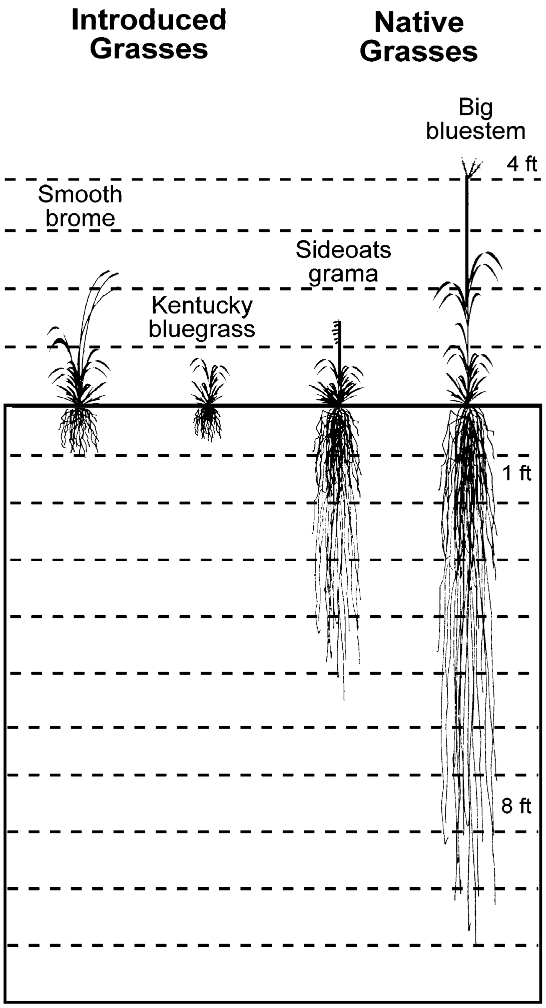
Smooth brome
- Root system reaches 10-15 inches in depth.
- Plant height is 2-3 ft.

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

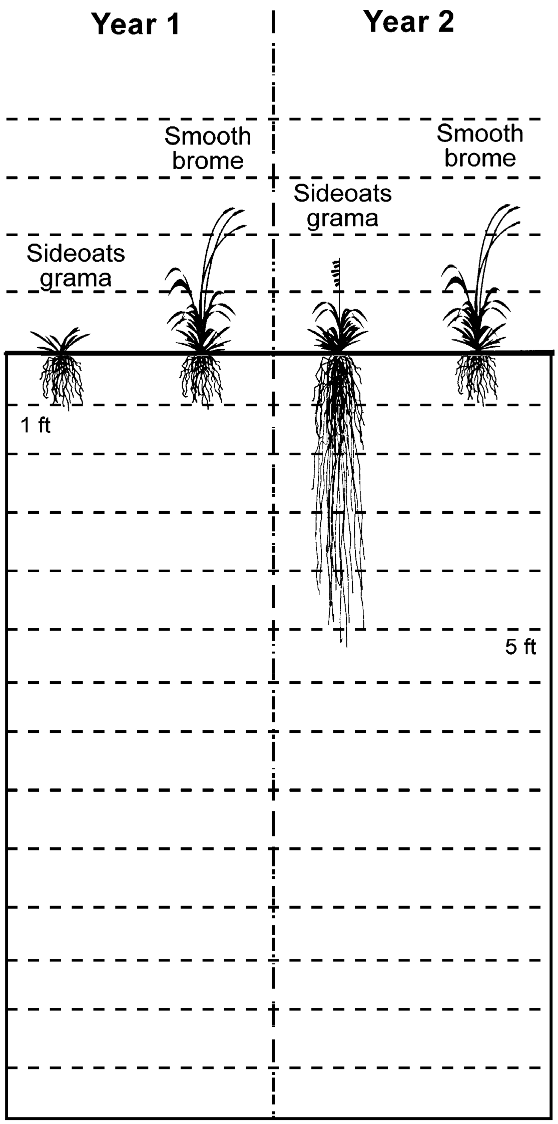
There is often a perception that native grass and wildflower plantings are a failure during the first growing season, even though they are establishing well. This is because

(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.

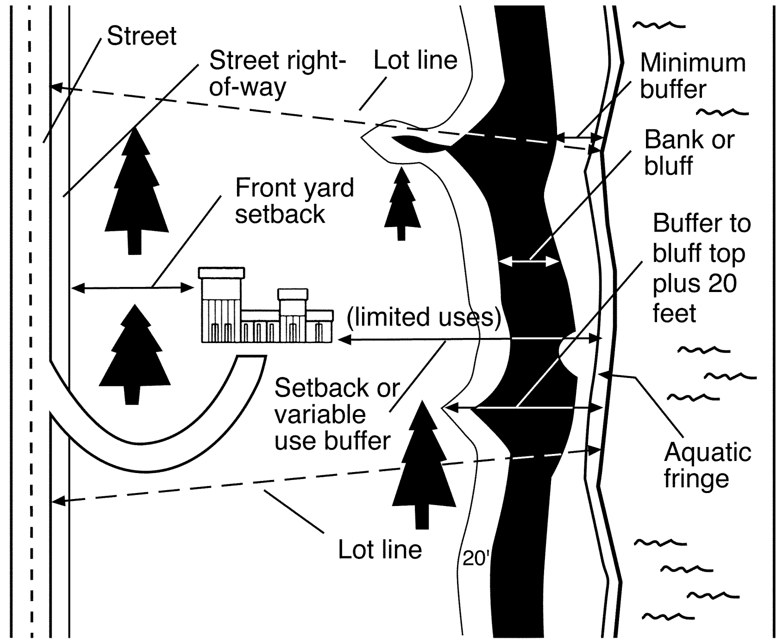


Figure 4.21-1 Buffers and setbacks

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).

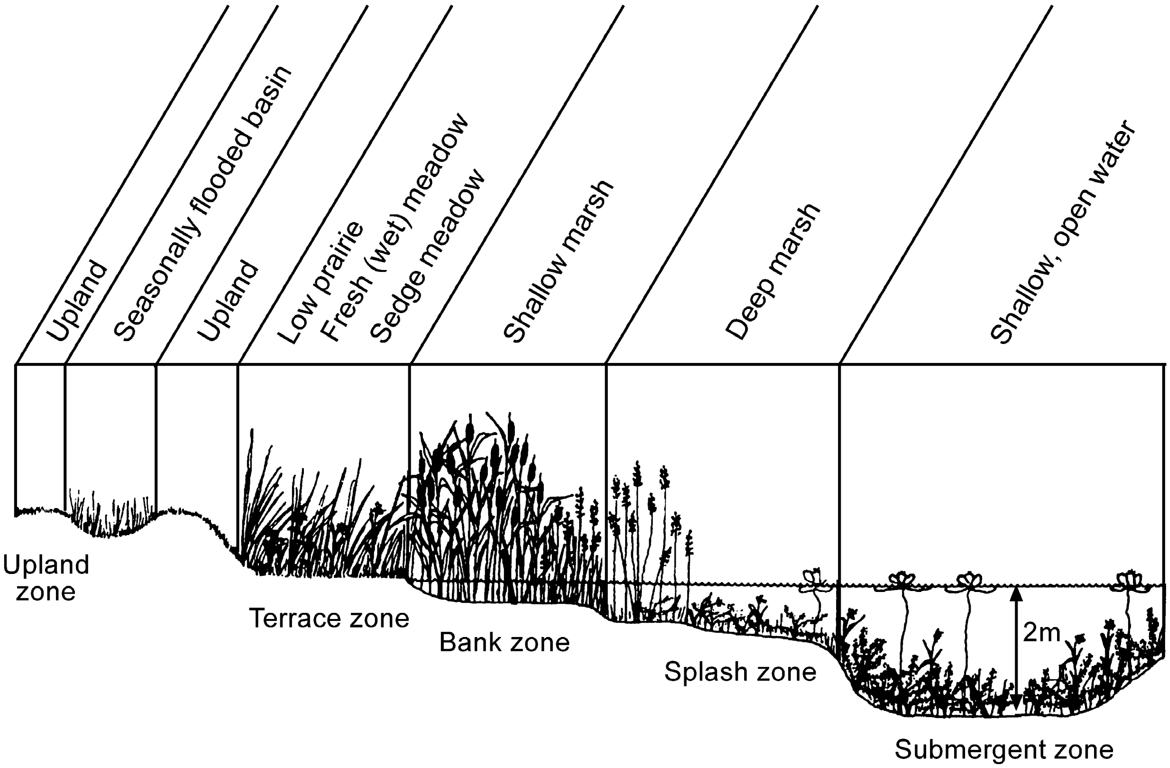
Ensure that measures will not be undermined by checking that bank and channel bottoms are stable before stabilizing the banks.

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.

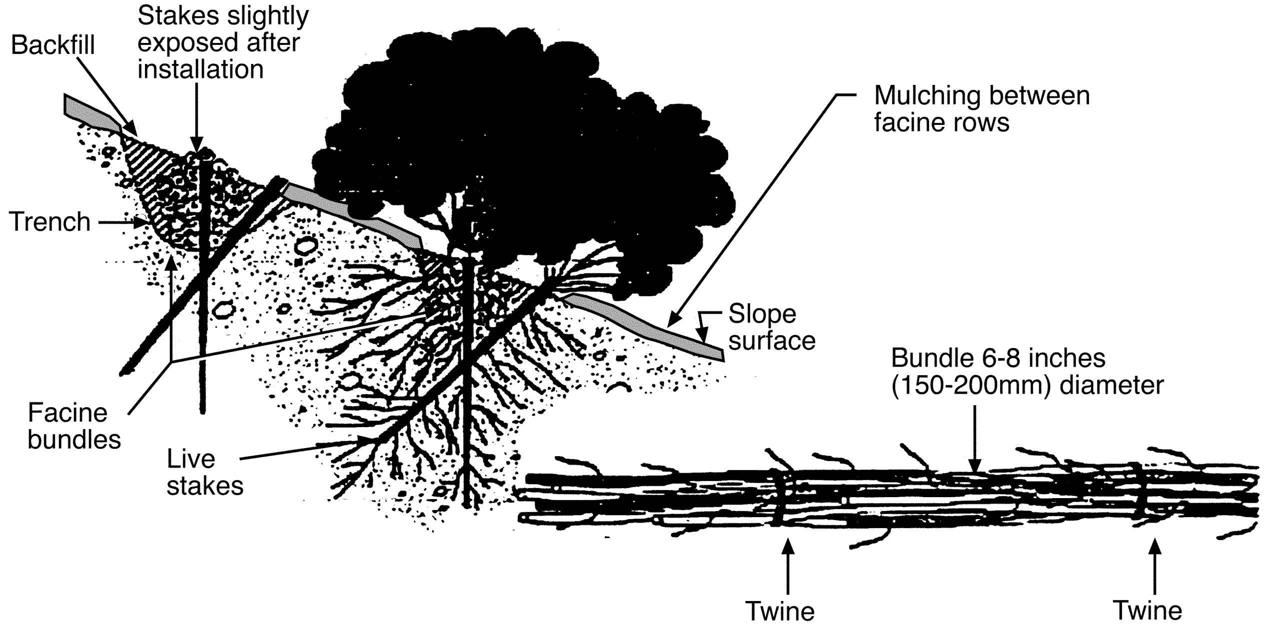


Figure 4.22-2 Wattling or live facines

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.

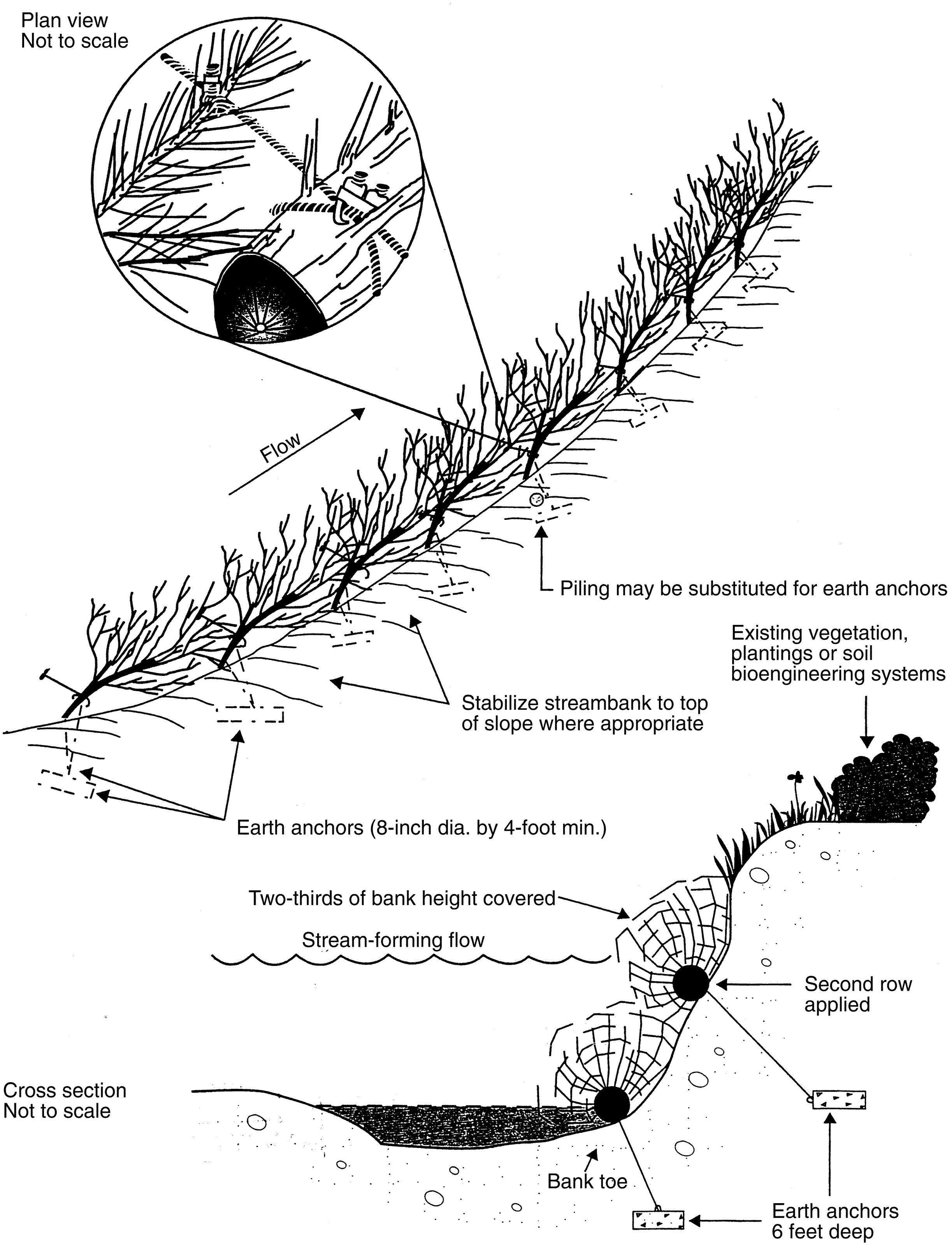


Figure 4.23-1 Tree revetment details

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.

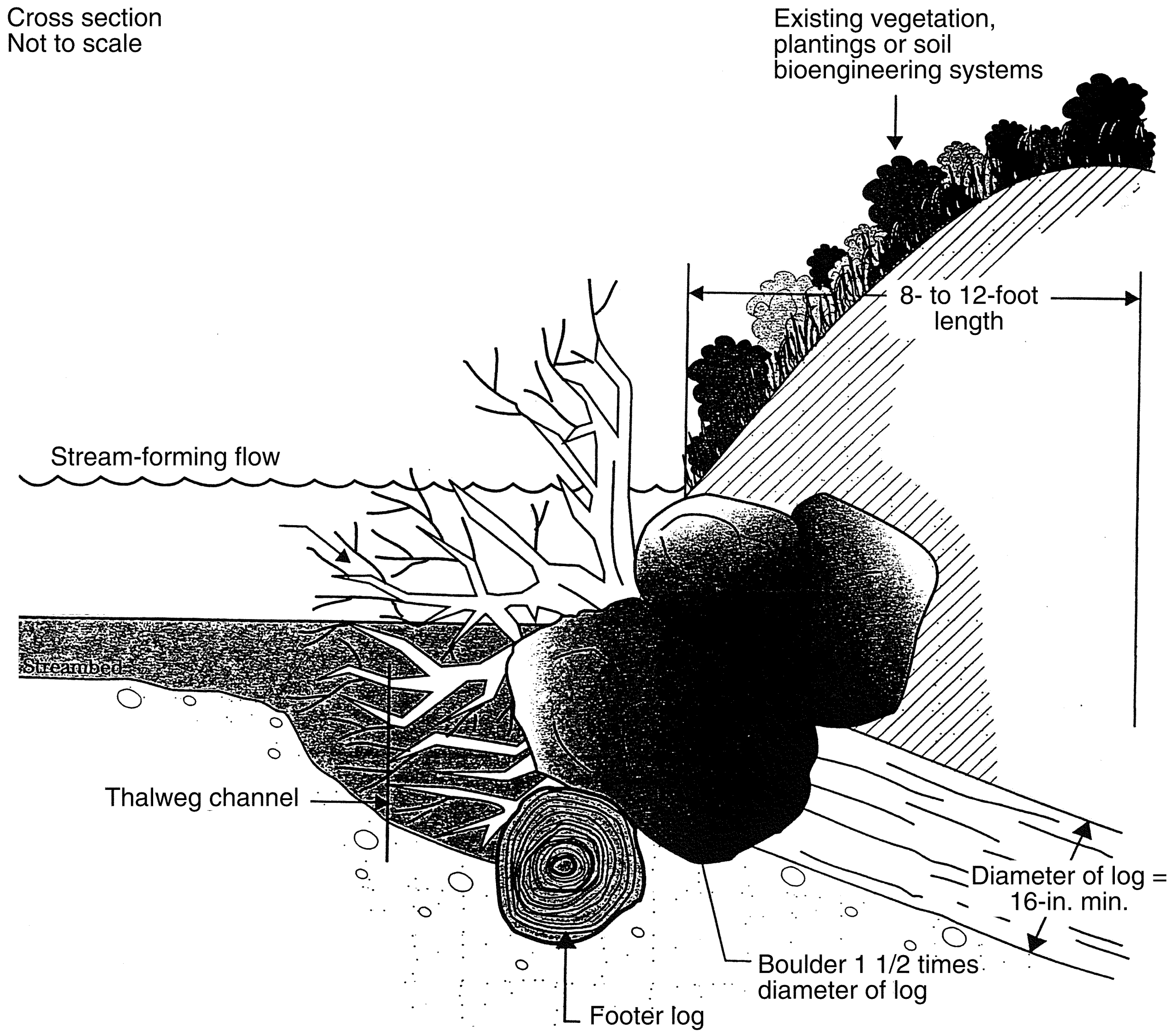


Figure 4.24-1 Log, rootwad, and boulder revetment details (Source: USDA, NRCS, August 26, 1998)

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.

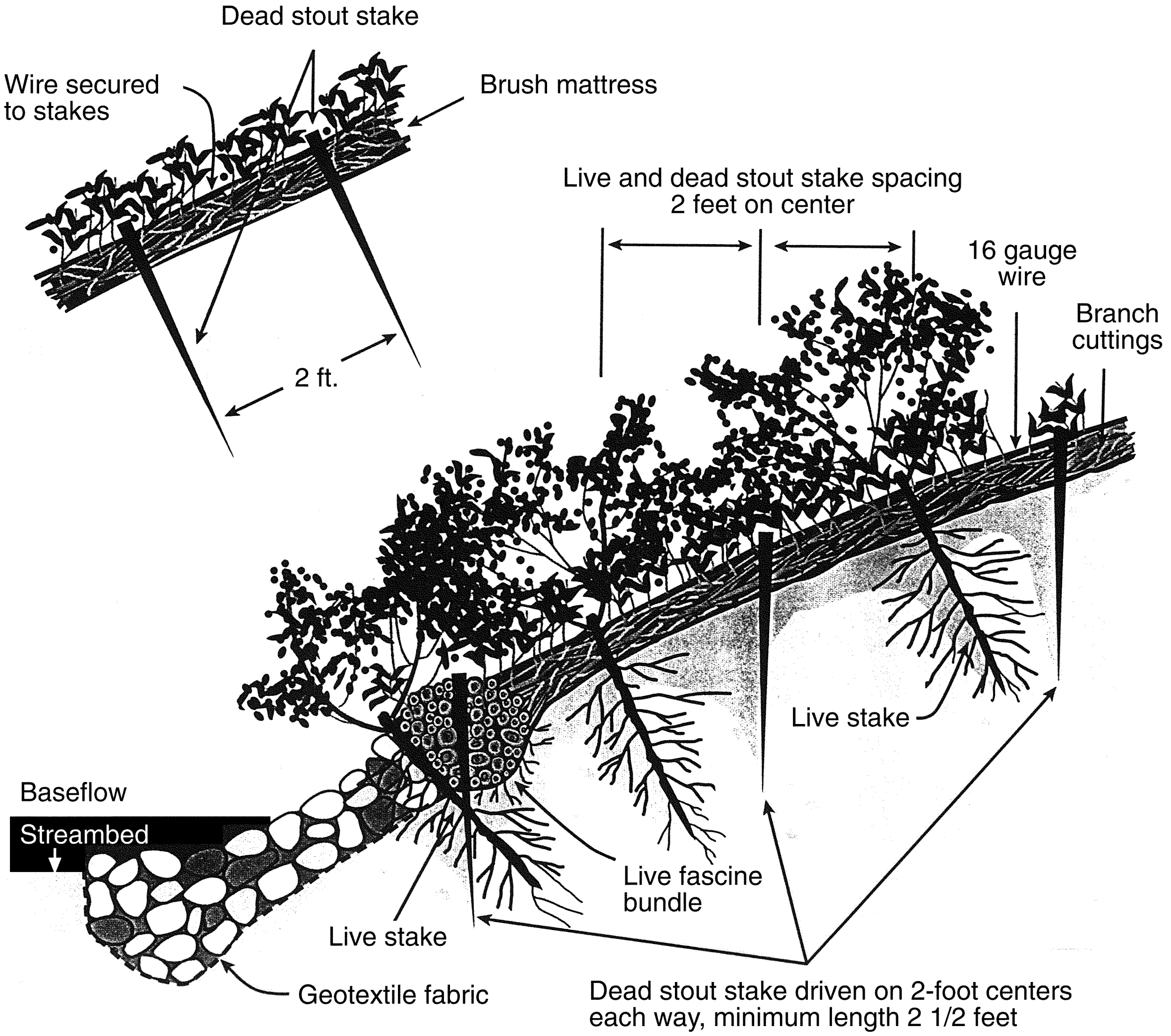


Figure 4.25-1 Vegetative stabilization: vegetated geotextile revetments (Source: USDA, NRCS, August 26, 1998)

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.

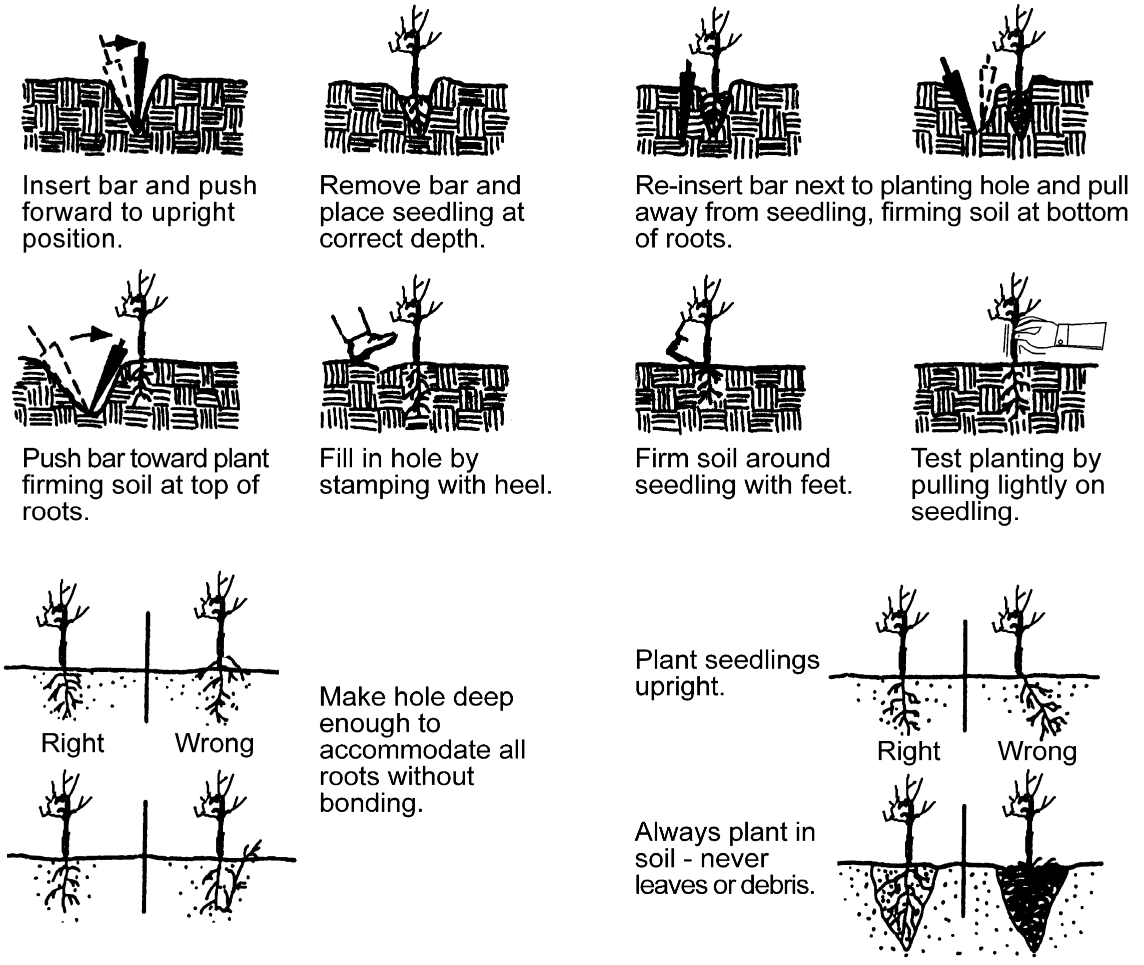
Bare-root stock does not have dirt protecting the roots. These trees are shipped in peat moss or moisture-proof containers to prevent their roots from drying. Do not let the roots dry while the planting is under way; keep damp moss or a mud slurry around the roots until the tree is in the ground. Bare-root 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



Insert bar and push forward to upright position.

Remove bar and place seedling at correct depth.

Re-insert bar next to planting hole and pull away from seedling, firming soil at bottom of roots.

Push bar toward plant firming soil at top of roots.

Fill in hole by stamping with heel.

Firm soil around seedling with feet.

Test planting by pulling lightly on seedling.

Make hole deep enough to accommodate all roots without bonding.

Plant seedlings upright.

Always plant in soil - never leaves or debris.

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.

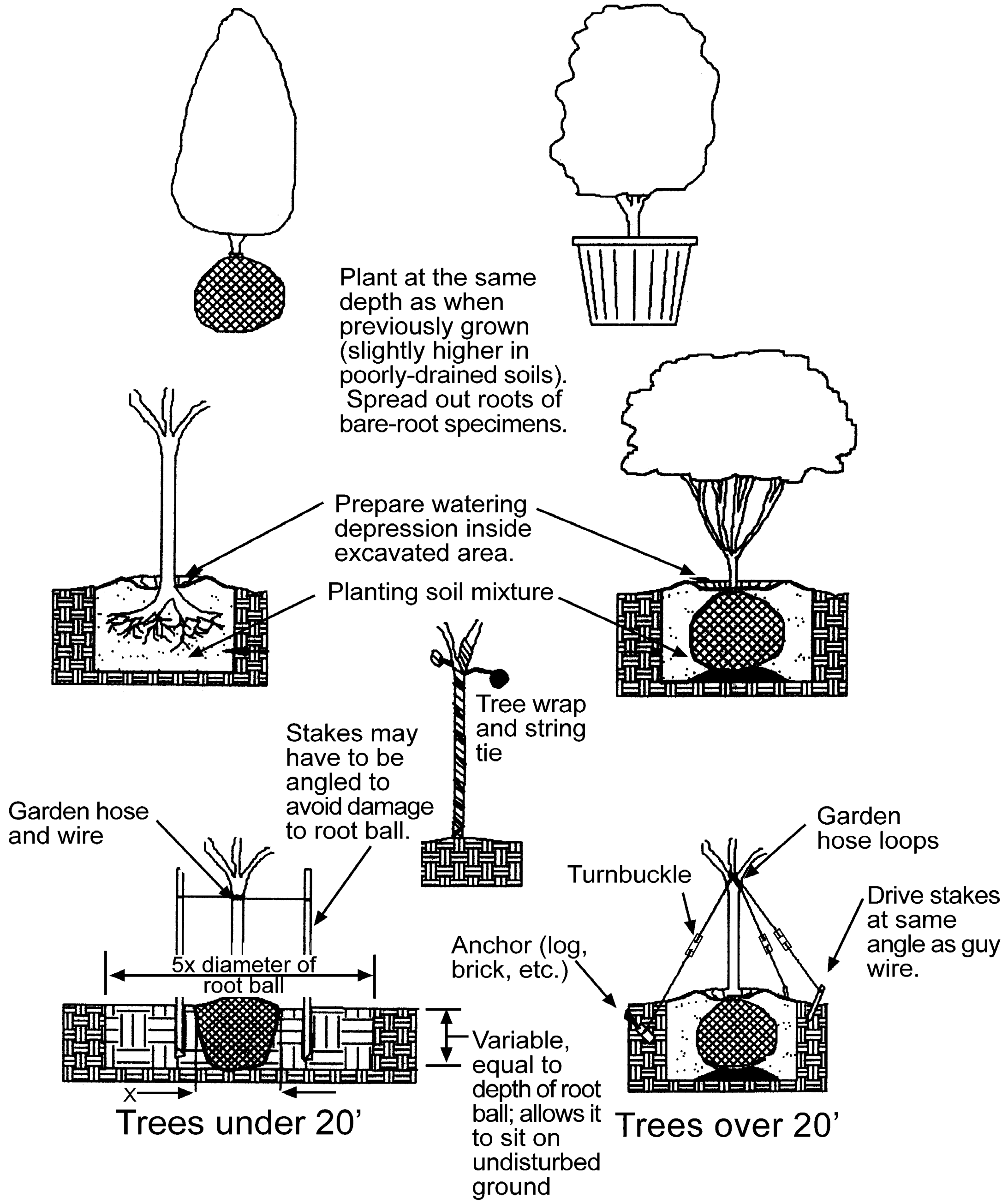


Figure 4.26-2 Planting balled-and-burlapped and container-grown trees (modified from Virginia Division of Forestry)

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.

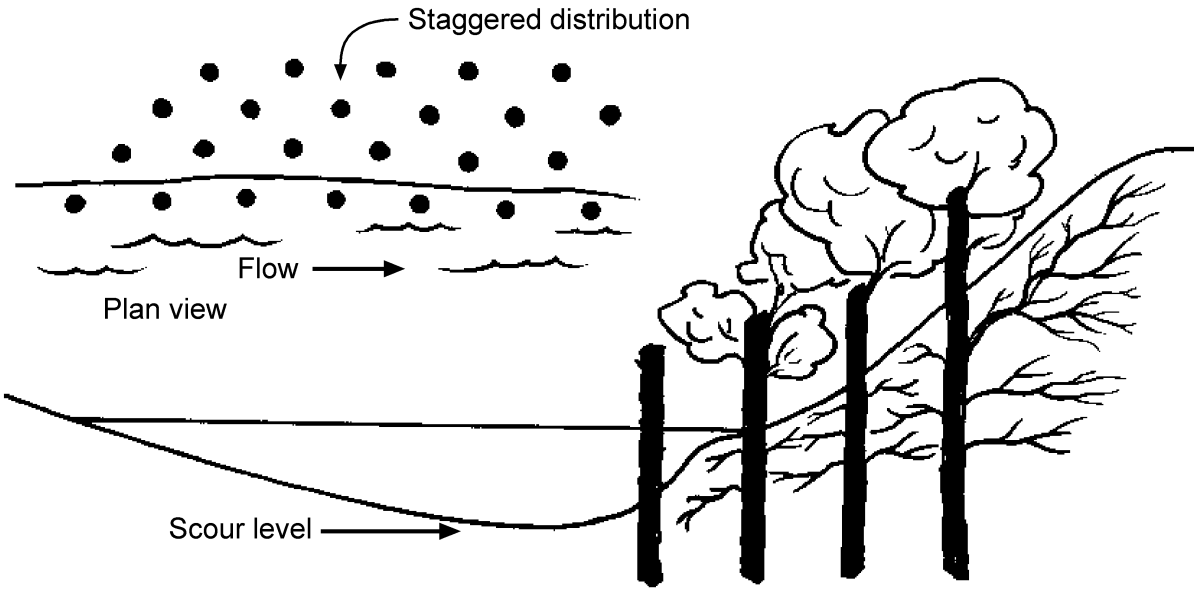


Figure 4.31-1 Willow posts

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.

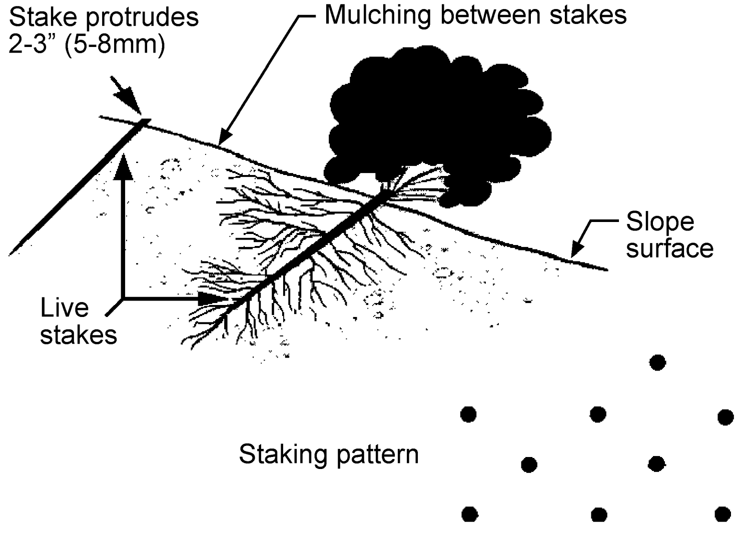


Figure 4.32-1 Live stakes

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.

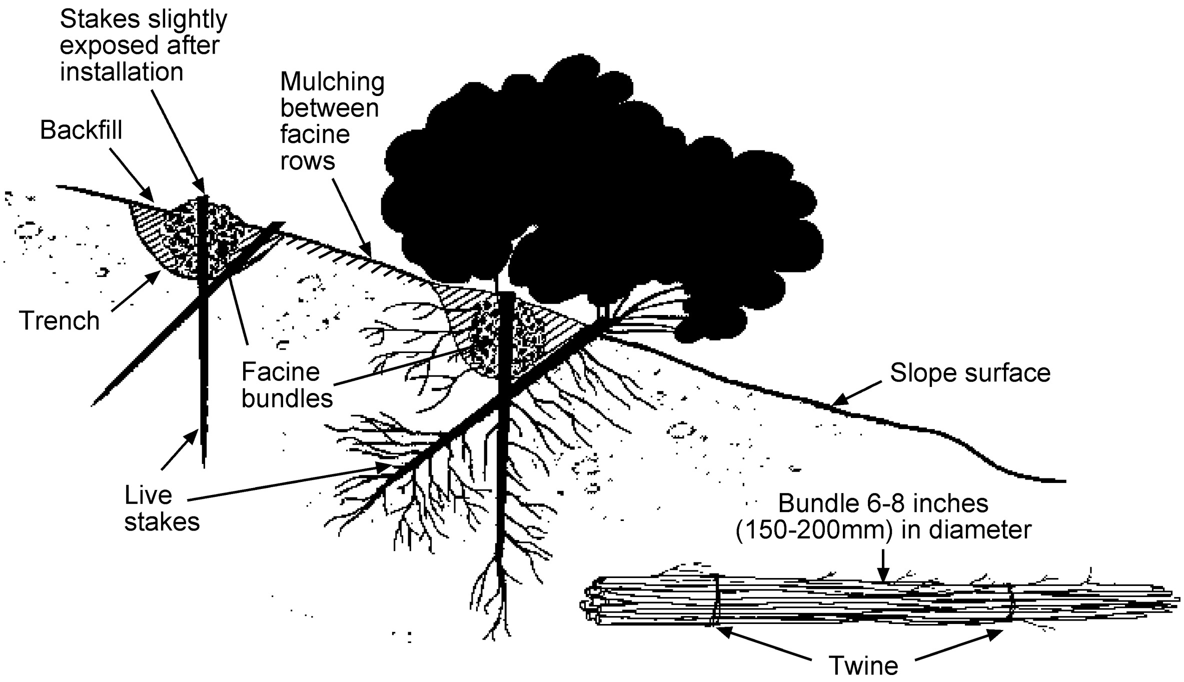


Figure 4.33-1 Wattling or live facines

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.

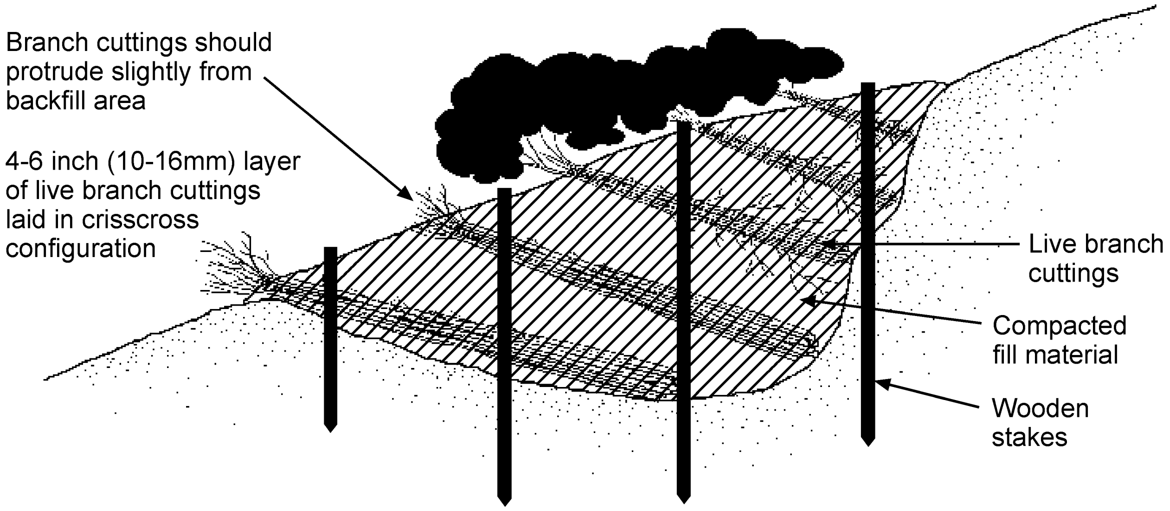


Figure 4.34-1 Branch packing

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.

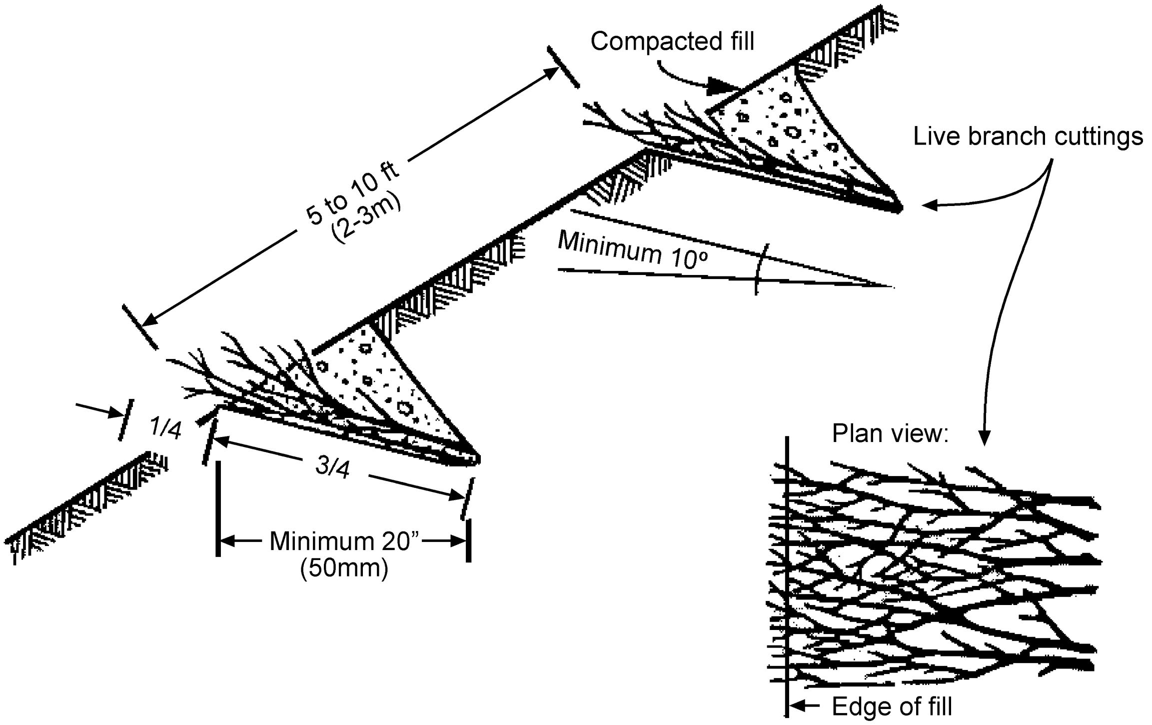


Figure 4.35-1 Brush layering

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.

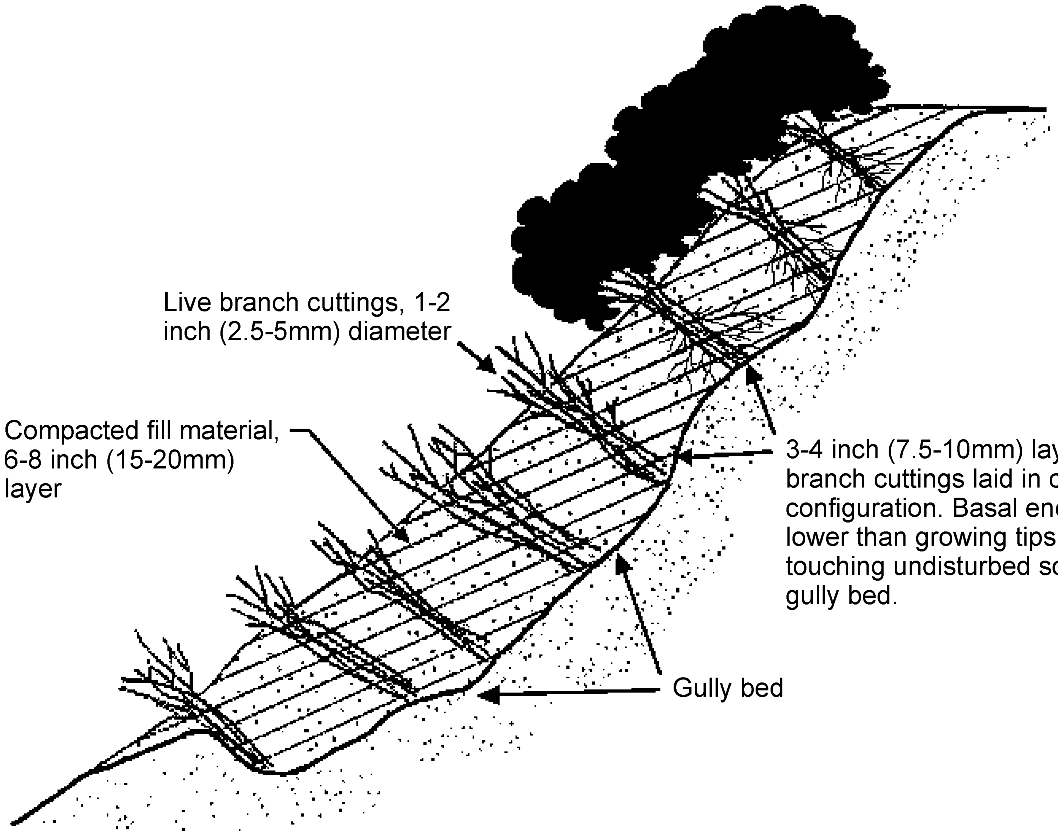


Figure 4.36-1 Live gully repair

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.

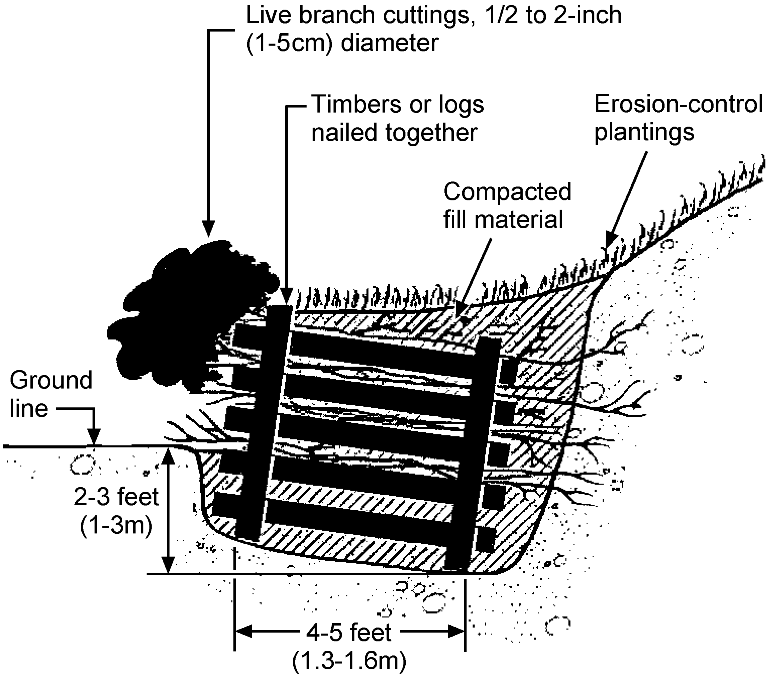


Figure 4.37-1 Live cribwall

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.

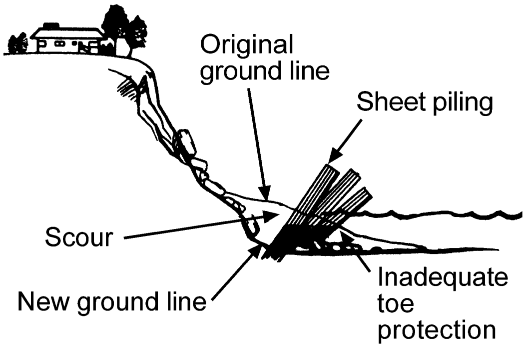


Figure 4.40-1 Inadequate toe protection (source: U.S. Army Corps of Engineers)

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.

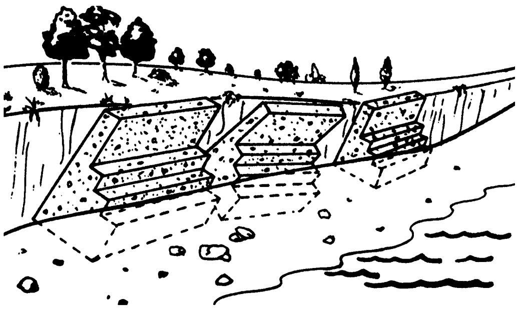


Figure 4.40-2 Inadequate foundation conditions (source: U.S. Army Corps of Engineers)

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.

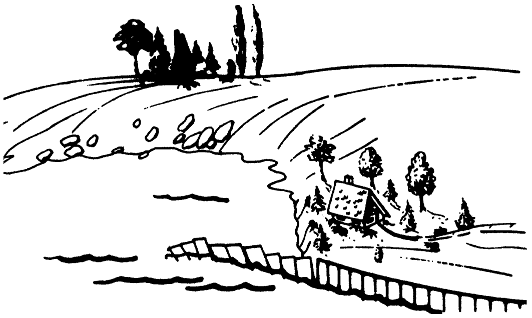


Figure 4.40-4 Inadequate flank protection (source: U.S. Army Corps of Engineers)

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 with-standing 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.

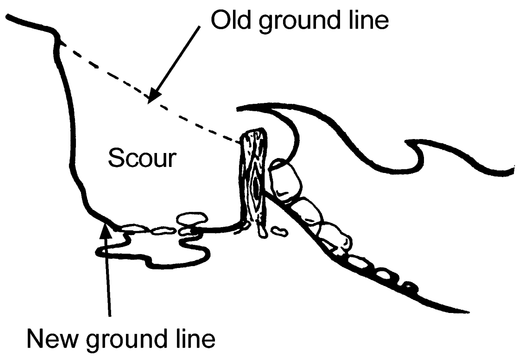


Figure 4.40-5 Overtopping (source: U.S. Army Corps of Engineers)

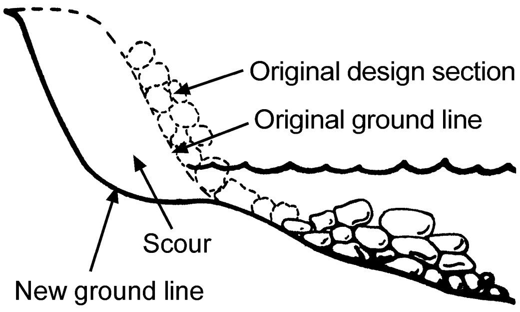


Figure 4.40-6 Inadequate scour protection (source: U.S. Army Corps of Engineers)

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.

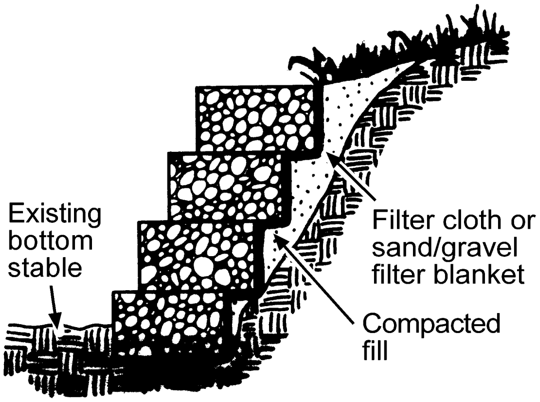


Figure 4.41-1 Gabions may be stacked to protect steep stream banks.

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

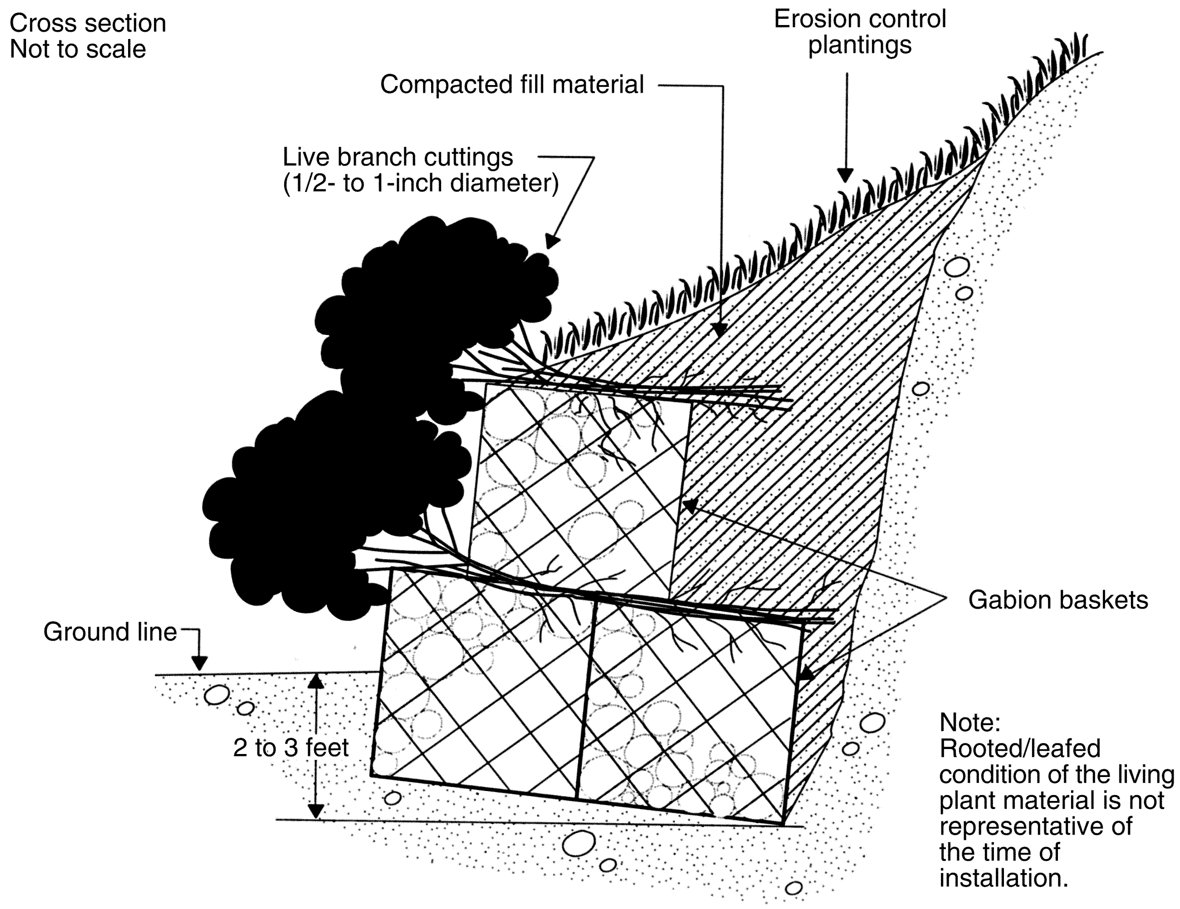
Vegetated rock gabions are used to improve aesthetics while providing permanent and stable structures.

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).



Note: Rooted/leafed condition of the living plant material is not representative of the time of installation.

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.

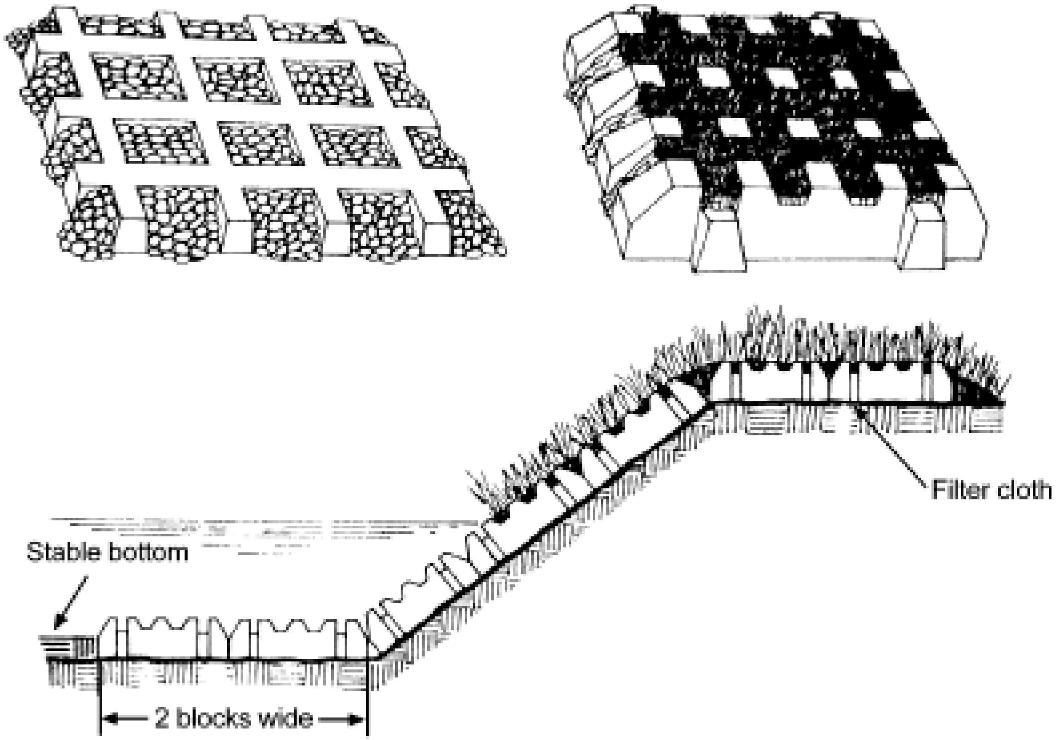


Figure 4.42-1 Voids in grid pavers may be filled with sand or gravel and established in vegetation. (Source: Virginia Department of Conservation and Recreation.)

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.

PLANNING CONSIDERATIONS

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

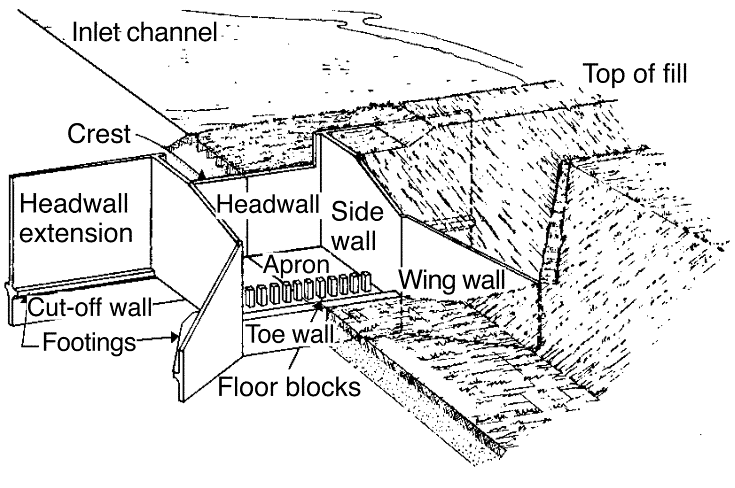


Figure 4.43-1 Full flow drop spillway

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).

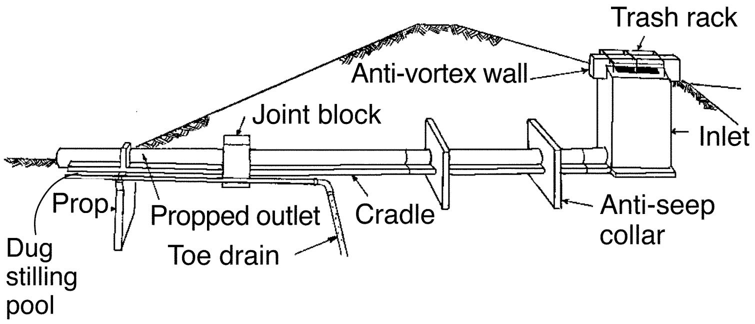


Figure 4.43-2 Drop inlet spillway

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).

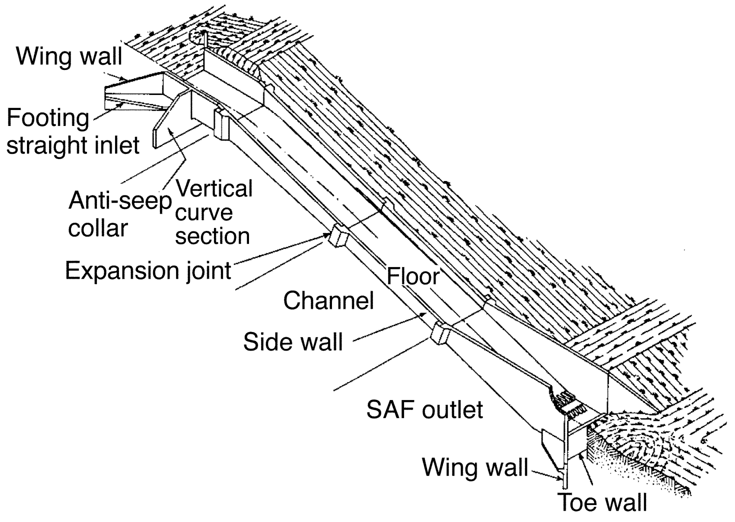


Figure 4.44-1 Chute spillway

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.

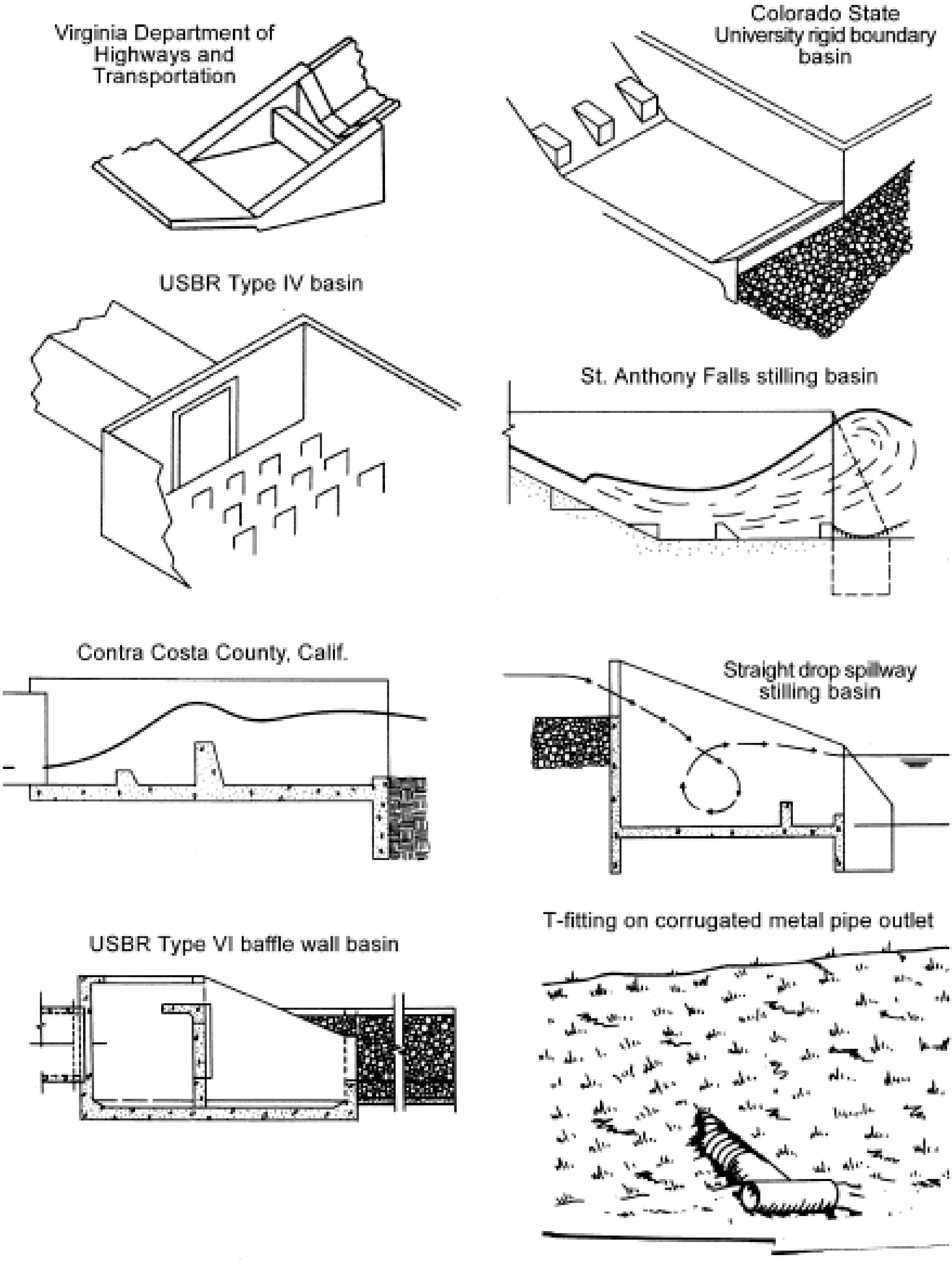


Figure 4.45-1 Alternative structures for energy dissipation at an outlet

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

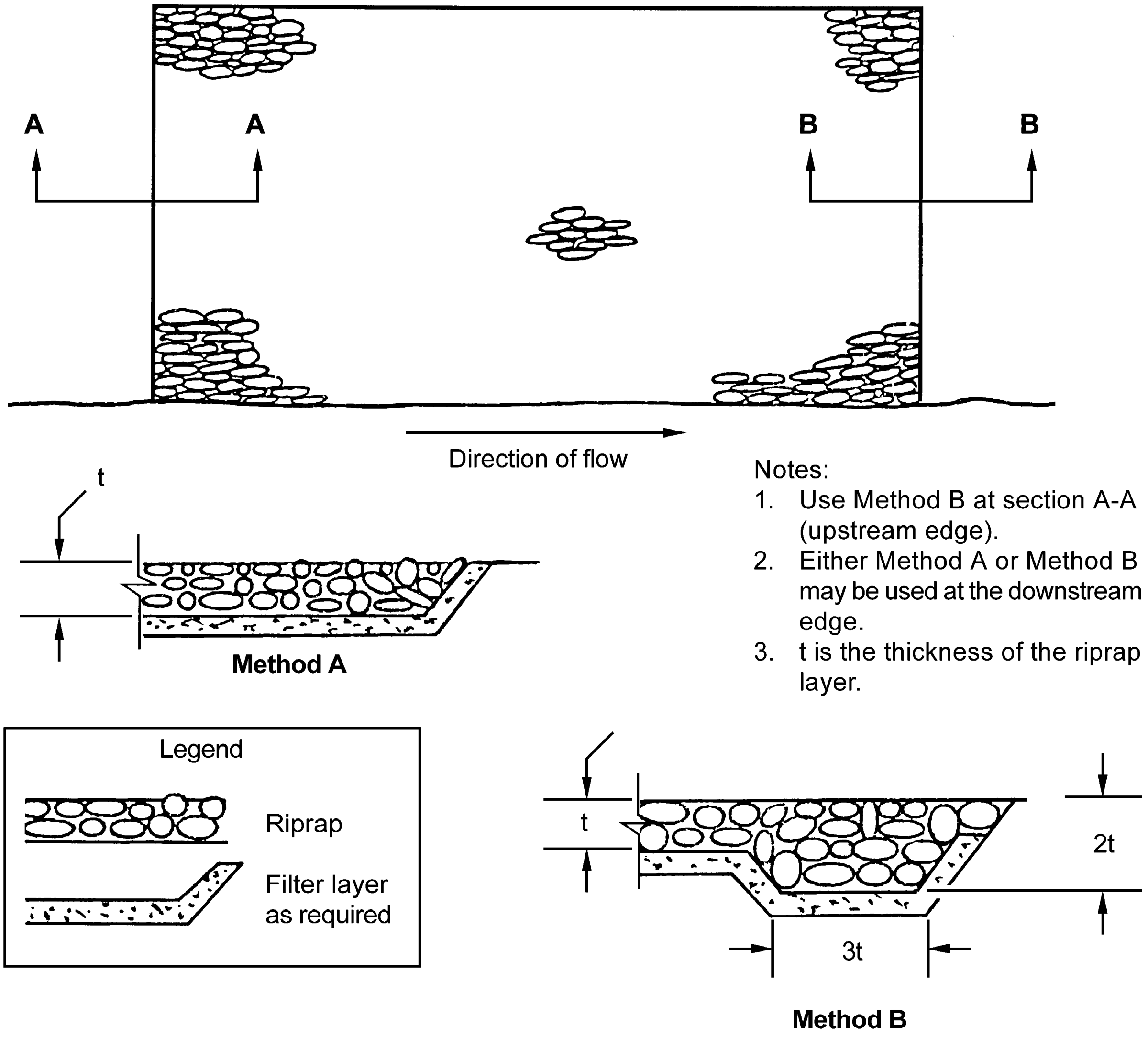
The stability of the riprap on the side slope of a channel is dependent on the angularity of the rock. The more angular the rock, the higher the angle of repose. The riprap stability is related to the side slope, rock size, angularity of the rock and the angle of repose. The maximum (steepest) slope 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.



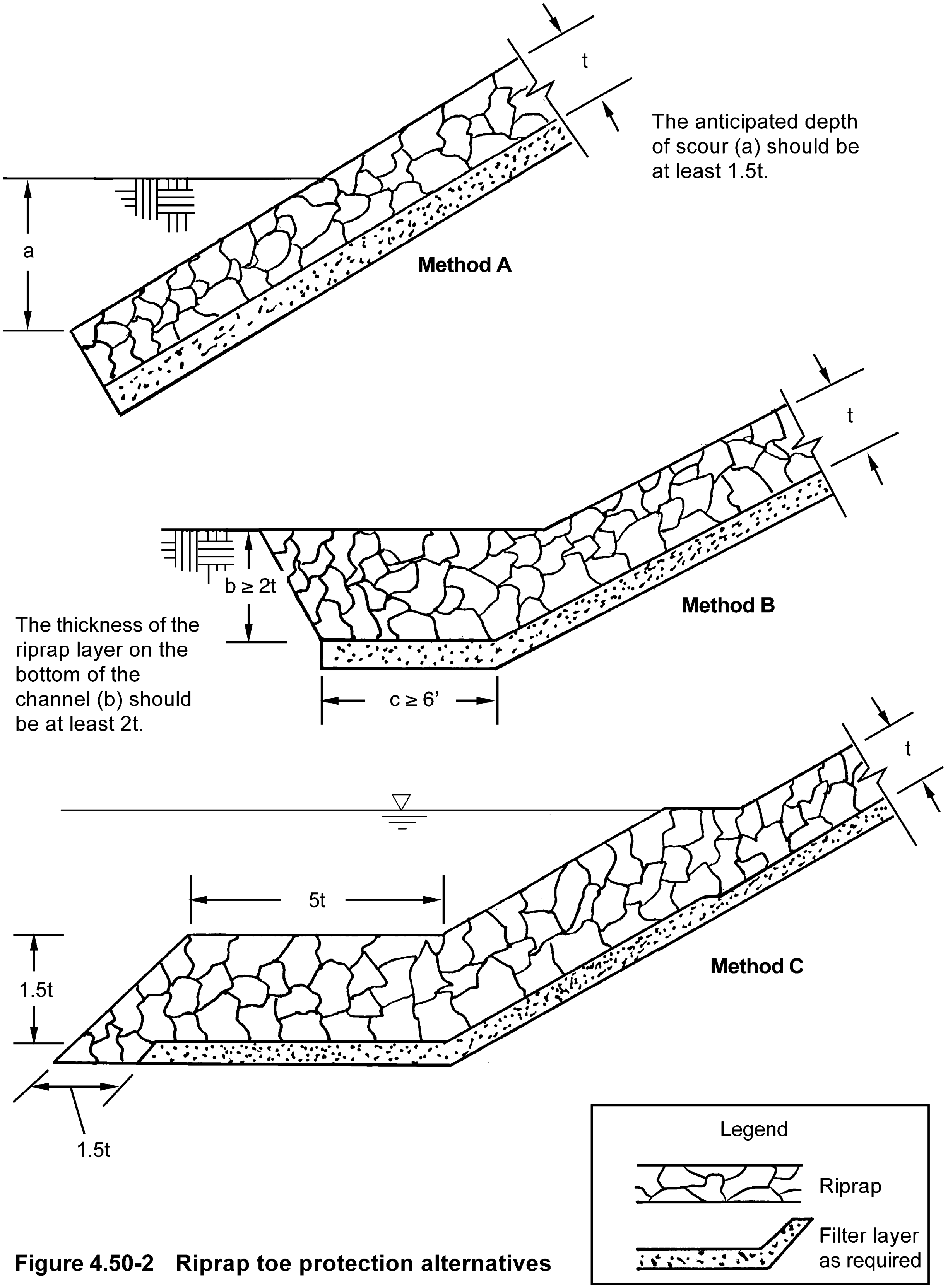
Notes:

1. Use Method B at section A-A (upstream edge).
2. Either Method A or Method B may be used at the downstream edge.
3. t is the thickness of the riprap layer.

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.



The anticipated depth of scour (a) should be at least 1.5t.

The thickness of the riprap layer on the bottom of the channel (b) should be at least 2t.

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

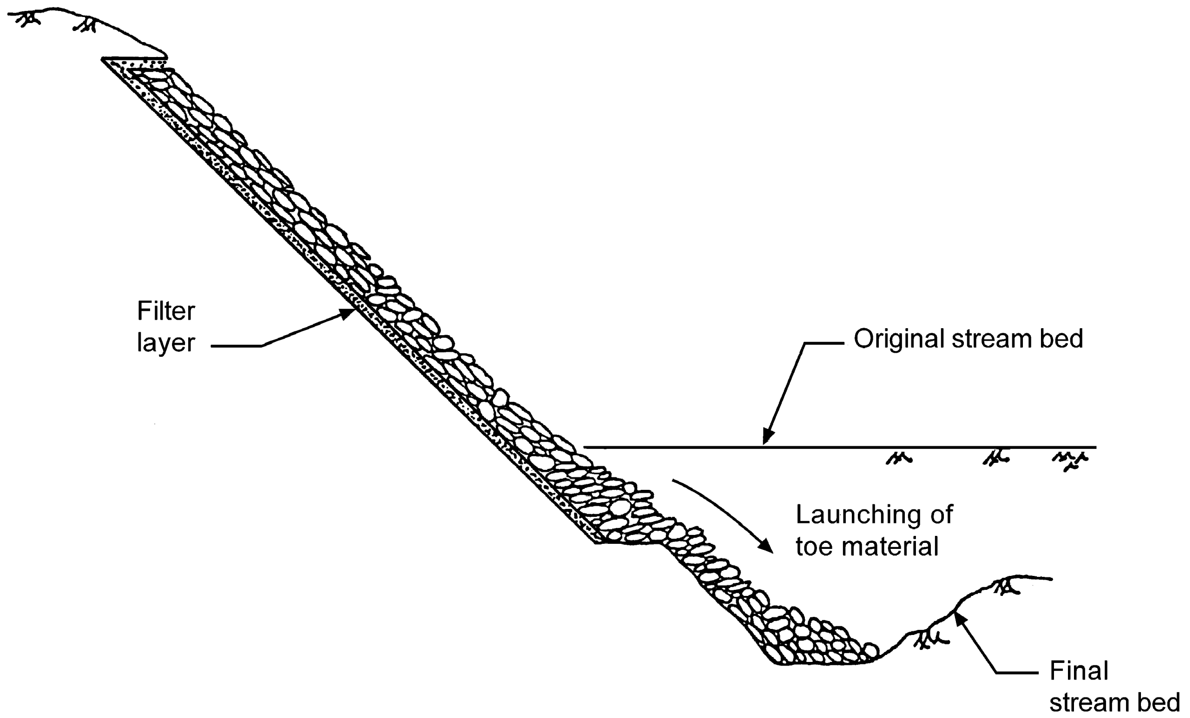


Figure 4.50-3 Launching toe material

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.

d_{50} (finer layer) > D_{50} (coarser layer)/40 **(Equation 4.50-4)**

d_5 (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.

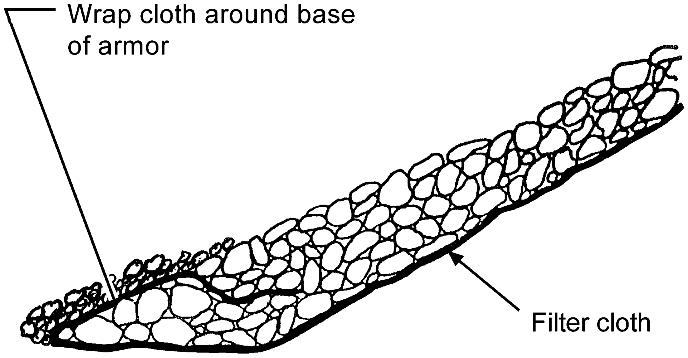


Figure 4.50-4 Dutch toe

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.

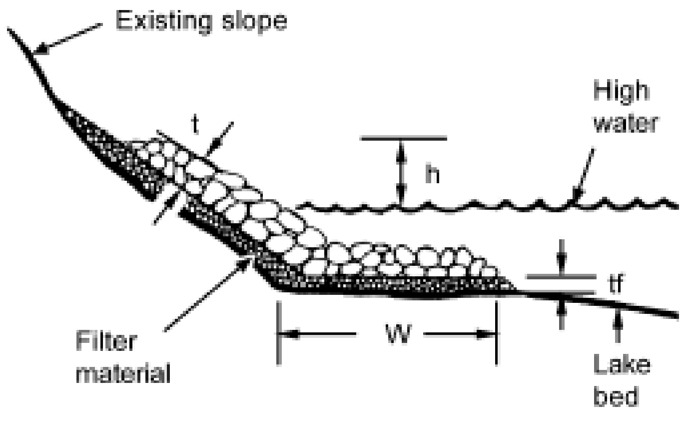


Figure 4.52-1 Riprap revetment

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).

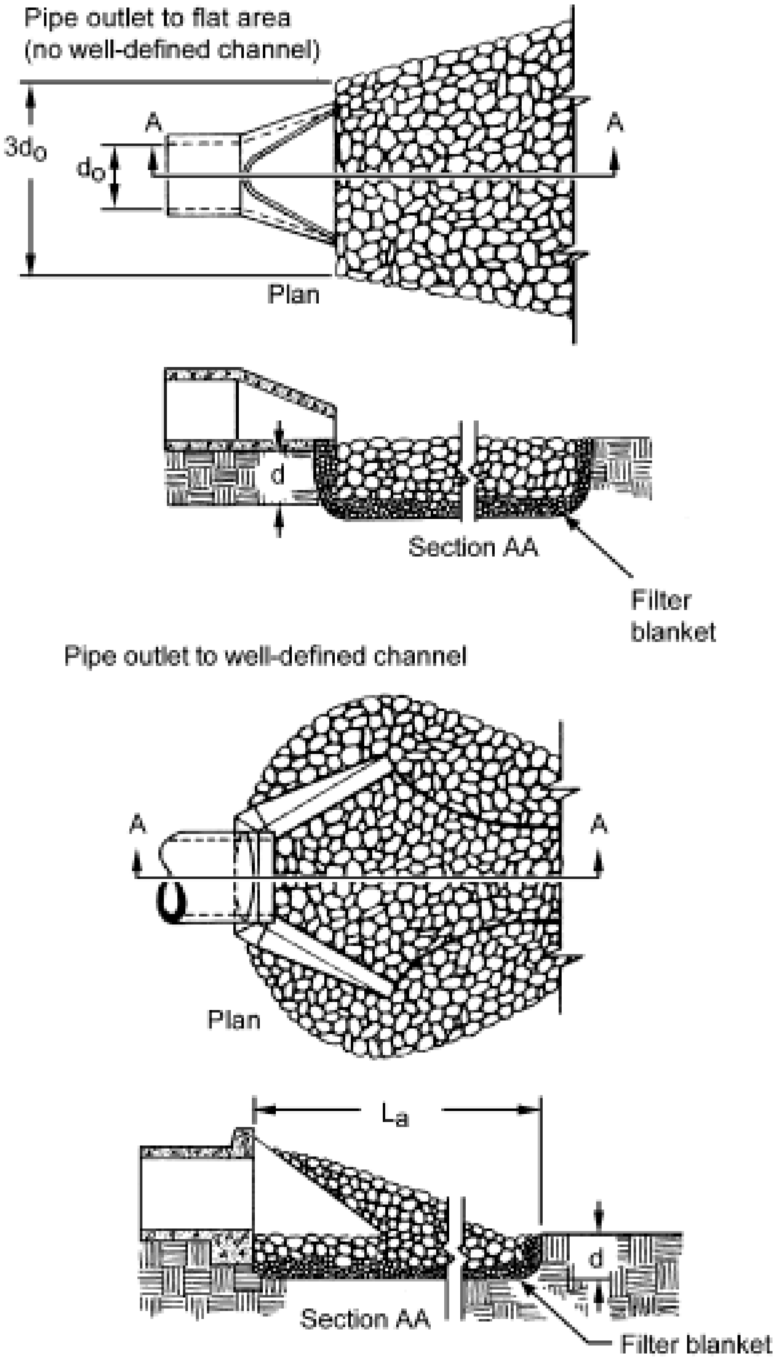
These projects may need state, federal or local permits, so check with the appropriate agencies for their requirements.

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 $\tau \le 1$ 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 $\tau \le 1.5$ 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 $\tau \le 2.5$ 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 $\tau \le 2.5$ 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.

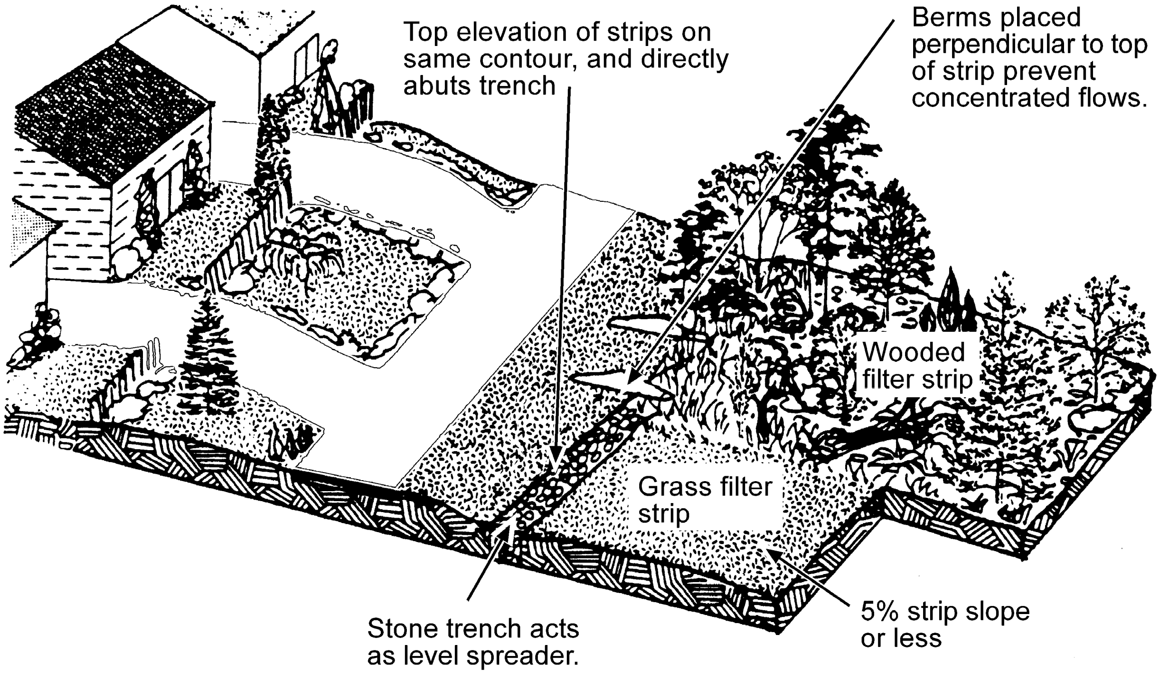


Figure 4.61-1 Schematic of a grassed-and-wooded filter strip (source: Schueler, 1987)

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.

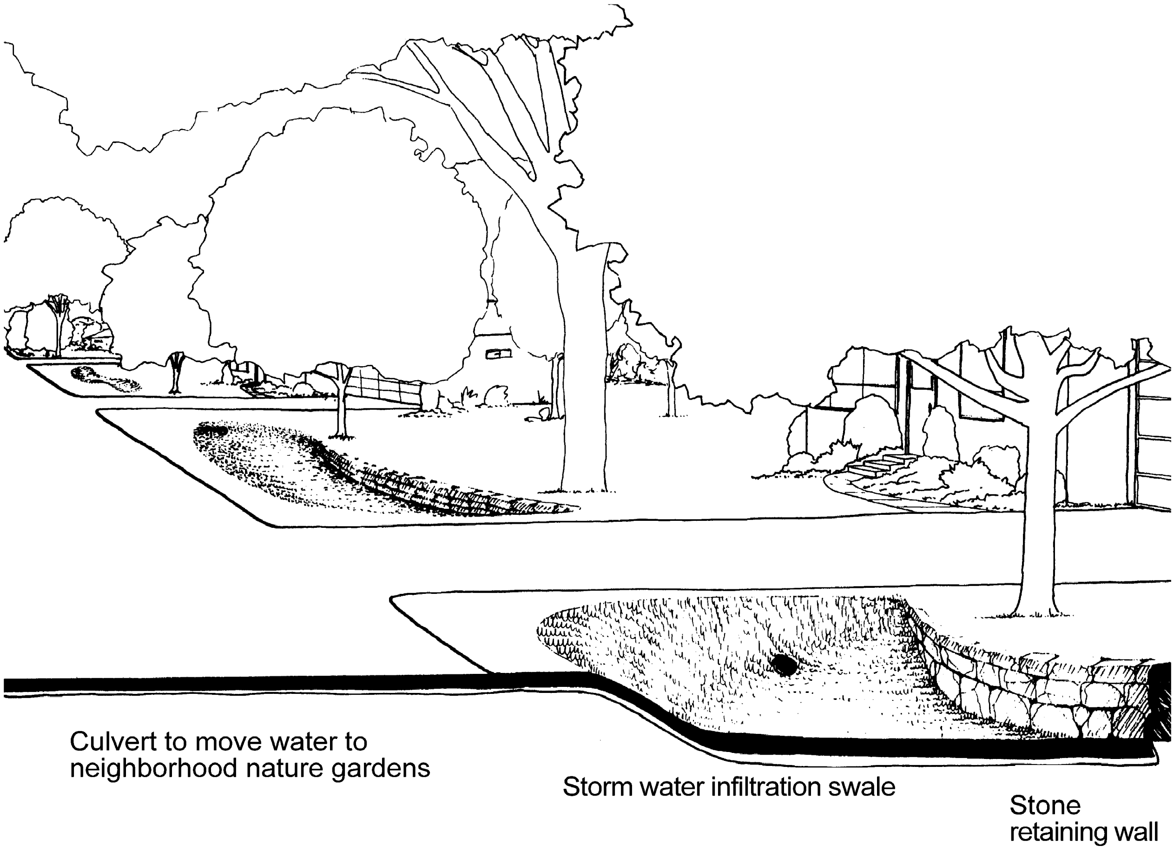


Figure 4.62-1 A turf swale can infiltrate storm water, but turf lacks the beauty and biodiversity of native plant gardens (Nassauer *et al.*, 1997).

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.

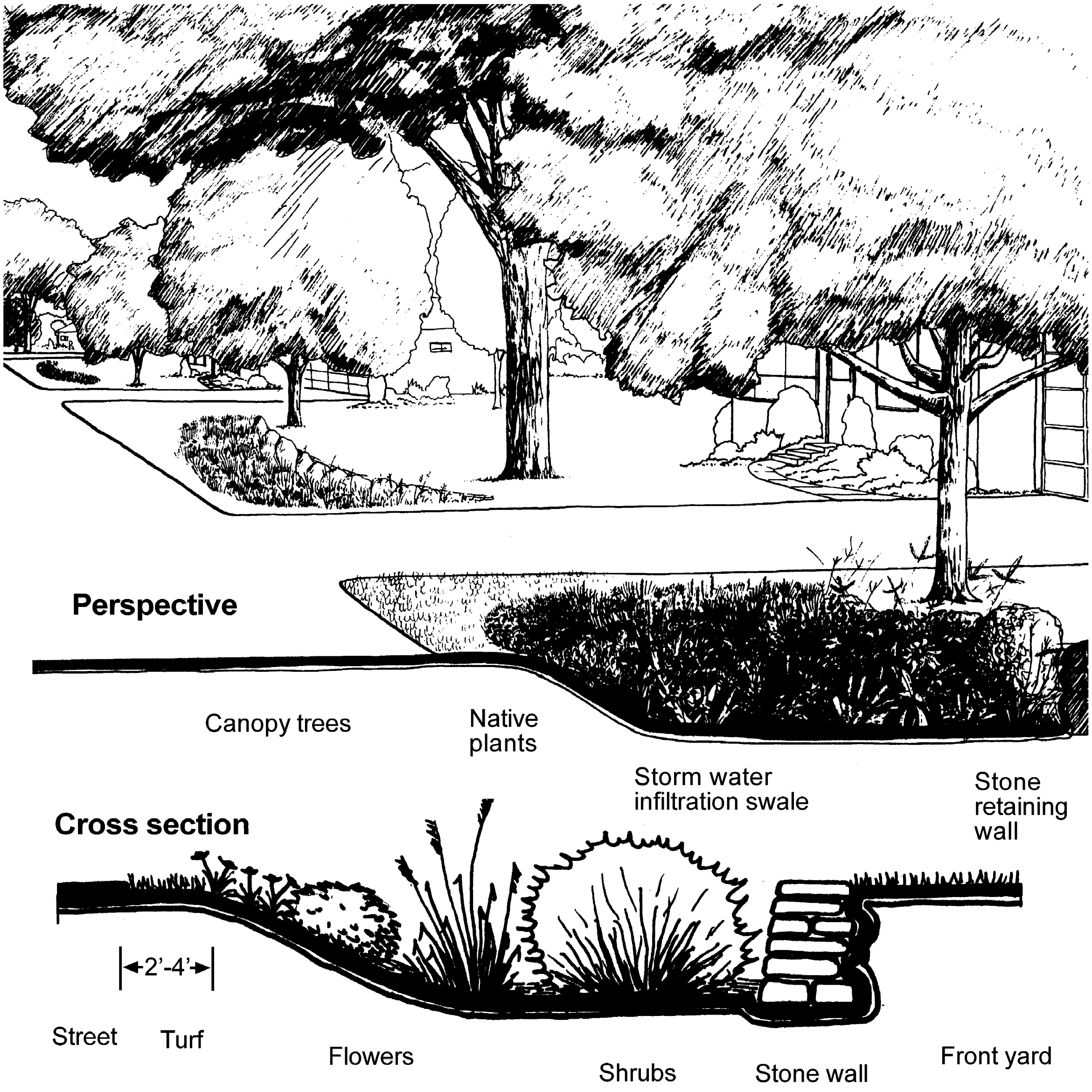


Figure 4.62-2 **Asymmetrical high-volume swale with front yard defined by masonry wall (Nassauer *et al.*, 1997)**

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.

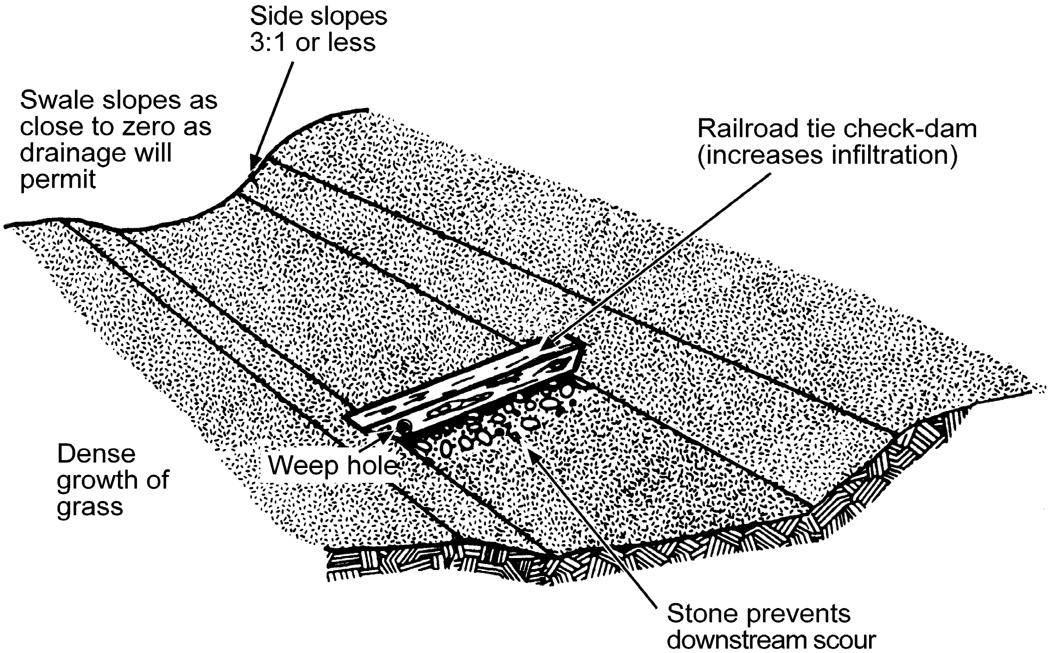


Figure 4.62-3 Schematic of an enhanced grassed swale (source: Schueler, 1987)

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.

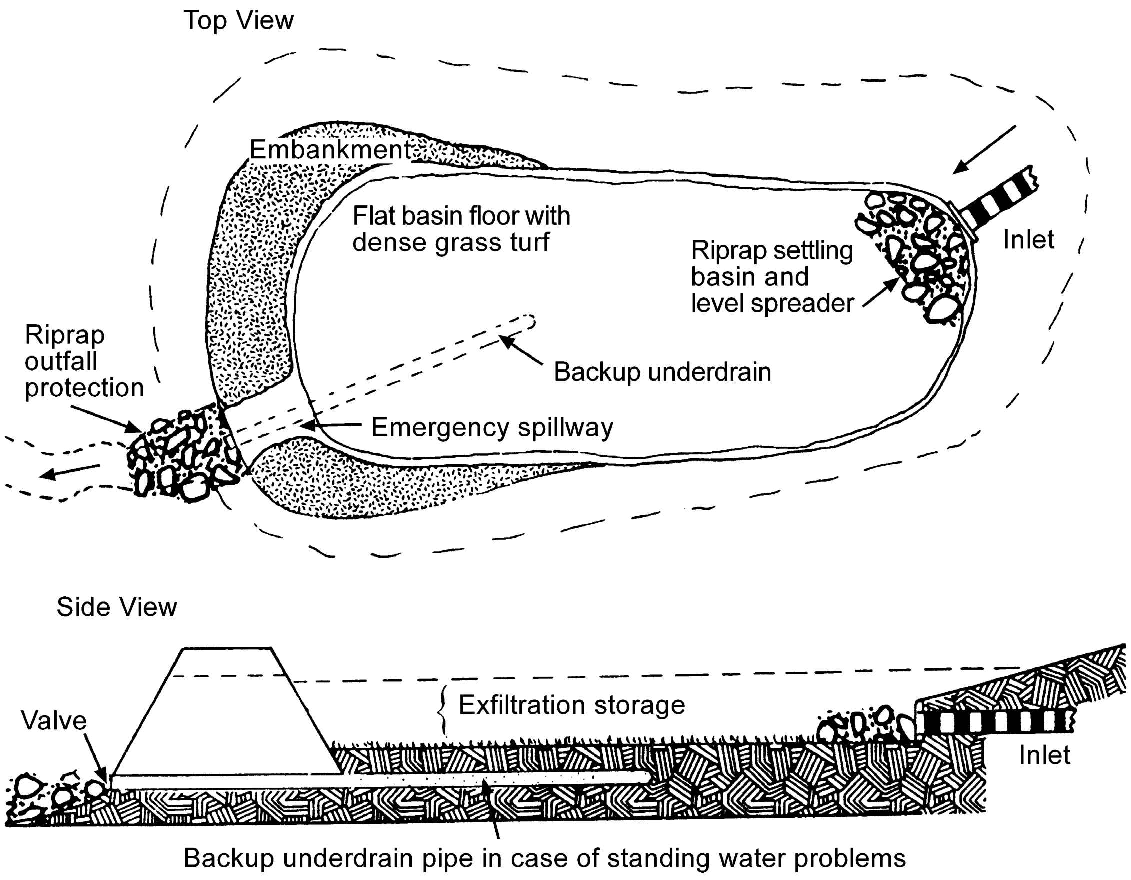


Figure 4.63-1 Schematic of an infiltration basin (source: Schueler, 1987)

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.

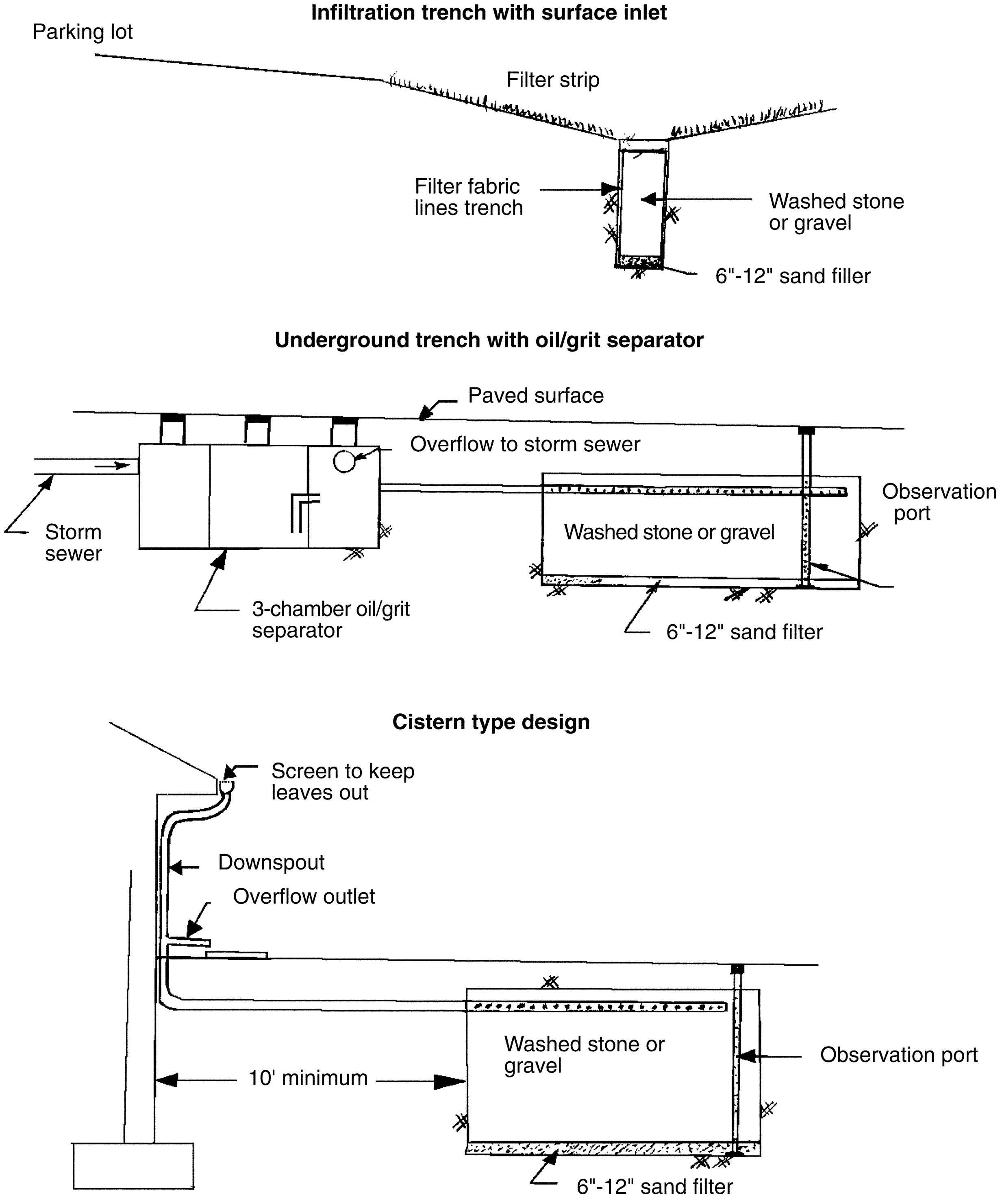


Figure 4.64-1 Schematic designs for infiltration trenches

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.

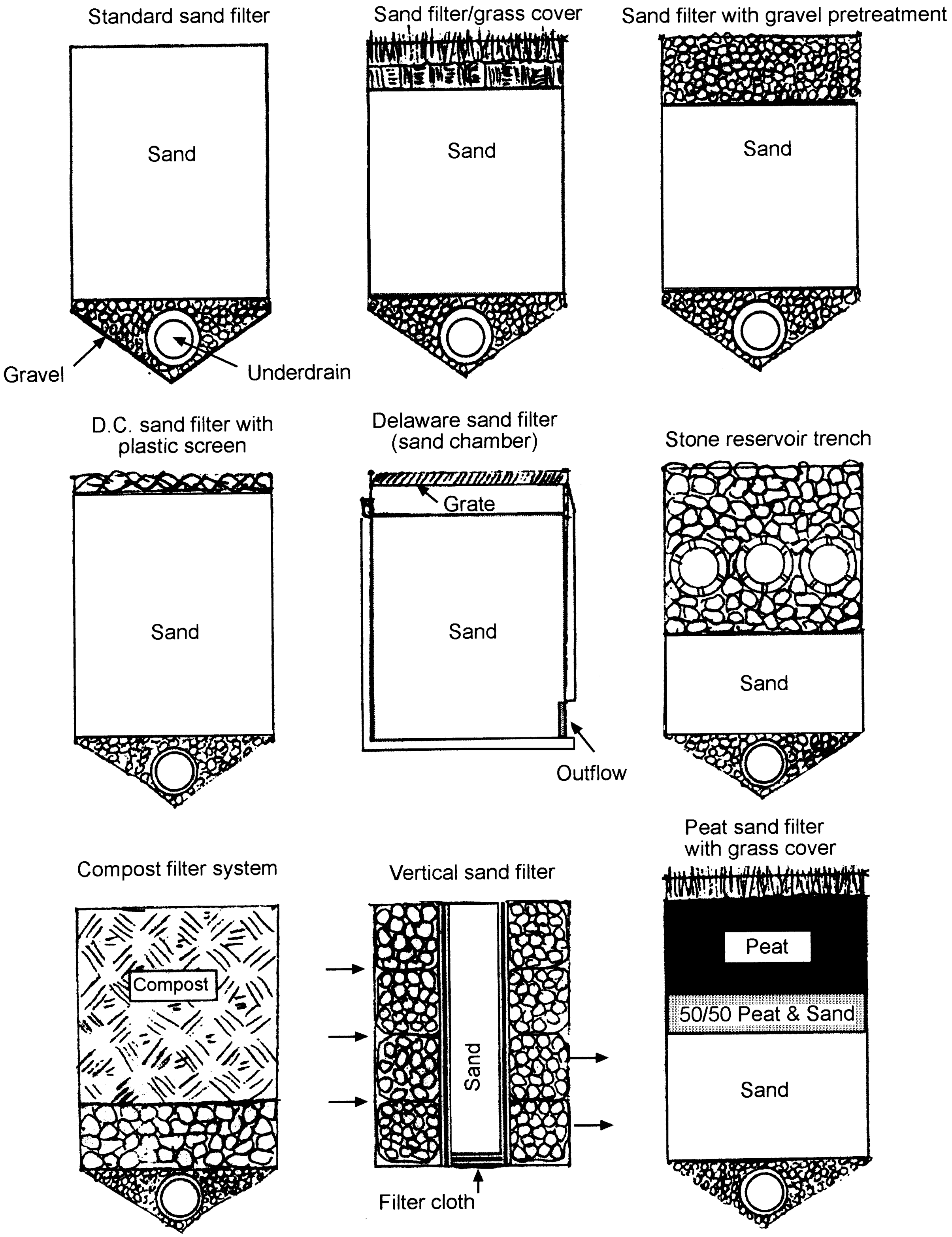


Figure 4.65-1 Cross section of sand filter design variations (source: Schueler, 1994a)

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.

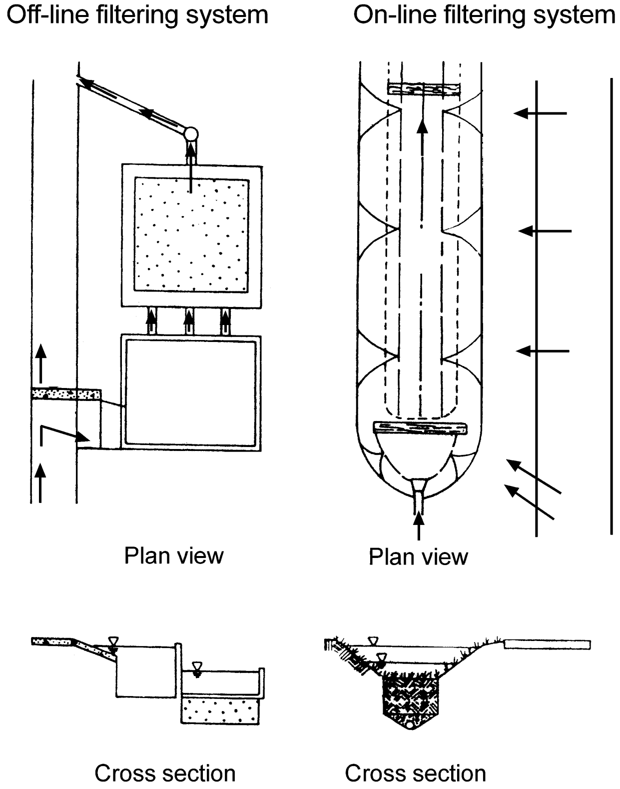


Figure 4.65-2 Schematic: on-line vs. off-line design